

ASOCIAȚIA GEOMORFOLOGILOR DIN ROMÂNIA

REVISTA DE GEOMORFOLOGIE

13



editura universității din bucurești®

2011

REVISTA DE GEOMORFOLOGIE / REVIEW OF GEOMORPHOLOGIE

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E-mail: editura_unibuc@yahoo.com

Internet: www.editura.unibuc.ro

Tehnoredactare computerizată: Meri Pogonariu

ISSN 1453-5068

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River-bed evolution during the Holocene in Kalavrita region (Northern Peloponnese, Greece)

L. STAMATOPOULOS¹ & N. EVELPIDOU²

Abstract: Environmental history often reveals the contribution of humans in the modification of natural environment, always in relation with the climatic factors. Archaeological settlements may be preserved through desiccation, however, they are commonly found in floodplain sediments. Archaeological evidences may provide with useful information about the processes and extent of environmental changes, but they may also be used as tools for the analysis of floodplain sedimentation, relative chronology of sedimentation events and for the geomorphological evaluation of the particular archaeological site. The characteristics of archaeological indicators and the deposits in which they occur, may indicate important aspects of their source, transportation way and age. Evidence of river migration may be found in alluvial plains, through careful observations. The study area is located in Kalavrita region in northern Peloponnese. The archaeological excavations carried out revealed the fortification wall of the ancient city of “Kleitōr” which is dated between the 3rd and 2nd century BC (Hellenistic Period). It may also provide clues for land surface development, reworking of sedimentary deposits, paleoenvironmental and climatic conditions. Sediments indicating considerable climatic changes are alluvial deposits of considerable thickness, covering areas with human impact. All the aforementioned become a tool for dating the course changes of the rivers and consequently a geomorphological instability. The relationship between geomorphology and history is recognizable also in the settlement distribution. This close relationship between environment and man provides a tool to understanding the landscape evolution from a geomorphological and historical point of view.

Key words: Kalavrita region, Hellenistic Period, Holocene, climate change, geo-archaeology, river migration, fluvial geomorphology

1. Introduction

The wider region of Kalavrita, northern Peloponnese, is characterized by the presence of plenty archaeological findings of the periods between the 10th century BC (Early Protogeometric Period) and 2nd century BC (Hellenistic Period) (Pausanias texts), buried under fluvial sediments.

The study area is located near the SW border of Chelmos (Aroania) mountain, 2341 m a. s. l. in northern Peloponnese, about 14 Km South of the Kalavrita city, and lies about 3 km west of Kleitoria village. The area belongs to the ancient Kleitor city and is rich in archaeological findings from the Hellenistic period (Petritaki, 1996).

The first archaeological stray findings from ancient Kleitor city were reported during 1940 and a systematic archaeological survey of the area started since 1987 (Petritaki, 1996). Archaeology may often date the landscape evolution at the timescale through site formation or destruction processes (Schiffer, 1987) or the use of artifacts and sites in

the studies of river channel changes (Brown 1997). Environmental changes and particularly denudation history in the Mediterranean has also been approached by using archaeological data (Vita-Finzi 1969) whilst only recently archaeological tools have been extensively used to interpret the morphogenetic evolution. Environmental histories often reveal the role of humans in modifying the physical environment, although this is not inevitable, as climate may be the overwhelming factor.

The main objective is to combine the archaeological information and environmental development in a direct chronological framework, to be able to interpret the morphogenetic evolution of the study area during the Holocene.

2. Study area

The ancient Kleitor city is situated on the fluvial terraces of Karnesios and Kleitor rivers valleys (Fig. 1).

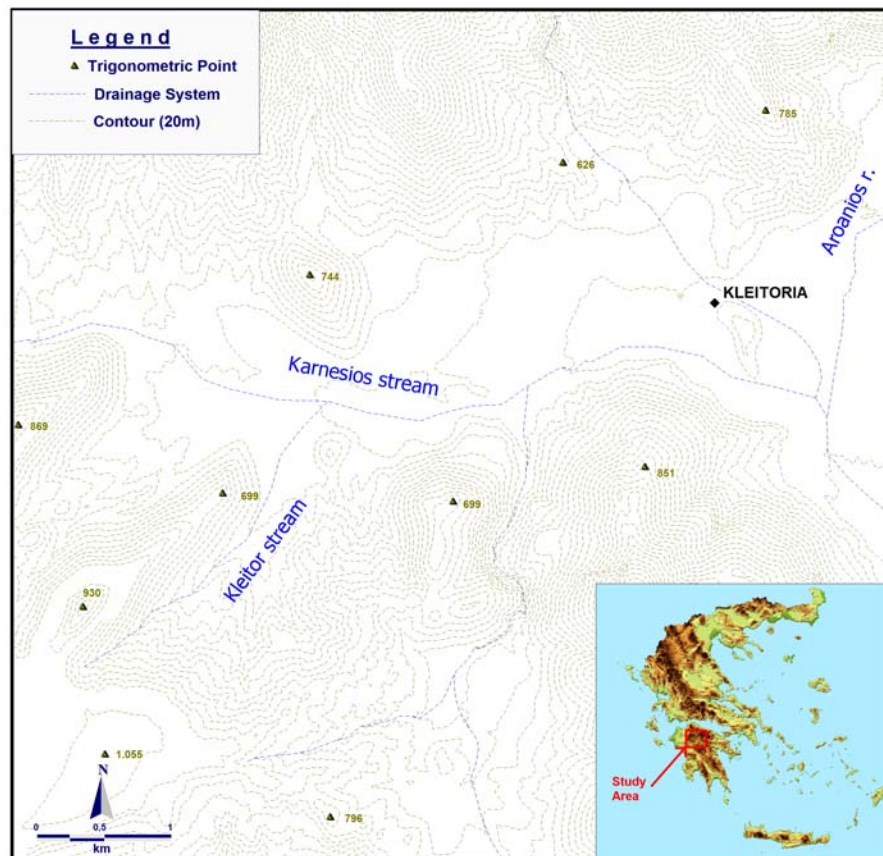


Figure 1. Topographic map of the study area (b), Location of the study area (a)

The study area is mainly composed of Eocene Flysch, Mesozoic (Upper Triassic - Cretaceous) limestones and dolomite basement of the Olonos - Pindos unit (External Hellenides) and Pleistocene fluvial sequences (Dercourt 1978). During the Plio-Quaternary, Peloponnese was affected by systems of North-South active normal faults, which have created rising and lowering blocks. The tectonic style of the Peloponnese is characterized by thrust napes and normal faults (Doutsos and Poulimenos, 1992).

The area is characterized by Mediterranean climate conditions, with the period of limited rainfalls i.e. dry period, during summertime. Moreover the mean lowest temperature during January is about 4°C and the mean highest temperature during July is lower than 22°C.

3. Methods

Geological and geomorphological investigations through field observation during the years (2008/09), interpretation of aerial photographs (scale 1:33,000; year 1982) existing maps and satellite images were accomplished.

The used maps were geological and topographic maps (scale 1:50,000). The maps were imported

into MapInfo GIS, were registered and digitized, in order to develop information layers concerning the drainage network, the geology and the topography of the area.

Information layers related to topography were analyzed with the use of Vertical Mapper software in order to create a digital elevation model (DEM) and specifically the algorithm “Triangulation with Smoothing”. Data derived from interpretation of aerial photos and satellite images as well as from field work was also imported into GIS and were used in order to develop the geomorphological map of the study area. Finally, all developed information layers with their databases were used for the palaeogeographical reconstruction of the study area.

4. Historical events and Geomorphology

The wall is estimated to have surrounded the ancient city in total length of approximately 2500 m, enclosing an area of 577 m². The excavated parts are dated between the 3rd and 2nd century BC (Hellenistic Period) (Petritaki, M., 1996).

The ancient city was surrounded by a fortification wall reinforced with semi-circular towers, whose foundations are preserved on all the sides, except the Eastern, where the river bed of

Karnesios stream existed. This torrent carried them away, before it joined with the Kleitor stream in the southeast of the ancient fortification wall.

Between the two streams and about 2.5 m westwards to the current flow of Karnesios stream and internally to the fortification buried parts of the ancient “Klitor” city are observed (Photo 1), 1-2 m below the present land surface, which is covered by silty gravels, fluvial sediments (Photo 2).

According to the above dating, it may be supposed that before and during the settlement, the study area was a fluvial terrace of Karnesios stream. Communities were located in the inner alluvial terraces, close and around the river channels.

During the Late Holocene, as observed in many locations worldwide, the study area underwent a rapid improvement of climate, marked by a widespread development of thick fluvial sedimentation and consequently of the river migrations. The new environmental conditions drastically reduced slope degradation processes and related aggradations of riverbeds. Maximum developments of deposition took place on the river beds. Fluvial deposition persisted in the belt, where river valleys extended from the present flow, as indicated by the stratigraphical analysis. All aforementioned conditions caused the complete or almost complete disappearance of the ancient “Klitor” city fortification and consequently the settlement.

5. Discussion

The geological–geomorphologic map (Fig. 2) presents the surface topography and the different types of deposits in the investigated area. The chronology of the identified environmental and morphogenetic variations is based on archaeological data.

The present investigation has provided with new information concerning the development in the floodplain area, which was influenced by the strong climatic changes. The morphological evidence reveals that during the Late Holocene the study area was represented by an archaeological settlement. Notable flood events with contemporary fluvial migration of Karnesios stream are responsible for burial of the settlement.

Environmental history often reveals the contribution of humans to the modification of the natural environment, always in relation to the climatic factors. Archaeological settlements may be preserved through desiccation, while they are commonly found in floodplain sediments. Archaeological evidence may provide with useful

information about the processes and extent of environmental changes, but they may also be used as tools for the analysis of floodplain sedimentation, relative chronology of sedimentation events and for the geomorphological evaluation of the particular archaeological site.

The characteristics of archaeological indicators and the deposits in which they are found, may provide with important information about their source of alimentation, transportation way and age of the sediments that compose the investigated area. Moreover evidence of river behavior, such as migration, may be found in alluvial plains through careful observations.

While the most obvious way in which archaeology may be used as a tool in geomorphology is by dating sedimentation or erosion and thereby establishing rates of flux, there are more applications, including the identification and reconstruction of factors on the earth system (e.g. climate) and the history of human influences on the landscape evolution.



Photo 1. Archaeological finds, buried during the Holocene alluvial deposits of the Karnesios stream



Photo 2. Middle – Late Holocene alluvial sediments of the Karnesios stream

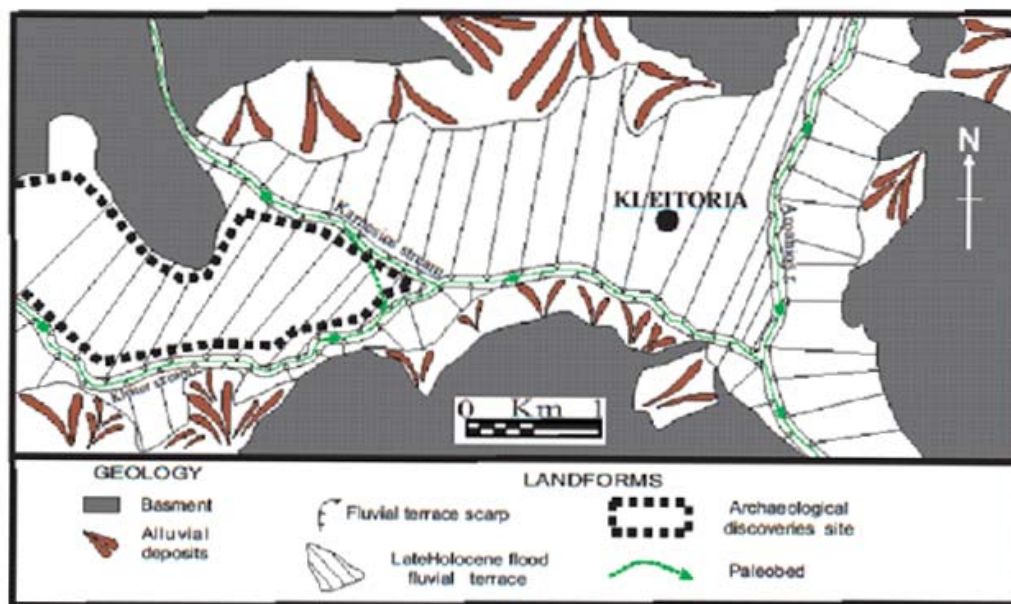


Figure 2. Geological and Geomorphologic Map of the study area

The evaluation of the aforementioned data provides with the geomorphological tools for the study of fluvial processes and hydrological conditions. Additionally, it may provide with evidence for the geomorphological evolution, through the palaeogeographical evolution and climatic conditions.

Considerable climatic changes may also be recognized in sediments from alluvial deposits of considerable thickness, in areas with human impact.

The stratigraphic evidence found in the area clearly indicate that, in the Late Holocene, human life was heavily affected by climate-induced environmental changes, such as flooding events and sediment deposition on the river sides. The scattered debris deposited at the foot slopes in the mountain sectors indicate how during the phase of climate deterioration, human impact significantly contributed to the enhancement of slope erosion and riverbed aggradations.

The phase of fluvial deposition suggests that, before recent historical times, the morphogenetic role of human impact was generally sub-ordinated to that of climate changes.

6. Conclusions

Interdisciplinary studies including geomorphologic and archeological data have produced new information concerning the environment in Kalavrita region during the Holocene, after the depositional processes and river migration on the channels induced by climate changes.

In the alluvial plains, it is possible to recognize several evidence of the river migration. The study of this evidence from a historical point of view may help to understand the role of man and the history of the landscape.

During the Late Holocene communities dominated the area, and natural factors were the main cause of the changes that took place.

Settlements in the lower valley sectors were destroyed as a consequence of the recurrent flooding episodes. The role of human impact on landscape evolution in Kalavrita region during the Early Holocene seems to be relatively limited.

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The Valley System Evolution in Romania

Mihai IELENICZ, Smaranda SIMONI (TOMA)

The Valley System Evolution in Romania. The valley system in Romania developed gradually from the Miocene until the Holocene, starting from the Carpathians outward (plains and Dobruja) as the morphologic units completed.

Its configuration depended on the time and spatial joint of many factors: the gradual emergence and uplift of landforms from the Carpathians to the plains; the regional influence of the extra-Carpathian base levels of erosion and the subsidence areas; the local influence of structural contacts, tectonic faults, etc. Therefore the valley system has several characteristics: convergence toward the Transylvania Depression, divergence outward Carpathians, many valley generations (the most numerous in the Carpathians and less in the plains), and a hierarchy with many distinct groups. This is the case of the *main valleys* formed by sector joint when the land gradually extended, with at least three distinct situations (from the Carpathians to the plains - the eldest Pliocene-Quaternary valleys, from the Subcarpathians to the plains – from mid-Pliocene until Holocene) and autochthon valleys with 1-2 generations (for each main landform unit) from upper Pleistocene and Holocene.

There are three stages of the system evolution considering the period when the main valley generation developed on the great landform units (the Carpathians, the hills and plateaus, the plains). The paper also points out some important evolutionary aspects of the main valleys.

Key words: valley system, evolution stages, Romania

1. General Aspects

The present valley system is complex and consists of several generations, aged Pliocene second half and especially Quaternary.

The system configuration (figure 1) was conditioned by several factors of general or local role in the valley genesis and evolution, namely:

- The major orographic system dominated by the Carpathian “ring”, surrounded by plateaus, hills and finally plains (southward and westward). This led to the development of a major valley system, convergent to Transylvania and divergent outward.

- The large tectonic basins (Pannonic, Transylvanian and Geto-Pontic) functioned as base levels of erosion toward which the adjacent rivers directed, and dictated indirectly the valley directions of different generations.

- The landforms developed gradually, starting with the Carpathian system completion (the end of Mesozoic-Paleogene – for the crystalline units and up to Pliocene for the volcanic mountains), then the plateaus (gradual emergence and slow uplift from the upper Miocene until the early Quaternary), and finally the filling of the last aquatic areas (Pannonic,

and Geto-Pontic) and the plain units completion (upper Pleistocene-Holocene). This general evolution dictated two major tendencies for the valley system development. The first one refers to the main valleys that cross those units that became land in different phases and stages. They are made up of different age sectors. The second tendency refers to the fact that an elder geomorphologic unit has more valley generations that form a hierarchic system with different morphographic and morphometric characteristics.

- The mountain or even hill massifs of well defined structure (volcanic, crystalline, conglomeratic) and sufficient height have a second level of divergent valleys with main outer collectors (the Călimani Mountains surrounded by the river Mureș and the Bistrița's affluents; the Ceahlău Mountains with the outer valleys Bistrița, Bistricioara and Bicăz; the Șureanu Mountains with the valleys Sebeș, East Jiu and Strei, etc.).

- The large (tectonic and volcanic barrier, erosion) depressions dictated hydrographic convergences (toward one or two centers – Brașov, Comănești), parallel valley systems, or tributary systems to a central collector (Ciuc, Gheorgheni).

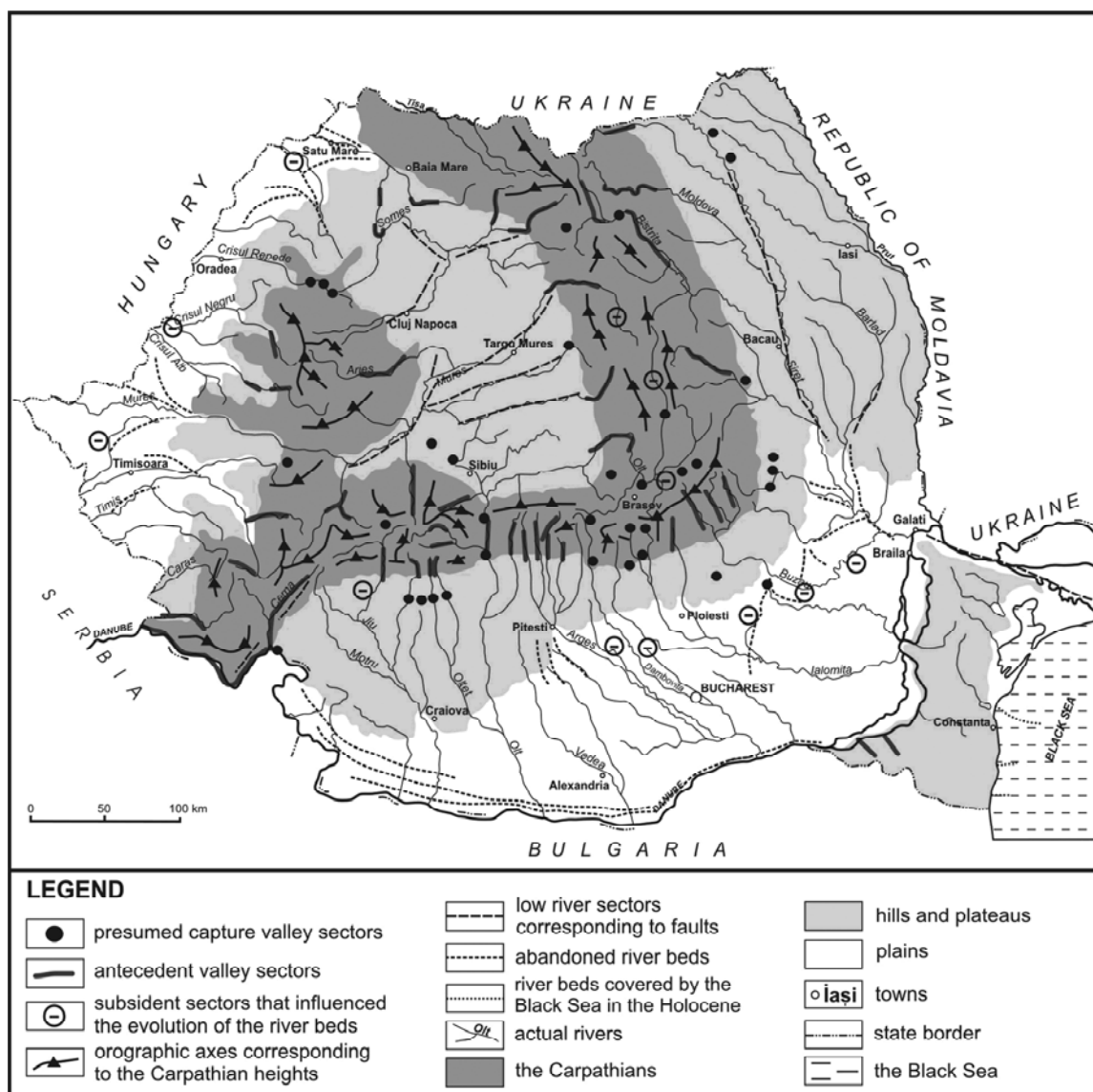


Figure 1. Elements defining the river system evolution in Romania

▪ The position of the structural units (especially within the Oriental Carpathians flysch), the main faults and tectonic flexures (along the rivers Siretului, Oltului, Târnave, Someș), and the grabens (the Occidental Carpathians) generated the primordial directions of the main valley system, many of them preserved by now, others left as hanged proofs (the canals at the Getic Sheet level in the Meridional Carpathians indicated by D. Burileanu are sheet waves according to Gh. Munteanu-Murgoci).

▪ The upper Pliocene-Quaternary subsidence areas represented and still represent hydrographic convergences, a fact that influenced the convergent valley development in some cases (toward the subsidence centers in the depressions Brașov, Ciuc, etc.), the asymmetrical valleys (with one-side valley terraces – for example the river Bârlad) or obvious deviations (changes) of the river beds (where the

active subsidence centers migrated – for example the rivers Argeș, Ialomița, Buzău where they enter the plain units).

▪ The piedmont and mountain glacises development was accompanied by the divergence of the rivers that made them and also by their own valley generation (Cotmeana, Căndești, Oltețului, etc.).

▪ Many valleys of the latest generations in the mountains, Subcarpathians and some plateaus were cut by river deepening on petrographic or structural contacts (especially along the thrust-sheets or faults in the Oriental Carpathian flysch).

▪ The river deepened first in the Pliocene accumulations of some depressions (in the Oriental Carpathians, the Western Hills or even when they entered the Western Plain) and then in harder strata (volcanic, crystalline) beneath them, generated epigenetic gorges (the rivers Someșul Mare, Crișul

Alb, etc.). There are also antecedent valley sectors, where the rivers deepened at the same time as the units uplifted tectonically.

- The Black Sea shoreline fell eastward in the Pleistocene as its level decreased and the Dobruja land extended along with its valley system. The Holocene transgressions covered part of this land and wipe out the flooded valleys, turning them into fluvio-maritime limans (Techirghiol, Taşaul, Tatlageac, etc.).

- During the late Pleistocene and early Holocene, the Danube set its course gradually downstream Drobeta-Turnu Severin and its main tributaries set their courses through the plain (until the mid-Pleistocene west to Argeş river, during the upper Pleistocene to Brăila, and during the Holocene downstream Galaţi).

- Part of the latest valley generation was generated in the plains and in some low plateaus covered with loess by the processes of sag, suffusion and rill-erosion.

2. Acknowledgement

Many Romanian and foreign geographers and geologists analyzed the valley system evolution, especially for the mountains and the Subcarpathians (the 19th century, the beginning of the 20th century), because some morphological elements along the main valleys and the reports between the large hydrographic basins had to be explained. Many analyses and genetic explanations regarded the long and deep gorges downstream some depressions (most of them tectonic depressions), the sudden change of some valley directions, the report between the different positions of the heights and the actual watershed with some low, large and gravel covered saddles, the continuity of valley levels and terraces in the hydrographic basin, etc.

These studies started first with the main rivers that crossed the Carpathians (Olt, Jiu, Danube), extended then in the Subcarpathians, plateaus and even plains. The opinions were based on two ideas – the actual valleys were formed by capture, or their gorges are antecedent or epigenetic. The arguments of these ideas referred to: the extent of terraces and erosion levels, the regional paleogeographic evolution, the correlative analysis of the deposits accumulated in the adjacent sedimentary basins that represented at the time local base levels of erosion and so on, all of them based on mappings, profiles, geological map interpretation, etc.

Important regional contributions were brought by: Emm. de Martonne, I. Popescu-Voiteşti, Gh. Munteanu-Murgoci, G. Vâlsan, I. Cvijic, N. Popp,

R. Fischeaux, A. Nordon, N. Al. Rădulescu, N. Orghidan, V. Mihăilescu, M. David, N. Lupu, Gr. Posea, I. Donisă, H. Grumăzescu, L. Badea, Al. Roşu, Gh. Pop, A. Posea, I. Mac, N. Popescu, M. Ielenicz, V. Gârbacea, N. Josan, I. Berindei, C. Brânduş, etc.

Many of the local and regional studies are part of some PhD theses, added to the syntheses of the large geographical units (N. Orghidan for the Carpathians, I. Donisă for the Oriental Carpathians, M. Ielenicz for the Curvature Carpathians and the plateaus, Emm. de Martonne for the Meridional Carpathians, Gr. Posea for the Carpathians, Transylvania and the plains, Florina Grecu for the Transylvania plateau, etc.) or the entire Romania (Gr. Posea).

4. The valley system evolution stages

The valley system developed gradually as the land extended definitively, during many stages dictated by the tectonic movements in the Carpathians and adjacent platforms. They also determined their structural completion and altitude. The intermittent rhythm of land uplift separated evolution stages and phases of external agent action that left many proofs: the erosion levels and surfaces, the piedmonts and the valleys with erosion benches and terraces, etc. The terraces belong to a different number of generations (from one unit to another) and form systems of different extent (for large units and hydrographic basins). The characteristics of the valley generations reflect the general evolution of the major landforms. *The existing proofs allow us to reconstruct the valley system generations from the Pliocene until the Holocene.* One cannot identify accurately the valley systems for the elder landform evolution stages (though the interfluves preserve proofs of their morphodynamics). There are some saddles presumed to be former valley, and also gentle slope surfaces on the cross profiles of the main valleys that might indicate elder drainage directions, probably Miocene. They were indicated by some authors to prove the antecedence and the age of some valleys. *But it is obvious that the elder and the most numerous valley generations are in the Carpathians and they decrease in number toward the plains.*

All these differentiate three evolution stages of the valley system (figure 2), according to the final emergence of the major landforms; these stages may be divided in some phases that explain the number of valley generations.

The name of the stages was given according to the period the main valley generation settled on the major landforms.

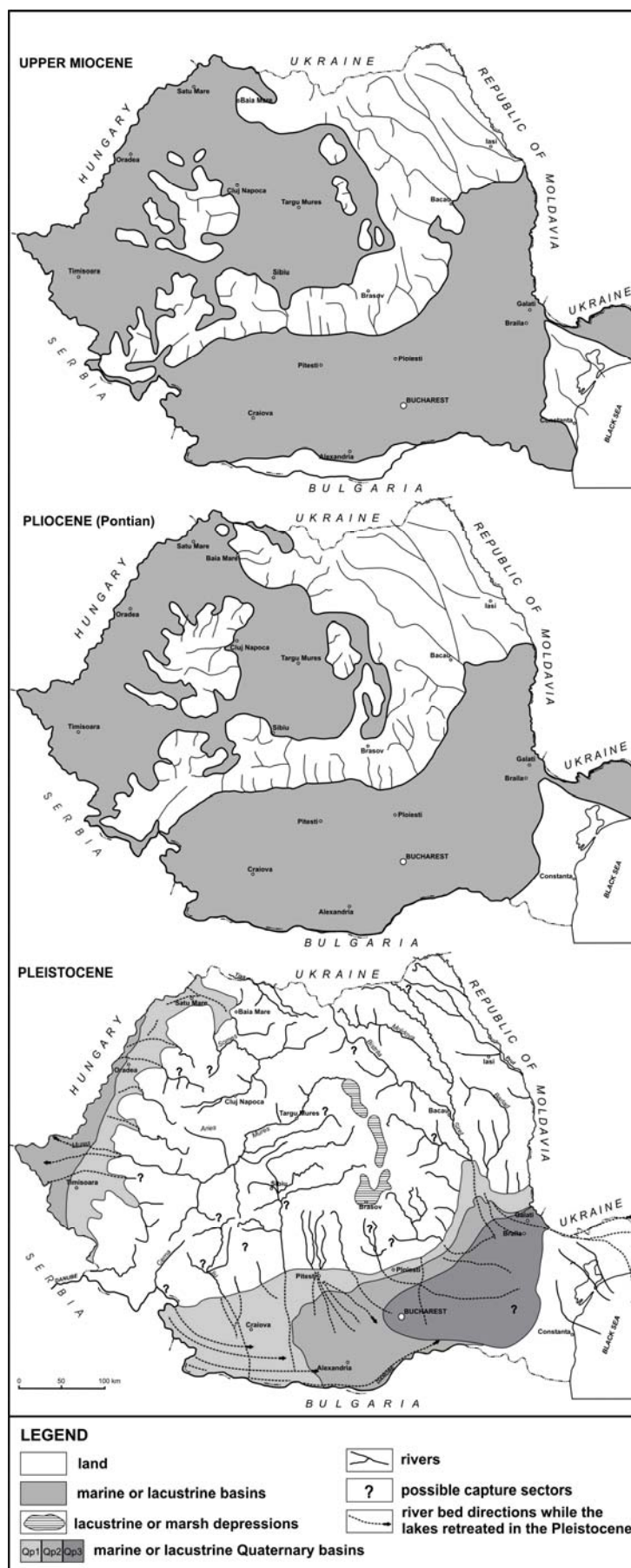


Figure 2. The valley system evolution stages in Romania

3.1. The upper Miocene-Pliocene stage of the Carpathian main valley generation. This is the eldest stage, includes almost all the Carpathian Mountains as the large valleys fragmented them into units of I-III degree. From the paleogeographic point of view, during the mid-Miocene, the Carpathians (the crystalline and flysch sectors) were a land crossed by tectonic couloirs (Badenian) that connected the surrounding sea basins (Pannonic, Transylvanian and Geto-Pontic). It was an archipelago with islands limited by marine couloirs and basins (the depressions in the Occidental Carpathians, the Hațeg-Petroșani depression, the Olt couloir, the Curvature Carpathians, etc.); on the first ones a valley system came into being, and sediments accumulated on the second. During the late Miocene and the early Pliocene, the external flysch completed its structure and emerges, then the valley system settled and continued the one from the previous land units (Bistrița Moldavă, Trotuș, etc.). In other words, the old main valleys extended by new sectors. On the other hand, part of the connecting couloirs between Transylvania and exterior filled with sediments and became lands. Some major valleys settled here and collected the Carpathian rivers. The proofs of a Miocene evolution are few. Some authors (Emm. de Martonne, M. David, I. Donisă, etc.) point out a few valley sectors as Râu Șes, the Olt gorges, Bistrița, etc., or thought they were some drainages that were destroyed later by the neo-tectonic uplifts or falls (the couloirs that might be primary waves of the Getic Sheet, according to the opinions of Gh. Munteanu-Murgoci, D. Burileanu). But the *Pliocene erosion levels* on these valleys are obvious (better preserved on the upper part of the couloirs cut into the crystalline rocks in the Meridional Carpathians and less preserved in the flysch units). *By joining, they indicate the primordial drainage directions that formed a valley system with springs in the Carpathian units.* On the other hand, *it represented the beginning of erosion for some transversal, long or oblique couloirs* compared to the geological structures. On one hand, the drainage directions show the lower alignments of that time, probably determined by tectonics or lithologic and structural contacts, and on the other hand, the attraction of the low base levels of erosion situated near the mountains – lacustrine or marine basins (Transylvanian, Pannonic and Geto-Pontic).

Concluding, *by late Pontian, the main Carpathian valleys (some of them were transversal couloirs) were formed, and the Carpathian uplift only gave them the antecedent character.* In some cases, *their direction was dictated by the graben*

alignments in Miocene-Pontian. They were filled with sediments, emerged gradually and became main collector directions of the Carpathian rivers. Probably when the land altitude was low, they experienced some changes by captures (other authors consider that these situations are presumed in the basins of the rivers Jiu and Olt).

3.2. The upper Pliocene-Pleistocene stage of the main valley generation in the plateaus and hills.

The intense tectonic movements (with many phases) of this period generated important structural changes and a gradual land extent. Among them, important for the Subcarpathians are the sediments fold in some sectors (the morphologic landscape with hills on the anticlines and depressions on the synclines) and the monocline structure formation in others. At the same time, the Carpathian landscape completed with the volcanic system that formed mountains of volcanic rocks, or mountains of sedimentary rocks penetrated by magmatic rocks (in the Oriental Carpathians and the south-east Apuseni Mountains). The tectonic uplift in Transylvania urged the uplift of the Badeanian salt blocks (resulting two major structures – diapirs and domes) and also generated the monocline sedimentary structures in the north, northwest and south of it. The other regions of Romania that are now plateaus and hills experienced slight uplifts that determined monocline (the Moldavian Plateau, the Western Hill) and tabular structures (the South Dobruja). The Villafranchian added to these some piedmont plains outside the Meridional and Curvature Carpathians; these plains uplifted with different intensity later. In consequence, a new hydrographic system settled on these new lands, made up of the Carpathian rivers that extended their flows as the emergences extended, and other rivers that sprang from the plateaus or hills. They followed three directions:

- the general slope of the new land (especially in the sectors of monocline structure);
- the lower sectors generated by the tectonics as new synclines (the Subcarpathians, the eastern Transylvania), some lower alignments as surface correspondents of the active deep faults or flexures (for the rivers Mureș, Târnave in N.Josan's opinion, Someș in M. Paucă's opinion, Siret, Dâmbovița, etc.), the former grabens filled with sediments by late Pannonian in the Oriental Carpathians, etc.;
- the general base levels of erosion of the lakes in the Pannonic and Geto-Pontic basins.

The river system deepening generated many types of valleys.

In the Carpathians there are two types – the pre-Pliocene *old valleys* and the *new valleys* (of their tributaries, with erosion benches on the cross profile, situated above the terraces) that belong to 2-3 generations.

In the hills and plateaus, the difference between the valley generations correlates with the emergence and uplift phases. Thus, in the regions that became land in the first half of the Pliocene (the northern Moldavian Plateau), the main valleys preserve two erosion levels (two evolution phases). Most hills and plateaus in Romania became land after the Dacian and the main autochthon valley system has a single, well preserved erosion level on its upper part.

In both mountains and hills, the existence of large saddles on the interfluvies, the alternation of depressions and narrow valleys (sometimes gorges), the existence of valleys with opposite directions led to *interpretations regarding the valley system evolution as frontal or lateral captures*. Some ideas were issued regarding the formation of the river Bistrița at Zugreni (the upper valley that directed to Transylvania was captured to the east), the river Bistricioara (the capture of the dam lakes in the depressions Borsec and Bilbor, and a similar case for the river Neagra Broștenilor and the lakes Glod and Drăgoiasa), the river Trotuș at Comănești (this river or the river Tazlăul Sărat probably crossed the saddle Moinești), the river Prahova (a capture from the south, through the gorges Posada; losing part its basin in favor of the river Timiș; two Prahova's tributaries, Jepi and Doru, captured the river Izvorul Dorului, the initial tributary of the river Ialomița), the river Crișul Repede (came from Oradea and captured the rivers Drăgan, Călata and upper Criș that directed initially northward, toward the Șimleu Depression), etc. In other cases, the researchers presumed that there were overflows of some lakes beyond the volcanic dams (the rivers Mureș in the gorges Toplița-Deda, Olt in the gorges Racu, Jigodin and Tușnad), or some basin sectors were beheaded by the occurrence of some tectonic depressions in the upper Pliocene (the upper Buzău, Bâsca Mare lost the rivers that flowed from the north toward the Întorsura Buzăului, and Comandău when the Brașov Depression occurred). There are similar interpretations for the later valley generations in the hills (the saddles on the left side of the river Siret in the Botoșani Hills are former valleys of the river Suceava, and inversely, some rivulets flowed westward on these saddles and were captured by the Prut's tributaries; the saddle between the Meseș Mountains and the Sălaj Hills is considered a former valley of the river Someș

westward, etc.). But notice that *for many of the above mentioned situations there are arguments for antecedence in the gorges and other geneses for the saddles considered fragments of old valleys*.

3.3. The upper Pleistocene-Holocene stage of the main valley generation in the low plateaus and plains. The Pannonic (from east to west) and the Getic (from west to northeast) lakes were gradually filled with alluvial deposits. At the same time *the Danube set its course* in the south Romanian Plain and also in the Pannonic Plain; *the Carpathian and hill rivers set their beds toward it* (the newest valley sectors). In the plains, *the first autochthon valley generation with permanent flow and a short one with torrential flow set*. Some Carpathian depressions turned from a lacustrine or marshy regime into a subsidence or piedmont one (Gheorgheni, Ciuc, Brașov), as the collector valley sectors set. The Danube Delta and the fluvio-lacustrine Razim Plain were formed during the last 2000 years.

Add to this evolution and the previous valley system a *new generation of short valleys in the mountains and hills, directed mainly on structural, petrographic and hypsometric contacts*. These valleys extended regressively and made local captures.

4. Valley sectors with controversial genesis

There are many geographic and geologic studies that analyze the evolution of some valley sectors, the most controversial are the large rivers, as the authors support either the antecedence, or the captures. Most studies refer to valleys in the Carpathians, the Subcarpathians, the Transylvanian Hills, the Romanian Plain and the Western Plain. Some of them are presented below:

The Danube formation from Baziaș to Vârciorova. Along Danube there are many basins and narrow sectors, and also sudden changes of direction. The Danube completion by capture or antecedence was differently interpreted. In only two studies the arguments for antecedence (J. Cvijić) or capture (Gr. Posea et al.) were based on the erosion levels and the terraces of the gorge. The others submitted for one of the two variants with geologic (especially the faults and the character of tectonic couloir in Miocene) and geographic arguments from the region or from the units situated downstream or upstream. For those that support the theory of capture, the moment the Danube completed in the gorge and the position of watershed between the

west and the east river are different (G. Vâlsan, R. Fischeaux, P. Coteț, Gr. Posea et al.).

The Mureș formation is proven by capture in the gorge Dobra at Zam (a river that came from Arad captured the river that passed the saddle Holdea to the river Timiș – Gh. Pop), and also the sector Orăștie-Alba Iulia-Aiud (Gr. Posea stated that a river that came from southwest beheaded more valleys that came from the Apuseni Mountains and headed to the Olt basin). Also the river crossed the gorge Toplița-Deda directed to the river Someșul Mare, but it was capture at Reghin by the river Mureș that existed in the middle of the Transylvania. Other authors supposed other captures between the rivers Mureș and Târnave at Ighiu-Șard (N. Popp) and between Târnava Mare and Olt over the saddle at the springs of Vișa (I. Rodeanu, Gr. Posea), etc.

Al. Savu considered that *the Someș basin* extended in Romanian over most Transylvania. He considered that there was a series of captures in the Quaternary that came from the rivers Mureș, Crișul Repede or the formation of the valleys Almaș and Agrij (that advanced on faults).

For the *Subcarpathians*, the researchers imagined longitudinal valley systems that were beheaded by the Quaternary captures into the actual structures. The ideas of Emm. de Martonne regarding the existence of some rivers that flowed parallel to the mountains and created one or two chains of depressions, and then they were captured by the rivers that advanced from the south or southeast were taken, amplified and proved for different sectors (N. Popp, N. Al. Rădulescu, Al. Roșu, L. Badea, Gh. Niculescu, H. Grumăzescu, etc.). There are also supporters of valley antecedence. They considered that the depressions near the mountains are the natural results of the more active uplift of the Subcarpathians. Thus, the lower depression couloirs are near the mountain, as they have a synclinal character, and they were closed outward by anticline hills. The rivers that spring from the Carpathians had an initial flow direction in accordance to the general slope, from the mountain outward. As the hills uplifted, the rivers cut in them epigenetic gorges and two-three terraces in the synclinal depressions (M. Ielenicz, N. Popescu, C. Brânduș, etc.).

In the *plains*, the valley changes were determined by two factors, namely the evolution of the active subsidence centers toward many rivers directed, and the rich alluvial deposits that generated meanders. G. Vâlsan (1915) analyzed the most eloquent situation in the Romanian Plain (the meanders in the basins of Ialomița, Prahova, Buzău

that left abandoned river beds), then N. Popp (the Buzău-Râmnic Plain), P. Coteț (the Oltenia Plain), Gh. Niculescu (the Ploiești Plain), Gr. Posea (for different sectors of the eastern Romanian Plain), Șt. Manciușlea, M. Paucă, Gr. Posea for the Western Plain (the rivers Timiș, Criș, Someș), etc.

In *Dobruja* there are two problems. The first one is the formation of the valley Carasu whose bed is directed from east to west (decreases from Constanța and flows into the Danube), opposite to the direction the watershed decrease (from west to east). The explanations of C. Brătescu (1928) are eloquent to accept the idea of epigenesis, along with the other rivers in southwestern Dobruja, given the neotectonic uplift of this region. The second problem is the valleys near the shore that in the upper Pleistocene were the springs of some rivers that advanced longer on the beach plain that extended eastward; when the sea-level increased, most of this plain submerged, then the strand-walls of the last millennium turned the rivers into limans.

5. Conclusions

- The actual valley system of Romania developed gradually from the Carpathians outward and mainly from the Pliocene until the Holocene.

- It is made up of valleys that cross the great landforms in different ways. The largest valleys that spring from the Carpathians and flow toward the plains (some of them into the Danube) are made up of joint sectors (the oldest are in the mountains, the youngest are in the plains). Each main hypsometric step (mountains, hills and plateaus, plains) has more valleys generations, according to the number of phases of epirogenetic uplift they experienced and the evolution of the regional base level of erosion. Therefore the number of generation is higher in the Carpathians and decreases in the plains and in Dobruja.

- Most valleys kept their directions with the general slope dictated by the emergence direction of different stages (mainly from the Carpathians outward) or adapted regionally to the neotectonic movements (with different intensity and direction), with more active local centers or certain directions (faults, flexures, tectonic couloirs, etc.).

- The valleys of eldest generations are transversal in the Carpathians and Subcarpathians, according to their directions toward the geographic and structural units. In the first case, there are valleys that cross the entire mountain chain or the Subcarpathians (the river Olt at Turnu Roșu-Cozia, the Danube, the river Crișul Repede), and other

cross most of them (Bistrița, Trotuș, Buzău, Prahova, Argeș, Crișul Alb, etc.). In the second hand, the situations are various: the valleys may cross entirely or partially the great structural units (crystalline, flysch, Subcarpathian molasses, eruptive) or their subunits (sheet alignments, anticlines, etc.). The second situation refers to the valleys with alternant transversal and longitudinal sectors (along important faults, the head of trust-sheets, the synclines, the waves of large sheets, etc.)

▪ The valleys of younger generations in the hills, plateaus and plains have a dominant direction dictated by the general slope of land extent, and by local influences generated by the neotectonics (subsidence sectors especially in the plains, active uplifts in the hills, the surface correspondents of deep faults and flexures on the rivers Siret, Someș, Bârlad), structural characteristics (especially the monoclinical structure), and petrographic contacts.

▪ Most valleys kept their initial directions so that many gorges are epigenetic and antecedent.

▪ The changes of some rivers accompanied by amputations or basin extents occurred in different situations:

- at the beginning of a valley generation evolution when the general landform amplitude and the river deepening were low;
- when the tectonic depressions occurred (Brașov, Comănești, the Transylvania basin and the golf depressions);
- when the volcanic chain developed and separated the Transylvanian basin from the central and western sectors;
- a normal evolution by regressive extent of the younger rivers, locally accompanied by captures;
- by diffluences in the sectors with rich alluvial deposits (on the glaciis plains), or by direction changes dictated by a more intense subsidence of some centers (in the plains), etc.

In general, *the morphologic arguments for the capture evolutions may be excluded from the upper Pliocene and up to present. The rest of them are only suppositions.*

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Geomorphological Mapping. Evolution and Trends

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Abstract. If we follow the opinions expressed by the most recent studies and concerns in the field, but also our own observations accumulated during our career, we find that in the last two decades the geomorphological mapping as a scientific discipline came under a shadow cone. The reasons are several, but we selected two in particular: (1) the geomorphological mapping is an expensive and time-consuming activity and (2) the geomorphological mapping has focused more on themes and applications than on complex maps with a holistic approach. It is surprising that the decline of the geomorphological mapping coincides with the powerful development of GIS techniques; the geomorphological maps based on the traditional mapping began to be overlooked in exchange for opportunities to combine with the GIS database.

In this paper we propose to draw attention to the fact that by neglecting the mapping of the landforms it happened to arrive to mediocre mapping achievements pompously titled geomorphological maps. Even if the maps are using the traditional method of symbolic representation of landforms, or software of the GIS platform, the result shows that there isn't a knowledge of the methodological norms for the preparation of geomorphological maps. We usually learn them during the university training. We have several examples in this regard.

In the second part of the work we plan to offer a model of geomorphological mapping using the modern techniques we have today, but with a very careful observance of the criteria for mapping the landforms. We will try to give an answer to the question whether the GIS software platform is feasible for constructing a general geomorphological map. For this we will present a practical application on a sector of the Putna valley from Vrancea county. The final comments and discussions on applications will help in finding the most appropriate graphic expression of the distribution of landforms, so that the geomorphological mapping could be widely used by young researchers.

Key words: mapping concepts, geomorphological legends, general geomorphological map, GIS

1. Introduction

The maps are fundamental components of the geographical investigation. Their importance was recognized long time ago if we remember the old Chinese proverb: „*a map is worth a thousand words*”. As the information presented on a map becomes complex we need much words to render the spatial variety in which a geographic phenomenon can appear. The usage of the map eliminates this drawback, especially for geomorphology where, as we will see, the spatial distribution of landforms must involve many attributes, so the final picture appears even more complicated.

For over one hundred years geomorphological maps were used to illustrate the spatial distribution of landforms and geomorphological processes, the relief mapping method being the touchstone of any geomorphologist. We would have expected that, under the old Chinese proverb quoted above, the geomorphological maps and the geomorphological

mapping method to get a development justified by the enormous progresses made in the modern techniques domain (of collecting information on the ground, of sending it far away, to create much more attractive maps, which should be easier to read by users). Or, if we follow the scientific productions abroad and here, at least for the past 20 years, we note with great regret that the geomorphological map was almost eliminated from the concerns of geomorphologic researchers, whether incumbents or start-ups. Perhaps the most obvious trend of this phenomenon is observed in developed doctoral works (which we watched ourselves in the last two decades in Romania); young people who get a doctorate in geography with a thesis in geomorphology are very reluctant (with some exceptions) in the development of geomorphological maps for their areas of investigation. This phenomenon creates much concern for the fate of our field, knowing that the basic method by which the fundamental objective of geomorphology is the mapping of the landforms.

The reasons for which the geomorphological mapping as a scientific discipline had relatively modest results in the last 20 years appears to have an economic nature: the detailed geomorphological mapping is an expensive and time consuming activity (Gustavsson et al., 2006). The result was that many scientists have focused on the elaboration of thematic maps with maps that are immediately applicable and they neglected the complex maps with holistic approach. Other authors, by contrast, believe that the use of maps and the geomorphological mapping are subject to an intense process of rebirth (Vitek et al., 1996) due to the emergence of new computer-assisted techniques.

It is surprising, however, that the geomorphological mapping process has not kept pace with the strong development of GIS techniques, for they neglected the new possibilities resulting of combining a GIS database with the traditional geomorphological legend based on the field mapping of landforms. It seems that here, as we shall see in subsequent chapters, the geomorphological experts have lost the pace of development imposed by GIS experts to investigate land. The production of maps in which the relief is the central object is made by specialists in other areas who have no relation to geomorphology (van Wasten et al., 2003). That does not mean that their quality is adequate.

Surprised ourselves by this situation, we tried to make our contribution since 2007 (Rădoane, Rădoane) to the invigoration of Romanian researchers' interest in geomorphological mapping, resulting in a positive signal in the specialty literature. Earlier concerns of real value (Posea, 2008) have been republished, new contributions for GIS applications for the geomorphological map have been brought (Mihai et al., 2008; Niacșu, 2009; Condurachi, in press).

In the same spirit, we have proposed in this paper to continue the efforts to increase interest from specialists for geomorphological mapping, but also from different categories of users, suggesting a brief scan of the evolution of this research method and to finally explore a modern way of mapping the land using GIS techniques. The structure of such an approach is the following: a) showing the evolution of the relief mapping concepts, b) discussing a geomorphological legend that can be applied in the context of GIS platform, c) own geomorphological mapping applications in GIS system.

2. Evolution of concepts of landforms mapping

The history of geomorphological maps has been extensively presented in several papers published

recently (Posea, Cioaca, 2003; Gustavsson, 2005; Gustavsson et al., 2006; Posea, 2008, Mihai et al., 2008; Finkl et al., 2008). In addition to these surveys, we made ourselves a referential of the geomorphological mapping with emphasis on the development of the geomorphological legend in Romania (Martiniuc, Băcăuanu, 1963; Martiniuc, 1971; Ungureanu, 1978; Ichim, 1979; Grigore, 1981; Posea, Badea, 1980; Posea et al., 1987; Popescu, Ielenicz, 2000). These views have been linked to the major international development in elaborating the geomorphological legend.

Until the late 1940s the description of a landform or of a set of landforms was made almost exclusively by written reports. Because of the lack of a precisely defined terminology it was extremely difficult, if not impossible, to make intelligible comparisons between the works made in different parts of the world. The so-called "physiographic maps" that often accompanied these reports were of limited utility, because they did not result from a systematic field research and were built to illustrate the author's conclusions (St-Onge, 1964).

It is surprising that the idea of building a mapping system to allow accurate comparisons did not come too soon. It seems that this occurred after the Second World War, when the requirements of planners, agronomists, civil and industrial engineers and others have required insistently a precise instrument of knowledge and assessment of relief.

The topographic maps were the first maps which provided information about relief. From their analysis we can obtain much information about the size and extension of landforms, but less on their genesis, stage of development, relations with the geological structure and the slope deposits. The first truly geomorphological map was presented by Passarge (1914) in *Morphological Atlas* in scale 1: 50 000 (cit. in Enciclopedia of Geomorphology, 1968) with information on slope, valleys shape, petrography and types of relief. Only at UIG Congress (International Union of Geography) in 1956 was set up a special commission to develop the geomorphological map and in 1968 was prepared a unified mapping system (known as the Unified Key) for detailed geomorphological mapping. To this project collaborated an important number of specialists from several countries, and the result was published in 1972 in Brno (Demek et al., 1972).

Despite all these efforts, so far were not accepted a form, content or cartographic symbols to make maps being compared, even when it comes to the same area. Instead, we note that we arrived to the recognition of common principles which should underpin the geomorphological map. One of them is

as follows: **the geomorphological map must restore the appearance of landforms (M), their genesis (G) and age (A).** Nicolae Popp greatly sensed this need since 1936: “*A map is actually the morphological graphic translation of a particular concept. It is worth only as much as this concept is worth*” that Klimáševski (1960, 1982, 1990) concretized as follows: “*The geomorphological map should inform on the distribution of landforms in terms of size, origin and age. It must include morphographical, morphometric, morphogenetic and morphochronological information*” (p. 267).

The acceptance of a fundamental principle of the geomorphological map by most scientists eventually resulted in a quasi-accepted legend (Demek et al, 1972) and in an impressive cartographic production for many regions of the Globe.

2.1. International geomorphological mapping

The manner in which each one carries out the geomorphological mapping, specifically, on the map, is still very different. To illustrate the situation, we decided to follow the evolution of the most popular systems of legends and how they illustrate the principle Morphometry-Genesis-Age (MGA) stated above. The contribution of the geomorphological mapping schools was briefly mentioned by Posea and Cioaca (2003) in which more or less, they also referred to the principle of MGA.

On our part, we chose to emphasize the manner in which each of the important geomorphological mapping schools used the principle of MGA or variants of it (Table 1).

Table 1. The way in which was interpreted and applied the principle Morphometry-Genesis-Age for the geomorphological detailed map (scales 1:10000 - 1:50000) by the major schools of geomorphological mapping (processing according to St-Onge, 1964).

Geomorphological legend name	Representative authors	Description
Russian legend	Başenina et al. (1960)	The general background given by grayscale representing lithology (L) . Geomorphological map focuses on the genesis (G) and age (A), and neglects the morphometry . Geomorphological maps are very attractive, but difficult to read because of the legend complexity (500 symbols), of overlapping colors, of the variety of shades. Value reduced from of practical point of view. Principle: LGA
Czechoslovakian legend (or Czech and Slovak legend)	Geographical Institute of the Academy of Sciences in Prague (1963)	The legend is based on the genetic classification. Landforms grouped in 4 large chapters: structural, denudational, accumulative and anthropogenic Genesis = by colour Age = indices over colours Morphometric information is missing. Principle: GA
Polish legend	Geographical Institute of the Academy of Sciences in Krakow (1950, 1952, 1963)	Polish have created the most attractive, clear and easy to read geomorphological maps Background : shades of colour for 3 values of slope (below 4°, 4 - 20°, over 20°) (M) Age : by colour only three periods: Neogene, Pleistocene, Holocene (A) Genesis : by symbols with different colors (G) There is no reference to the lithological information Principle: MGA
French legend	Center for Applied Geomorphology in Strasbourg (1962)	The background is given by lithology by colours (L) Genesis - symbols overlaid on lithological colours (G) Age of the relief - by colours of the symbols on 8 classes from “Neocene” so far (A) The morphometric information is missing . Maps difficult to read because the symbols colours overlap with those of lithology Principle: LGA
Belgian legend	Gullentops (1964)	Slopes = by shades of different intensities according to the slope value (M) Genesis = colour of the symbols (G) Age = intensity shades of the same colour (A) Lithology of forms of sedimentary origin = points of different sizes (L) These maps are difficult to achieve by conventional techniques but are feasible in modern techniques Principle: MGAL
Unified legend (Unified Key)	Demek et al. (1972)	Genesis = colour of the symbols (G) Slopes = shades of gray (M) Age = symbols (A) Principle: GMV

From this summary we note that all major international contributions are concerned to respect a fundamental principle of the geomorphological map, accepted by the scientific community since 1968, namely, Morphometry (M), Genesis (G) and Age (A). There are, however, slight variations on this theme, namely, some legends also include the presentation of lithology (the Belgian legend) or they replace the morphology with the lithology (the Russian and French legends) or they drop out the two entities, retaining only the genesis and age (the Czechoslovakian legend). The Polish Legend was estimated at that time (St-Onge, 1964) to be the origin of the most expressive, more attractive and clear geomorphological maps.

Special attention should be paid to *the unified legend* (Demek et al., 1972) which managed to combine around a clear concept the complexity of the landforms and now it forms the basis for the geomorphological legend in GIS system. Thus, the main emphasis is put in the legend on *morphogenesis*, expressed by ten colours (red, brown, purple, pink, yellow, ultramarine, black, grey and blue). The various landforms are represented by 353 symbols. The genesis of the landforms is grouped into three categories representing the endogenous processes 13 categories representing the exogenous processes. Red is reserved for endogenous forms, black for the

biogenic/ anthropogenic ones, grey for the contour lines and slope classes, blue for surface water and river system. The remaining colours describe different exogenous erosion and depositional forms. To describe the landforms with complex genesis can be used two colours, one of them as the base colour to indicate the initial origin and the second one by symbols indicating the subsequent transformations of the form of relief. The slopes are divided into six categories of gradients (0 - 2°, 2 - 5°, 5 - 15°, 15 - 35°, 35 - 55° and > 55°). For indicating the age of landforms a black-letter code was used. In conclusion, *it is the only legend among the discussed ones in which the order of presentation of the three fundamental elements on the geomorphological map starts with Genesis, then Morphology and Age*. This element is to emphasize because in the geomorphological map that we created using GIS system it will be the dominant principle.

2.2. Geomorphological mapping at national level

In Romania, the concerns for the geomorphological legend and map were synchronous with the events at the international level. The most important achievements are presented in chronological order in a summary table (Table 2).

Table 2. The main achievements in Romanian geomorphological mapping

Cartographic achievement	Source	Description
1960 Geomorphological map of Romania 1:1000000	Geographical Monography (1960) Authors: P.Coteț et al.	General Background = structure and lithology by colours and shades (L) Age = geomorphological complexes by colour tints and shades (A) Genesis = left on the second plan, described in the legend box and by a few symbols distinguished by colours (G) (Fig. 1)
1964 The first geomorphological legend elaborated in Romania Scale 1:50000	G. Posea, N. Popescu (1964)	The background of the map is given by layered morphogenetic surfaces and slopes (M) Age = by colours (A) Genesis = symbols by different colours (G) The sample of the map produced by the authors stresses the inclined and plane surfaces differentiated by age and passes in second plan the genesis of landforms. (Fig. 2)
1976 Geomorphological map of Romania 1:1000000	Institute of Geography of the Romanian Academy	The map emphasizes the morphography and morphometry Morphometry = rendered by colour hues according to the relief steps (M) Age = specified in the main titles of the legend in accordance with the large morphographical units (A) Genesis = is put in the background, almost neglected (G) (Fig. 3).
1971-1978 Detailed geomorphological legend 1:50000; 1:25000	C. Martiniuc (unpublished), I. Ungureanu (1978) Processing after Klimaševski (1965)	Genesis of the relief by 306 symbols grouped by colour Geomorphological maps made by Ichim et al (1976), Ichim (1979) were based on this legend
1976-1987 Geomorphological map of Romania 1:200000	L. Badea (coord)	The general background of the map is given by geodeclivity (M) Type of superficial deposits by shades (L) Genesis of the relief - more than 220 symbols by separated colours (G) Age of the relief is not specified The resulting maps are difficult to read, structural and lithological shades are mistaken for these of fragmentation; symbols of the morphographical categories are mistaken for the genetic symbols

1976 General geomorphological map 1:50000	I. Ichim N. Rădoane M. Rădoane	Structural and lithological categories (general background of the map) - 15 symbols (L) Geodeclivity – arrows with the slope value (M) Genesis - by 108 symbols (G) Age - by letters and numbers (A) The resulting maps (sheets Piatra Neamt and Gheorgheni) are expressive, but quite hard to read because of the lack of colours (Fig. 4)
1979 General geomorphological map 1:50000	I. Ichim	Geodeclivity = four categories of slopes (the general background of the map) by shades of colour (M) Genesis of the relief = symbols of different colours (G), chronologically grouped (A) The resulting map (Stănișoara Mountains) in 8 colours is expressive, easy to read. The concept of the map is closest to the MGA principle of the Polish legend (Fig. 5)
1980 Geomorphological map of Romania 1:400000	G. Posea, L. Badea	The authors declare themselves followers of the MGA principle by outlining the exact area of expansion of different types of morphogenetic surfaces or by conventional signs, all grouped on categories of agents and age. Morphology = contours (M) Morphogenesis = delimitation of morphogenetic (G), flat or inclined surfaces, dominated by a particular agent and a certain age (A). <i>Note.</i> Too much subjectivity in assessing the genesis and age of a surface which is typically polygenetic.
2000 General geomorphological map 1:50000	N. Popescu, M. Ielenicz	The legend is dominated by the same concept of morphogenetic areas (Posea, Popescu, 1964). MGA principle is abandoned, focusing almost exclusively on the genesis of landforms. <i>Note.</i> The slopes are generically presented with colour hues for three categories of slopes. With colour hues are also presented other landforms that come into the category of slopes considered for slants (terminal glacis of slopes, rises etc.) which leads to confusion, because two different shades of colour cannot be combined. (Fig. 6)

The first geomorphological map of Romania is elaborated by a group of geographers, lead by Coteț (fig. 1), within *The Geographical Monograph of Romania* (1960). Deeply influenced by the Russian experience, the map is dominated by the structural and lithological element. On this background the relief units are separated by colour shades and hatchings. The genetic part of the relief

is left in secondary plan, being vaguely described in the legend box or by sketchy symbols in different colours (Lithology-Age-Genesis principle). This characterization does not diminish the importance of the first relief map of Romania. Made in scale 1: 1500000, it is a valuable building and pioneering for the Romanian geomorphology and, for us, for the geomorphological mapping.

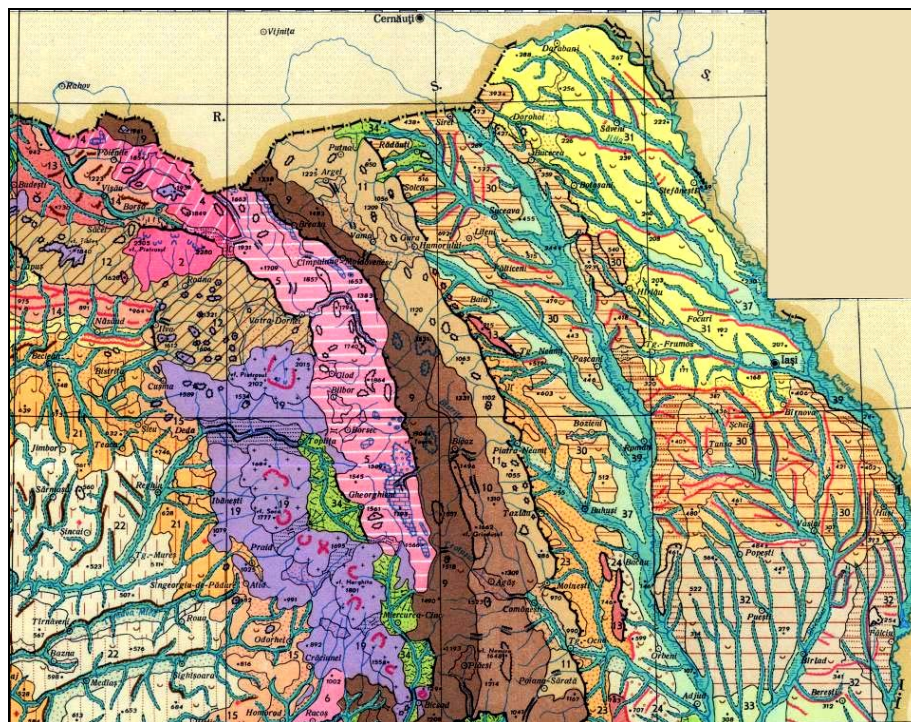


Fig. 1. Extract from the geomorphological map of Romania, scale 1: 1 500 000 (Coteț, 1960)(other comments in Table 2)



Fig. 2. Extract from the general geomorphological map, 1:50 000 (Posea, Popescu, 1964) (other comments in Table 2)

In 1964 was published the first general geomorphological legend in Romania (Posea, Popescu, 1964) (Fig. 2). Emphasis is placed on outlining the landforms as multi-stage morphogenetic surfaces (as horizontal and near-horizontal surfaces) and as inclined surfaces (slopes), all geo-chronologically separated. Over them are overlapping signs rendering different

genetic forms of relief represented at the map scale. In addition, the map also contains some significant contours. Regarding the principles underlying the geomorphological map, we can estimate that the two authors have focused on morphology (by identifying the flat and inclined surfaces and contours), then age and only thirdly the genesis (MGA principle).

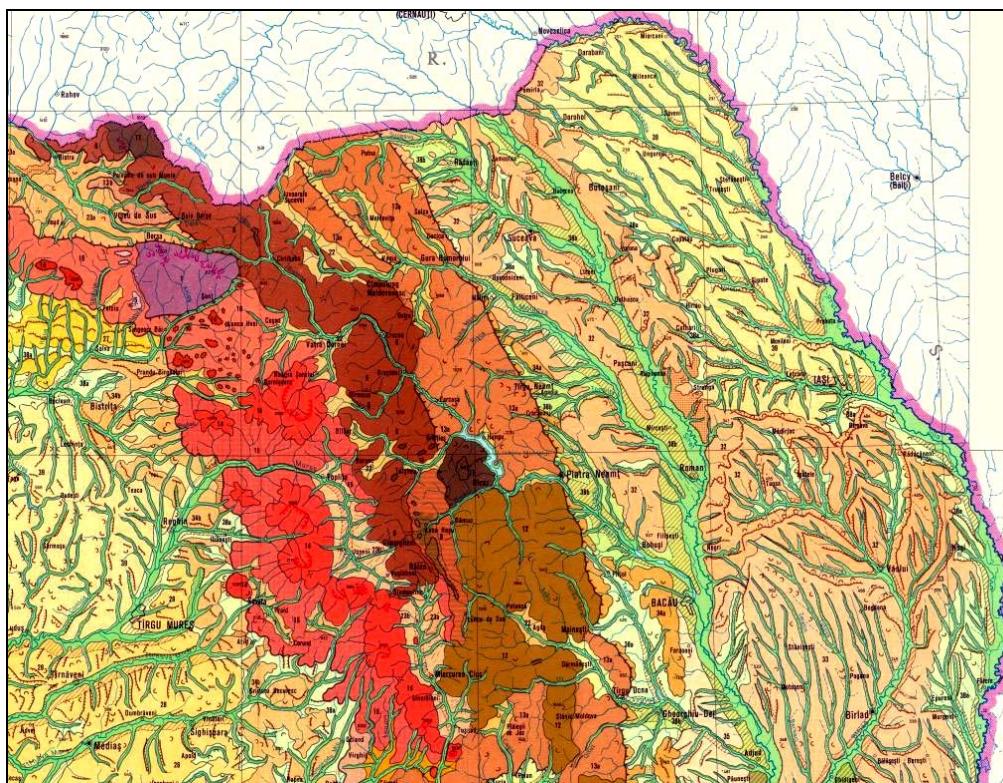


Fig. 3. Extract from the geomorphological map of Romania, scale 1: 1 000 000 (Institute of Geography, 1976) (other comments in Table 2)

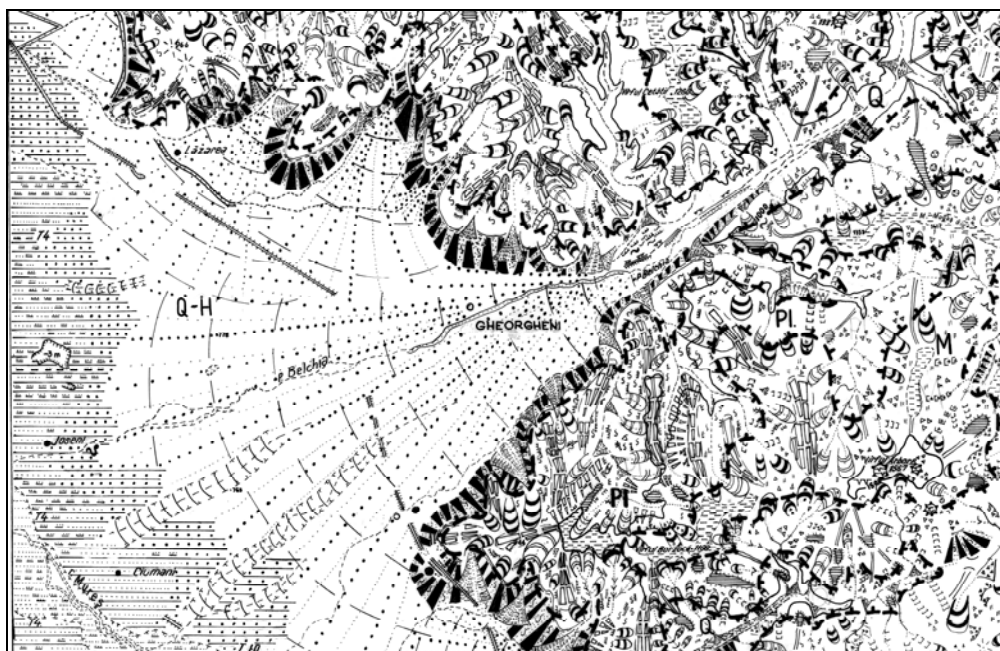
Between 1972-1978, a team of geomorphologists from the Institute of Geography of the Romanian Academy, led by Lucian Badea, develop The geomorphological map of Romania in a scale of 1:1000000 (Fig. 3). The general background of the relief map is given by the morphometry of the relief by colour shades depending on the altitude of relief steps (M). In the legend are described then the membership of each altitudinal floor to the tectonic, structural and lithological complex (L). As regards the genesis of landforms, the problem is expressed briefly in the legend (G), and the age, only in the main chapters of the legend (A). Thus, the chosen principle is MLGA. It is interesting to note that if we overlap the areas of the identified major landforms on a map (1960) and on the other one (1978), even if they were developed on different driving forces, they coincide to a very large extent. This coincidence has often been maliciously commented in scientific meetings at that time (I Ichim, personal communication).

However, the concerns about this research area were particularly effervescent in all centres where were activating geomorphologists, universities, institutes and research stations. In the period 1971-1978 in Iasi, C. Martiniuc (1971, manuscript), Irina Ungureanu (1978) have developed the detailed geomorphological legend in which the fundamental principle is the genesis of the relief represented by 306 symbols. In fact, the developed legend is an adaptation of the Polish legend of Klimařewski (1963). The authors have not developed maps based on this legend, but Martiniuc's students have used it in their works (Ichim et al., 1976 – fig. 4; Ichim, 1979). The geomorphologic map of Stănișoara

Mountains (Ichim, 1979) (Fig. 5) currently remains a model of clarity, logic and professionalism in Romanian geomorphological mapping. Built in 8 colors, it is expressive, easy to read and complies with the MGA principle of the Polish legend.

Between 1976 and 1987, L. Badea coordinated an ambitious program to develop the geomorphological map of Romania in a scale of 1:200 000 after a legend that combines the geodeclivity (M), the type of surface deposits (L), the genesis of relief by 220 symbols (G) and without age specification. The map sheets have not come to be published because of high costs, of technical difficulties in reproduction of colours, shades, symbols (many of them overlapping), etc. Analysing a few sheets for the eastern part of Romania in the manuscript stage, we could see that, overall, that map is unclear, difficult to read and less attractive to the drawing techniques of the 1980s.

In 1980 is published the Geomorphological map of Romania on a scale of 1:400 000. The concept map is based on the geomorphological legend elaborated by Posea and Popescu (1964) on the so-called “principle of surface types”, regarded according to the genesis and separated by age. These areas represent the general background of the map on which they are overlaid, by symbols, subsequent, minor forms, genetically differentiated. By this, the authors declare themselves as advocates of the MGA principle by exactly outlining the area of expansion of different types of morphogenetic surfaces or by conventional signs, all grouped by agents category and age.



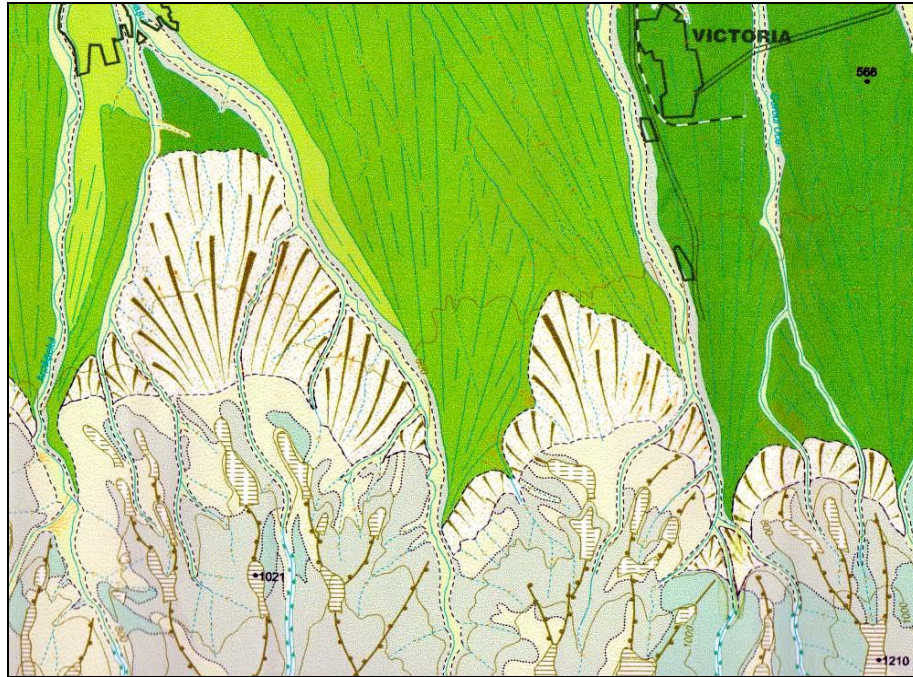


Fig. 6. Extract from the general geomorphological map, 1: 50 000, Victoria sheet (Popescu, 2000)

This completes the review of the main mapping developments in geomorphology in Romania. In the last decade we have not noted concerns for the general geomorphological map, many authors preferring the pragmatic approach in this area, namely, the production of maps for a specific purpose. A popular example in this respect is the hazard and geomorphological risk maps that focus only on those processes responsible for the hazards in a particular region (Keinholz, 1978; Bălteanu et al, 1989; Cioaca et al., 1993; Grecu, 2002, Mihai, Sandric, 2004; Armas, 2006; Mihai et al, 2010; Bălteanu et al, 2010).

However, since 2006 there is a shy concern, especially from the young geomorphologists (Condurachi, 2006; Mihai et al, 2008), of elaborating the geomorphological map in GIS system, in close relationship with relevant international events. But this phenomenon will be discussed in the next chapter.

3. Is GIS a solution for geomorphological mapping?

From the international and national history of development of geomorphological maps we can clearly retain the general observation on the difficulty in manually achieving such works and how they gradually dropped from the construction of general geomorphological in favour of the applicative maps. With the development of the

software and of the various applications in GIS of the 90s we passed, as was natural, to an increased interest in the representation of landforms distribution using this platform (Evans, 1990). So far, GIS applications referred to many areas where the landforms items have been in the spotlight, such as: mapping landforms (Jakobsen, 2003; Vasiliniuc, Ursu, 2008); analysis of slopes and natural hazard zoning (Dai Lee, 2002; Otto, Dikau, 2004; Voiculescu, 2009; Bălteanu et al., 2010); ordering the relief of remote sensing data in combination with the Digital Terrain Model (Bocco et al., 2001; Patriche, 2004; Gaspar et al, 2004). All these applications contain a consistent geomorphological database, especially on the morphometry of the territory and which was assembled in GIS system. Instead, it does not manifest a clear project to create a GIS database containing structured information on morphometry/morphography, genesis and age of the relief. Moreover, the geomorphological experts have difficulties in formulating their knowledge in the decision rules necessary in GIS based modelling. An analysis in this regard was made by Van Westen et al (2003) on the implementation of maps of landslide susceptibility. Thus, it appears that GIS experts have to make decisions in the absence of geomorphologic knowledge about processes and types of landslides. If geomorphologic experts would fill this gap, the accuracy of maps of susceptibility to natural hazards made in GIS system would increase from 52% to 76% and that only by adding information on

detailed geomorphologic maps (Van Westen et al., 2003). Unfortunately, the geomorphologic mapping systems based on symbols can not be easily used in GIS because they must be converted to classified polygons before digitization. If conversion rules developed by experts would exist, then the information on the traditional geomorphologic maps could be transferred into GIS databases, geomorphologically functional. For this should exist the equal sign between the geomorphologist and the GIS expert.

The person who explicitly proposed such a mission is a Swedish author who along with his team, have a remarkable activity in this regard (Gustavsson, 2005; Gustavsson et al, 2006; 2008; Gustavsson, Kolstrup, 2009). A fairly detailed presentation of the results of the Swedish team was made in Rădoane, Rădoane (2007) and we do not come back here. In the same paper we recalled the main Romanian achievements until now of the geomorphologic map in GIS system.

From the achievements of these authors we conclude that when designing a new mapping system using GIS should be chosen one of the principles of classical geomorphologic legends. We have already seen that all revolve around themes: morphometry/morphography – genesis – age – lithology (MGAL). Choosing the combination of information that must be presented on the geomorphologic map depends not only on the author's subjectivity, but also by the specific of the region to be mapped. For example, a region where dominate the slopes and the slant of slopes controls the stability of the deposits and the degree of activity of mass movements, obviously we can choose a combination MGA or GMA focusing on land form and slope. For such a region, depending on the map scale and, adding the lithology, would make the map difficult enough to read. Conversely, for a region where prevail the alluvial plains, the plains of all types, flat surfaces we can choose LGAM, the resulting map would be quite "light" to also stand the information on the geological substrate.

In GIS system many of these shortcomings can be overcome by the fact that a geomorphologic map supports behind it, any information we think is necessary (rock, vegetation, soil, ground water, etc.) and need not be shown on the map, but only in its annexes (rather related to the power of computer and its resources) and on which we can make the mixes we want to explain a phenomenon.

In conclusion, the answer to the rhetorical question at the beginning of this chapter is strongly affirmative: *the GIS software platform is a solution*

for the geomorphologic map if the geomorphologists themselves are ready to access it. The theoretical knowledge base of a geomorphologist and the education he has for the identification on ground of forms and processes are of great necessity to enrich the GIS software platform for GIS experts, the condition being that the geomorphologic experts are quite familiar with the computer principles of GIS software.

The answer to this observation is in the new trends now manifested in higher geographical education where young geographers are bound to attend at least one course in GIS or, at a higher level, they can attend the courses of a master in this field. Same goes for a doctoral specialization. Thus, we believe that at least at the level of the young generation, geomorphologists are prepared for expertise both in geomorphology and in GIS software platform and all this for the sake of scientific knowledge and proper resolution of many practical problems.

4. Applications of GIS-based geomorphologic mapping

In this section of the paper we will present the steps we followed to achieve the general geomorphologic map using GIS techniques. All documentation done up to this point has the capacity to order, simplify and confer value to its own enterprise in achieving such an objective. From the documentary we have to remember some guidelines of elaborating the general geomorphologic map we list below (Verstappen, 1970; Klimaszewski, 1982):

(1) Field research in conjunction with the analysis of aerophotograms are the recommended instruments for the geomorphologic mapping;

(2) Mapping at scales between 1: 10,000 and 1: 100,000 appropriately represents the relief and its features;

(3) Mapping should include all aspects of the relief, respectively morphography, morphometry, morphogenesis and morphochronology, thus we will understand the past, present and future of the relief evolution;

(4) Colour and symbols are used to convey information through the map;

(5) The chronological order of evolution of the landforms must be determined and depicted on the map and in the legend;

(6) Lithology should be incorporated into mapping units as far as possible;

(7) Map legend must be arranged in the genetic and chronological order;

(8) Detailed geomorphologic maps are essential for the future development of geomorphology.

In accordance with the foregoing information, the first task that we performed was to determine which legend is best suited for mapping the relief of Romania and which principles to follow in building the map. From the long list of various legends presented in the previous chapters and comments attached to them we considered that:

4.1. Genesis of landforms

is the most important feature to be represented on a general geomorphologic map. This requires symbols and colours.

Colour

is best captured by the human eye and therefore it is used by almost all the legends for rendering the genesis of the landforms. The list of colours represented in Table 3 is simplified to basic colours (11) to be easily identified by the human eye. The colours are ordered on the genetic criterion of landforms, including the agent, the process and the age. For each colour we also indicated the RGB codes to precisely indicate the shade used. We mention that some legends have proposed a large number of colours, for example. Klimaszewski (1965) has not less than 69 colours and shades to represent the genesis, the process (for construction or destruction) and the age of landforms. Their identification on the geomorphologic map leaves place to much confusion.

Table 3. The colours proposed for the geomorphologic map in a 1:25 000 scale published in GIS system (in accordance with the international scale of colours of the geomorphologic legend).

Landforms	Agent	Process	Age	Colour	RGB codes
(A) Tectonics (B) Volcanic (C) Structural	Endogenous forces Exogenous forces (gravitation)	Constructive Destructive	Tertiary Pleistocene Holocene	Red	254,0,0
(D) Denudational, (E) River- denudational	Gravitation and water	Destructive Constructive	Paleogene Neogene Pleistocene Holocene	Brown	127,51,35
(F) Karstic (G) Sufozional	Surface water, groundwater	Distructiv/solutie Constructiv	Tertiary Pleistocene Holocene	Dark orange	251,149,1
(H) River	Flowing water	Destructive Constructive	Tertiary Neogene Pleistocene Holocene	Green	0,153,0
(I) River-glacial	Pro- and underglacial flowing water	Destructive Constructive	Pleistocene Holocene	Olive	148,151,0
(J) Marine, lacustrine	Lacustrine and marine water	Destructive Constructive	Pleistocene Holocene	Dark turquoise blue	0,168,255
(K) Glacial	Glaciers	Destructive Constructive	Pleistocene Holocene	Violet fuchsia	204,0,205
(L) Periglacial	Freeze-melting, snow	Distructiv Constructiv	Pleistocene Holocene	Light violet	255,201,253
(M) Aeolians	Wind	Distructiv Constructiv	Pleistocene Holocene	Dark yellow	254,180,3
(N) Biogene	Plants, animals	Destructive Constructive	Holocene	Kaki mustard	173,129,3
(O) Anthropic	Man	Destructive Constructive	Holocene	Black	0,0,0

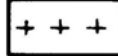
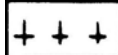
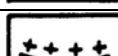
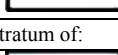
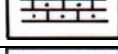
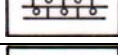
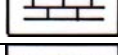
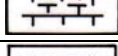
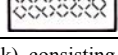
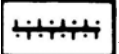
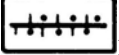
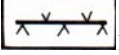
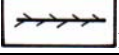
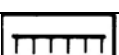
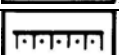
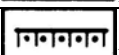
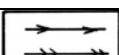
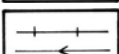
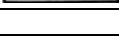
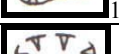
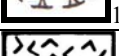
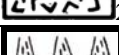
Symbols

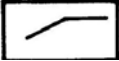
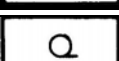
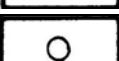
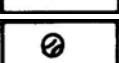
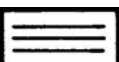
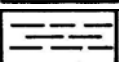
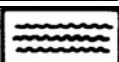
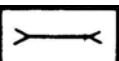
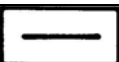
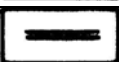
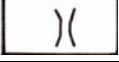
are the most common way to genetically describe a landform and to generalize too small landforms to be mapped to the scale. Symbols are drawn as to suggest as close as possible the appearance of these landforms. For example, the

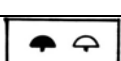
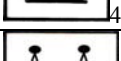
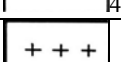
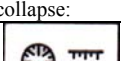
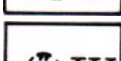
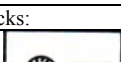
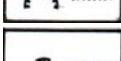
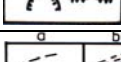
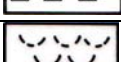
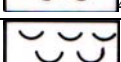
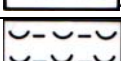
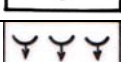
lines are used to indicate the rivers, faults, or boundaries between different geomorphologic units, the shade patterns are used to describe the lithology of landforms (eg, a structural plateau on limestone or sandstone is represented by such shade models). A problem with these shade models is when they

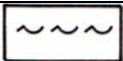
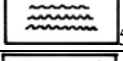
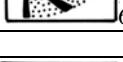
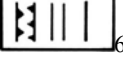
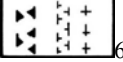
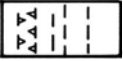
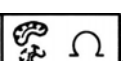
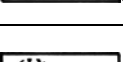
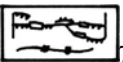
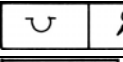
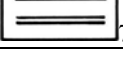
are drawn in too powerful and too bold colours, because they tend to dominate the other information on the map. An example of this is the general geomorphologic map Posea, Popescu (1964) (Fig. 2) where the shades being too bold representing “morphogenetic flat surfaces” leave completely in shadow “the morphogenetic inclined surfaces” for which are used signs that are less bold. On the other hand, shade patterns are welcome when rendering a geomorphologic map in black and white (a good example is the maps Ichim et al, 1976, Piatra Neamt and Gheorgheni sheets, 1:50 000).

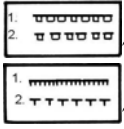
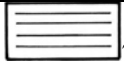
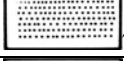
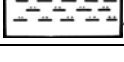
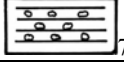
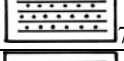
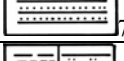
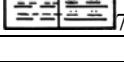
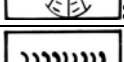
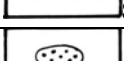
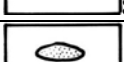
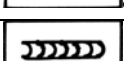
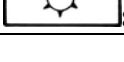
Table 4. Simplified symbols for The geomorphologic map in GIS system
(adapted with a focus on Romania's relief after Klimaszewski (ed), 1963 and Martiniuc, 1978, manuscript)

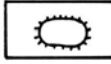
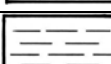
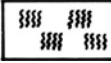
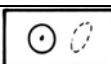
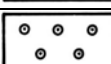
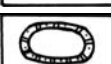
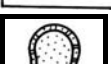
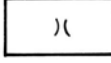
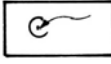
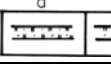
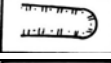
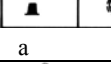
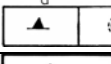
Name and description	Colour	Symbol
Landforms due to endogenous forces		
A. Tectonic and structural forms		
1. Steep slopes of rent:		
a) highly fragmented		 1a
b) weakly fragmented		 1b
c) abrupt on charriage cloth		 1c
2. Symmetric anticline peak		 2
3. Assymetric anticlinal peak		 3
4. Sinclinal valley		 4
5. Combe, anticlinal buttonhole		 5
6. Diapiric dome		 6
7. Limits of regions of recent lifting		 7
8. Limits of regions of recent dive		 8
9. Fragments of structural surfaces on substratum of:		
a) gresie		 9a
b) cuarțit		 10b
c) calcar, dolomit		 11c
d) marls		 12d
e) igneous rocks		 13e
14. Ridges (increase) of resistance (hogback), consisting of:		
a) limestone, dolomite		 14a
b) sandstone		 14b
c) quartzite		 14c
d) igneous rocks		 14d
e) crystalline rocks		 14e
15. Monoclinial ridges consisting of:		
a) limestone, dolomite		 15a
b) sandstone		 15b
c) quartzite		 15c
d) igneous rocks		 15d
16. Surface of structural terraces (the geological fund is listed as 24a-e)		
		 16
17. a –d. Consequent valleys, Reconsequent valleys, Subsequent valleys, Obsequent valleys		
		 17a,b
		 17c,d
B. Volcanic forms		
18. Crater frame:		
a) weakly modified		 18a
b) strongly modified		 18b
19. Caldera frame		
a) weakly modified		 19a
b) strongly modified		 19b
20. Volcanic plateaus covered by blocks		 20
21. Rests of the slopes of the cone		 21
22. Parasitic cones		 22

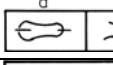
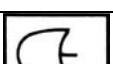
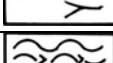
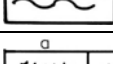
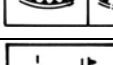
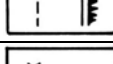
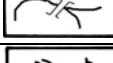
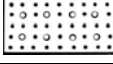
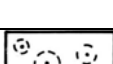
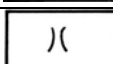
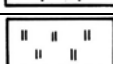
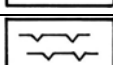
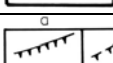
23. Neck			23
24. Dyke			24
25. Barancos			25
26. Lava columns			26
27. Crack with mofette			27
28. Crack with hot spring			28
29. Cave in lava			29
30. Mud volcanoes			30
Landforms caused by exogenous forces			
C.Denudational landforms			
31. Initial sculptural surfaces			31
32. Degraded sculptural surfaces			32
33. Fragments of exhumed sculptural surfaces			33
34. Fragment of active pediment			34
34. Fragment of inactive pediment			34
35. Ridges of intersection of the slopes:			
a) narrow and sharp (in the rock)			35a
b) narrow and rocky			35b
c) narrow and rounded			35c
36. Forms of large mountain peaks:			
a) sharp and rocky, needles, towers			36a
b) conical			36b
c) rounded			36c
d) dome-shaped			36d
37. Small peaks, in hard rocks or weak rocks:			
a) conical			37a
b) rounded			37b
38. Saddle			38
39. Residual forms and their slopes:			
a) sandstone			38a

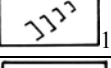
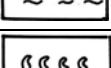
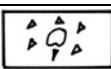
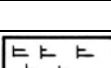
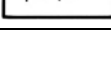
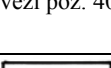
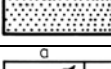
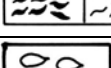
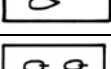
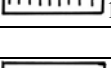
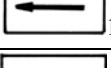
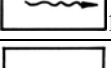
b) limestone, dolomit			38b
c) metamorphic rocks			38c
d) volcanic rocks			39d
40. Small residual forms:			
a) stone "mushrooms"			40a
b) stone « needles »			40b
c) stone « fortress »			40c
d) stone bridge (natural bridge)			40d
e) residual blocks overcrowding			40e
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47. Rotational slidings			47
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51. Insequent sliding			51

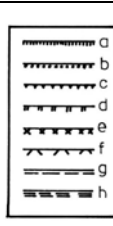
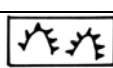
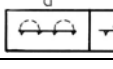
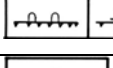
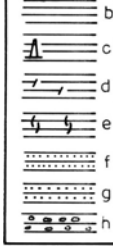
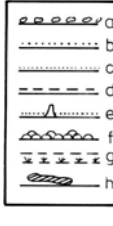
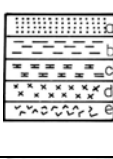
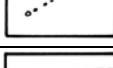
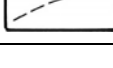
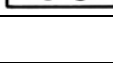
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4.2. Morphometry (quantitative description of the relief)/morphography (qualitative description of the relief)

On the geomorphologic maps until now these elements are represented as classes of slope and contours. In GIS system the scanned topographic and geo-referenced map is the base map for the geomorphologic mapping, so that information on the contour and slope gradients is included from the beginning. The submission of this information on the final geomorphologic map can be made by drawing contours using grey; by creating areas with shades of the same colour with certain values of slope (for slope classes - unified Legend, 1972; Ichim, 1979 or depending on the purpose for a certain region); contours and arrows pointing in the direction of the slope, and on the arrow is indicated the value of the slope in degrees, using black (Gustavsson, 2005). The discontinuities on the slope, the small ripples on the slope are shown by symbols in the colour of that morphogenetic process. In this way the map is no longer filled with subdivisions of slope in different colours and which would charge it too much.

4.3. Age

This is entered on the map with codes of letters in black (table 5), following the geological time scale (Haq model, 2006, published by Elsevier). Other authors combine the age with the type of rocks using colour coded letters with the colour of the exposed geological layer (Gustavsson, 2005).

4.4. Lithology

is divided into hard rocks and unconsolidated materials. In the Gustavsson model (2005), the type of rock in situ is shown by letters, their age by colours (according to the geologic standard), and the unconsolidated rocks with symbols and shades. By the combination of the three can be represented a variety of field situations. From our point of view, adding lithology on the general geomorphological map (especially if we analyze a mountainous area and we use a scale 1: 50,000 or 1: 25 000) hides the genetic message to be send by the map with priority. Exceptions are those areas where quaternary rocks would dominate and the geodeclivity would be reduced. It would be better to create a separate layer with the geological composition containing both the qualitative and quantitative information needed to genetically explain landforms.

Table 5. Geologic time scale and codes of letters and digits

Geological period			Code
Precambrian			Pc
Cambrian			Cb
Paleozoic			Pz
Ordovician			O
Silurian			S
Devonian			D
Carboniferous			C
Permian			P
Triassic			T
Jurassic			J
Cretaceous (inferior, medium, superior)			K (K ₁ , K ₂ , K ₃)
Paleocene			Pg ₁
Eocene			Pg ₂
Oligocene			Pg ₃
Inferior, medium, superior miocene			M ₁ , M ₂ , M ₃
	Sarmatian	Buglovian	Bg
		Volhinian	Vh
		Basarabiasn	Bs
		Kersonian	Ks
	Meotian		m
Pliocene (Pl)	Pontian		p
	Dacian		dc
	Romanian		rm
Quaternary (Q)	Pleistocene	Inf.	Qp ₁
		Medium	Qp ₂
		Superior	Qp ₃
	Holocene		Qh

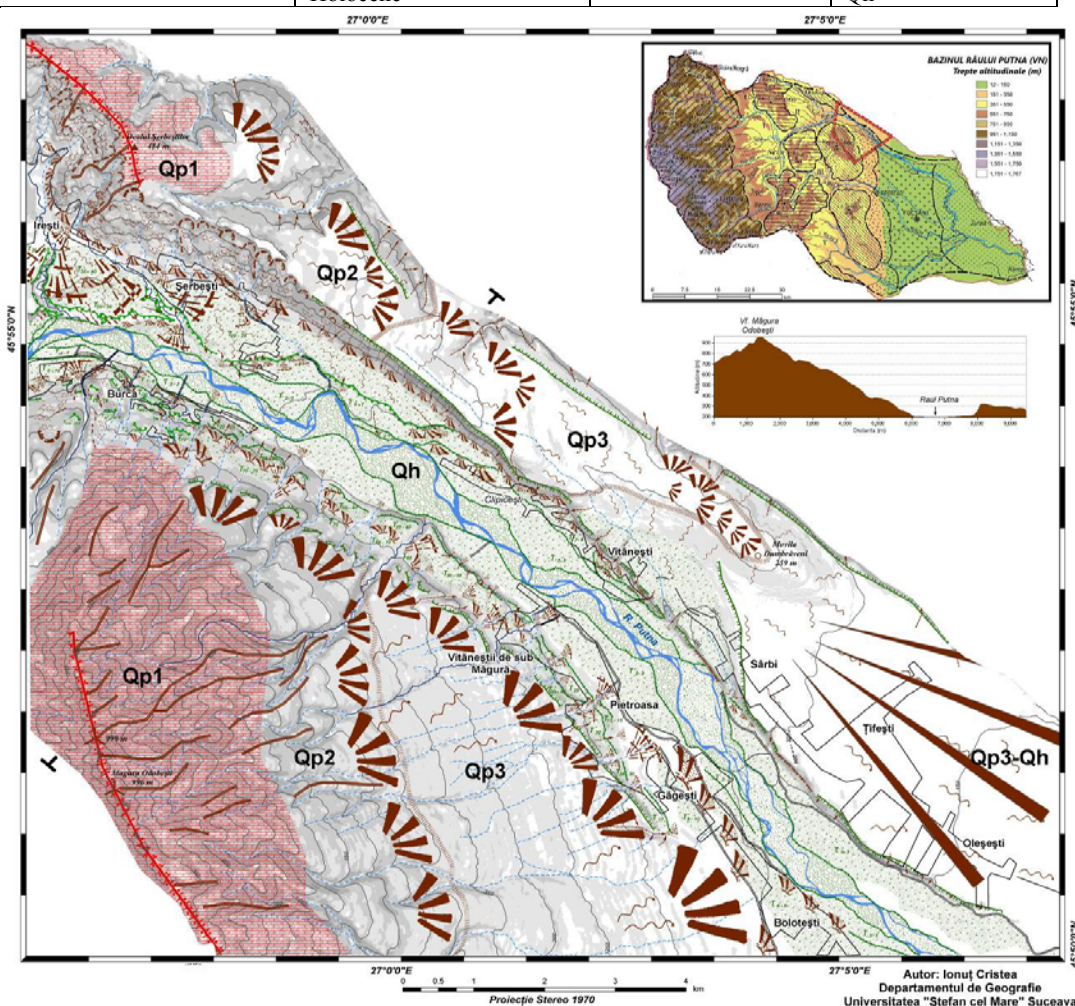


Fig. 7. Extract from the general geomorphologic map of Putna valley, Vrancea, generated by combining GMA, using GIS platform (legend is conform to Table 4)

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5. Discussion and conclusions

This paper emphasizes the importance of geomorphological mapping for geomorphologists, in order to improve the relief details on all maps. The main issues discussed in previous studies on geomorphologic mapping were concerned with the nature of the **geomorphological legend**. Even if a 100 years old history of geomorphological mapping exists, the scientific community still doesn't use a common legend. However, during the '60s and '70s, a large number of geomorphologists accepted the following principle "*the geomorphological map must provide information on landforms distribution, considering their **dimension, origin and age**. It must contain morphographic, morphometric, morphogenetic and morphochronologic information*". This definition has led to the quasi-accepted **unified legend** (Demek et al., 1972), which has been used in an impressive number of cartographic products in many regions on Earth.

A generalized collapse of geomorphological mapping occurred in 90's, following the development of GIS techniques. A rapid increase of spatial representations emerged, but less attention was paid to genetic types of relief. The cause were, on one hand, the "delay" of geomorphologists to learn the new computer skills; and, on the other hand, the difficulty to adopt in GIS the symbol-based geomorphological legends.

Beginning with the early 2000s, geomorphologists started to „speak a common language” with GIS experts, so that a GIS-based geomorphologic map became feasible. Our team is part of this tendency; however the project we have developed respects the legends of the classical geomorphologic map (GMA - Genesis, Morphology, Age, MGA - Morphology, Genesis, Age or MGAL - Morphology, Genesis, Age, Lithology). The results will further be improved, following the increase of our own GIS applications, but also by using work done by other authors.

In conclusion, we present the main guiding lines for GIS-based geomorphologic map development (similar for the classical ones, as well):

1. Geomorphologic maps must be based on field mapping.
2. The map must offer a global vision of the relief, including physiography, morphometry, genesis and age.
3. Based on scale, investigated area and interest of the researcher, a geomorphologic map should also include lithology (with special symbols).
4. The legend must be arranged in both genetic and chronologic order.
5. Detailed geomorphologic maps (1:10.000) are essential for the future development of geomorphology.

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Relationship between trees colonization, landslide and debris-flow activity in the sulphur mining area of Calimani Mountains (Romania)

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Abstract: Between the 1970s and the 1990s, the intense sulphur mining activity created specific landforms (quarries, waste dumps, dams, tailing ponds, etc.) in the central part of the Calimani Mountains (Romania). The newly created waste dumps are today intensely affected by geomorphic processes such as landslides, debris-flow and hyperconcentrated flows. The tree colonization of the landslide and debris flow deposits depends on the intensity and location of these processes. Therefore, the tree density and age is directly influenced by the landslide and debris flow activity. Our study analyzed the relationship between morphology and tree colonization downstream the Pinul waste dump.

The field survey and the existing documents have indicated that this area is geomorphologically very active and therefore the tree colonization is inhibited. The ecological rehabilitation methods based on reforestation cannot stabilize landforms created by the above-mentioned human-induced processes.

Keywords: opencast sulphur mining, waste dump, landslide, debris-flow, tree colonization, dendrochronology.

1. Introduction

There a number of studies on the colonization mechanisms and plant evolution during the revegetation of landforms resulting from recent geomorphic processes (Walker et al., 1996; Francescato et al., 2001). Vegetation is one of the very sensitive elements of internal dynamics of the landforms resulting from landslide occurrence (Nagamatsu and Miura, 1997) and debris flow (Pabst and Spies, 2001). Erosion-sedimentation processes and the associated disturbances have impacts both on floristic composition and the growing rate of the vegetation from affected areas (Hack and Goodlett, 1960; Scatena and Lugo, 1995).

Research focused on relationships between geomorphic and vegetation colonization processes has been undertaken in natural environments concern processes like mud flow, debris avalanches (Dale and Adams, 2003; Pabst and Spies, 2001), volcanic mud flow (Kroh et al., 2000), debris-flow (Beschel and Weidick, 1973; Hupp, 1983; Gehu, 1986; Harris and Gustafson, 1993; Shroder and Bishop, 1995; Kozłowska and Rączkowska, 2002; Palacios et al., 2003; Brancaloni et al., 2003;

Canone and Gerdol, 2003; Baroni et al., 2007) and landslides (Langenheim 1956; Moss and Rosenfeld 1978; Hull and Scott 1982; Hupp 1983; Garwood 1985; Miles and Swanson 1986; Walker et al. 1996; Myster et al. 1997). Within glacial and periglacial environments of the Italian Alps, Cannone and Gerdol (2003), Caccianiga and Andreis (2004), Baroni et al., (2007) have undertaken interdisciplinary studies based on the relationship between landforms and vegetation.

The study of the landform colonization resulting from the anthropic action has dealt with the problem of ecological rehabilitation and vegetation succession in relation to the morphology of mining areas (Pietsch, 1996). However, there are no general models of vegetation evolution which can be applied to any mining area. As a result of the peculiarity of each mining area, a proliferation of timely studies of this kind is necessary. Our study highlights the relationships between landforms (debris-flow deposits and landslides) specific to a certain mining area of sulphur exploitation in Romania and their tree colonization. Here we will also show the liability of some rehabilitation strategies through natural tree colonisation and plantation which are to be used in the study area.

2. Regional setting

The Calimani Massif belongs to the volcanic chain of the Eastern Carpathians (Romania) and it comprises the most extensive andesitic stratovolcano in the Carpathians, with the highest altitudes (2100 m a.s.l., Pietrosul peak).

The volcanism which occurred between 11,9 and 6,7 MA (Pécskay et al., 1995; Seghedi et al., 2005) consisted mainly of effusive, explosive and extrusive activity and the formation of subvolcanic bodies. Apart from lava flow related forms, piroclastic plateaus, domes, etc, the evolution of the massif also followed a constructional phase of a collapsed caldera, with a diameter of over 10 km in its central part.

In some parts of the massif, successive flank destabilisations such as debris avalanches (Szakács and Seghedi, 2000; Szakács and Krézsek, 2006) and intense postvolcanic erosion led to the formation of primary volcanic surfaces and the exhumation of subvolcanic elements. During the postvolcanic period with intense solfatarian and fumarolian activity, sulphur beddings were formed by sublimation.

The sulphur is found within the Negoiu Romanesc and Pietricelul stratocone structure, in the southern part of the caldera (fig. 1), cropping out in native form, or impregnated within deeply altered piroclastic deposits. These deposits are covered by andesitic and dacitic lava in the upper part of the two cones.

Though the presence of sulphur has been known in these areas since the 17th century, its exploitation on an industrial scale started as late as the 1960's. At first, geological prospecting actions were carried out, in order to localize the areas with the highest sulphur concentrations. The communist regime from that period of time insisted on opening a sulphur exploitation in this massif, because this was the only one in the country. In addition, they wanted to cut down or even cut off the sulphur imports from other countries. The sulphur exploitation ended in 1989, the mining activity being re-opened in the period 1992-1997; afterwards it was definitively closed as a result of non-profitability.

The mining activity in galleries and quarries meant the dislocation and open casting of huge rock volumes. The sulphur was being extracted from rocks in a specially-designed grinding plant and the sterile material was laid nearby as waste dump. The location and construction of waste dumps did not follow the regulations. This led to their destabilization and the occurrence of compressions, falls, landslides, debris flows, hyperconcentrated flows, rollings, etc, with the waste-dump talus, as the source area.

There are few scientific studies regarding the dynamics of those geomorphic processes. The studies so far have been limited to enumeration of the processes and indications about the years when they occurred, without giving details related to their spatial extent (Bojoi and Brandus, 1984, 1985).

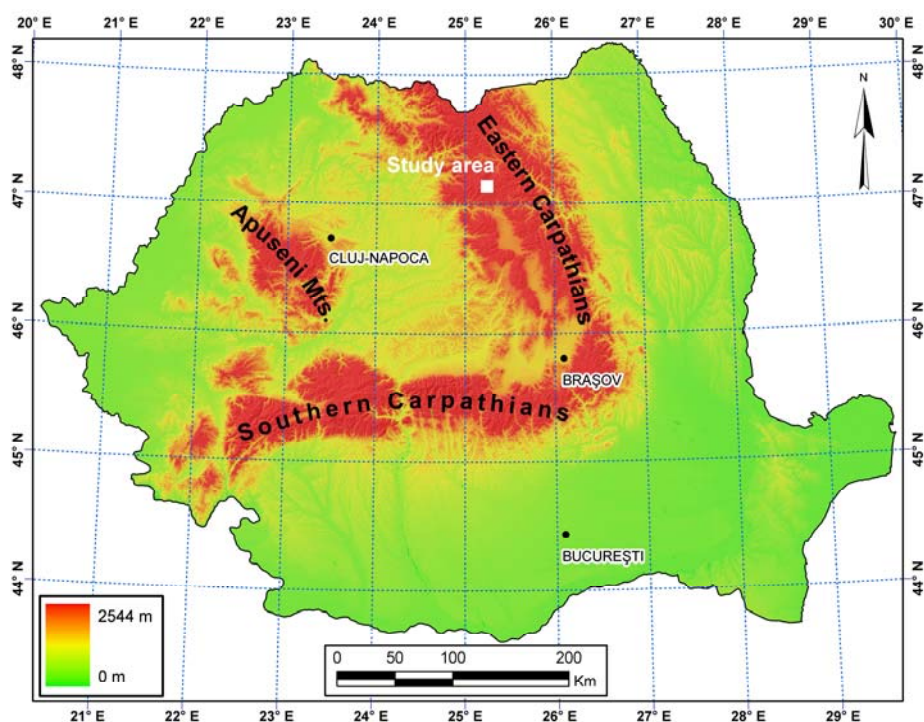


Figure 1. Map location of the study area in Romania

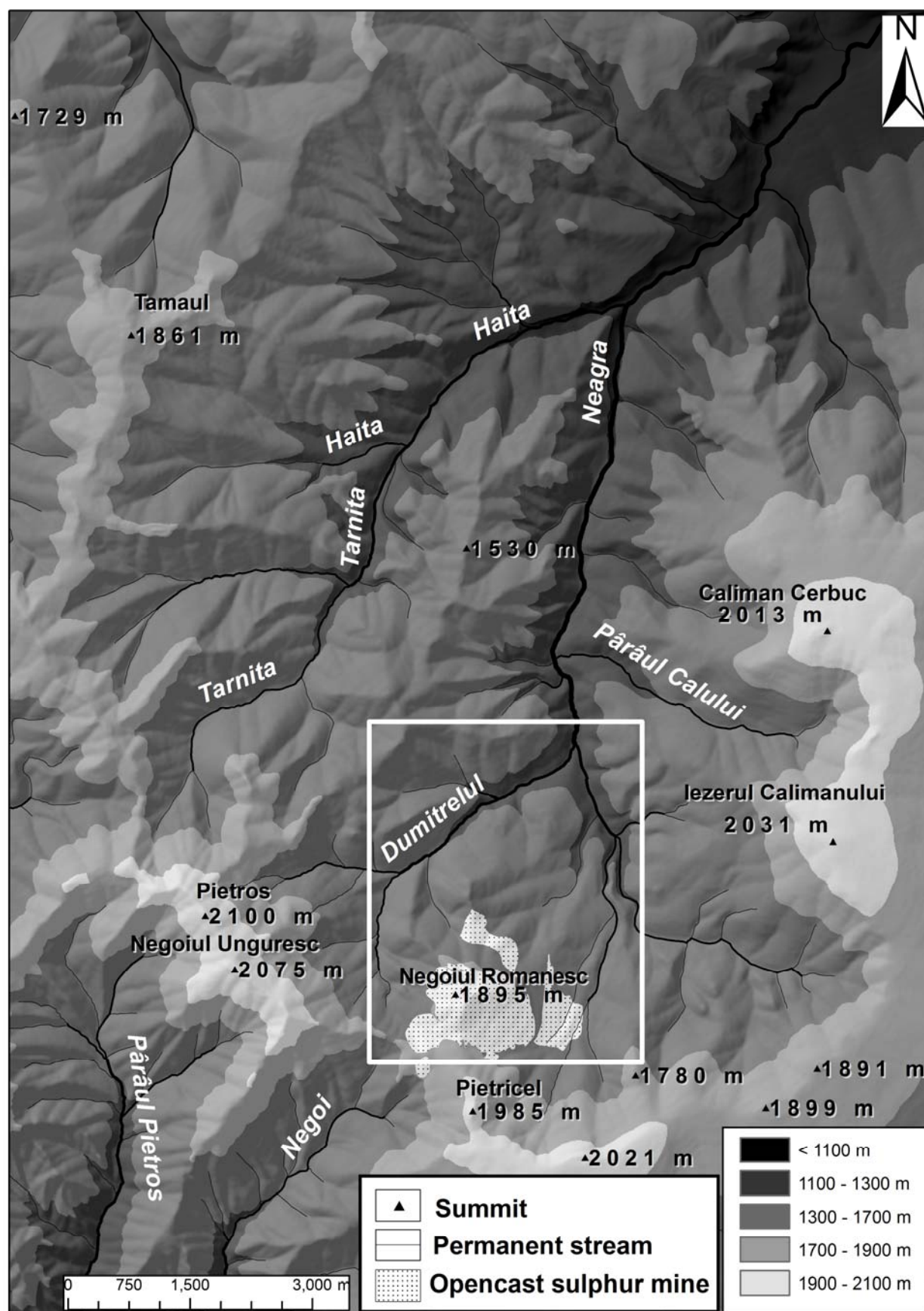


Figure 2. Central part of Calimani Mountains: the white rectangle represents the sulphur mining affected area

The waste dump structure and composition reflect working phases within the mining galleries, quarries and the sulphur preparation plant. At first, of extracted material from the galleries was deposited, which was though in small quantities. Out of husing within the quarry zone, large quantities of soil and barren rock were deposited, those being the basis of the waste dump. The granulometry of the materials which form the waste dumps is variable, starting from clays to blocks of metric dimensions. The blocks resulted from quarry explosions, transport processes, separation the waste grinding and sulphur extraction in the sulphur plant.

The most extensive surfaces affected by landslides and debris-flows lie downstream from Pinul waste dump, in the northern part of the quarry and the sulphur preparation plant. According to Bojoi and Brandus (1984, 1985), major landslides occurred in 1975, 1979 and 1983. The biggest landslide occurred in 1979, affecting the central part of the waste dump. The process continued through debris-flows and hyperconcentrated flows passing over the dam on the Pinul River, the waste going into the bed of Neagra River. The access road to the quarry was destroyed, eventually being rebuilt, in order not to interrupt the mining activity. The sliding waste dump body took the shape of a succession of hills and micro-depressions. Later, the materials forming the slide body were partial reworked by debris-flows and hyperconcentrated flows.

The tree colonization of the landside and the debris-flow deposits was different according to some both favorable and non-favorable geomorphological activity. Today, 20 years since the landslide, the colonization of the surface indicates various proportions of spruce (*Picea abies*), birch (*Betula verrucosa*), poplar (*Populus tremula*) and goat willow (*Salix caprea*).

3. Materials and methods

The first working stage consisted of constructing a preliminary geomorphological map, on the basis of *photointerpretation* and *orthophotoplans* from 2004 edition and analysis of topographic maps, on a 1: 5000 scale (1984 edition). On this map, we delimited and identified the areas affected by

geomorphic processes downstream of the Pinul waste dump. Using ArcGIS 9.3, we constructed the working geomorphological map, used during the field campaign.

The next stage consisted of the validation in the field during the field survey activities (June 2008) of the preliminary geomorphological map and the creation of the final geomorphological map. During the fieldwork, we used the preliminary geomorphological map, orthophotoplans of the study area, geological maps, topographic detailed plans, GPS device, compass, tape and clinometer.

The resulted map contains the landslide dump micromorphology and identifies the main geomorphic processes within the study area. We have choose the conventional signs according to the specificity of every geomorphic process and their form. Using the GPS device we located the morphologic units and the dynamic processes within the study area. Finally, with the help of GIS techniques, we created the geomorphologic map at a 1: 1000 scale of micromorphology within Pinul waste dump.

Using the final geomorphological map and the GPS devices, we then selected and located in the field, representative study plots with trees from each identified morphologic typology. Thus, we analyzed the tree characteristics (density, age) in each study site located on the surface of the landslides. We did the same thing for those on the debris-flow deposits. Within the selected study sites (5 m width each), we identified the present species. The number of trees (10 for each study plot) was settled and used afterwards, to indicate their density on geomorphological units. Within each study area, we determined the minimum tree age in order to determine the beginning of the colonization. Age determinations were made either by counting branch whorls, in the case of spruces, or by counting the rings on the stem discs or increment cores (237 samples measured).

Increment cores and stem discs were extracted as near to the ground surface as possible using an increment borer, in order to eliminate the errors which could appear when trying to settle the age for trees when at breast height (Pierson, 2007). Also, the height and diameter of the trees selected for age determination were systematically registered in field records.

In the laboratory, the increment cores fixed on wooden blocks, discs and wedges were dried and polished. The age of the trees was determined by counting the annual rings. Field data and age determinations from the laboratory were processed in ArcGIS 9.3 and the results were represented by thematic maps, tables and graphics. In the upper part of the site, near the base of the waste dump, we did not select any study plots because of the high degree of anthropic influence due to dumping.

4. Results

The Pinul waste dump is located on the northern slope of Negoiu Romanesc cone, at the base of the mining quarry. It was built by deposition resulting from the sulphur exploitation process.

The waste dump contains andesitic volcanic rocks (altered pyroclastic rocks and lava flow blocks) deposited in the former valley of Pinul Creek. The deposit is made by an heterogeneous mixture of coarse and friable unconsolidated rocks with very variable granulometries (from clays to blocks with metric diameters).

In the southern part of the study area (fig. 3) there are two waste dump berms, initially created by anthropic activity (the process of deposition and leveling) and afterwards, by erosion. At present, the talus slopes reach values between 40° and 60°. The berms and especially the taluses are dissected by channels and gullies resulting from rilling and debris-flow processes. On the talus contact between the waste dump and the surface of the Pinul valley, erosion processes are more intense, with increasing density of channels and gullies (fig. 4).

Following the two berms, for a distance of about 2.5 km within the former Pinul valley, we can find less steep surfaces of the waste material deposits, remobilized by human-induced landslide and debris-flow processes. The detailed morphology of the study area downstream from Pinul waste dump reveals a group of stabilized slide bodies, gullies and debris-flow deposits. The landslide bodies have a hummocky surface, separated by micro-depressions with small temporal lakes. Landslide bodies are generally stable, with a very variable granulometry, cut off by other gullies that mostly erode their bases.

Pinul Creek has changed its initial course; at present it flows through a new river bed eroded into the waste dump deposits. On the re-worked waste dump surface in the former Pinul Creek valley, two main gullies have appeared where the water from rainfall and the snowmelt frequently concentrates. Debris-flow processes concentrated in the gullies generate lobe deposits and lateral deposits of different ages.

In the western part of the study area there are two other gullies which reach the nearby forest area. The gullies are filled with debris flow deposits. They join about 1500 m downstream, creating a debris cone which reveals material sorting between the apex and the lower part.

About 3 km downstream from the waste dump, there is a dam behind which the finest materials have been transported by hyperconcentrated flows (fig. 5). Unlike the upstream debris-flow deposits, there is a good sorting of the sediments, those with the finest granulometry (clays) being located in the immediate proximity of the dam.

Figure 6 shows the total density of the trees which have colonized the landslide bodies and debris-flow deposits downstream of the Pinul waste dump. The density classes have values between less than 1 tree/m² and up to 3 trees/m². Regarding the distribution of tree density, we found an unequal tree distribution throughout landslide bodies and debris-flow deposits. Numerical values on the map reveal the maximum age of sampled trees, within each zone crossed by the transects. The maximum age determined in field and laboratory on sampled trees varies between 8 and 27 years.

The age varies for each landform type. The slide bodies are colonized by trees between 8 and 21 years. On the debris-flow deposits, the maximum age reaches 27 years. A particular situation is shown by the presence of trees with a high density (up to 3 trees/m²) and maximum age (29 years) on a debris-flow deposit located at the base of the waste dump.

In Table 1, the total density values are represented according to species and maximum age at each study plot. Out of the four species present on the waste dump we can see a domination of spruce, followed by birch, poplar and goat willow.

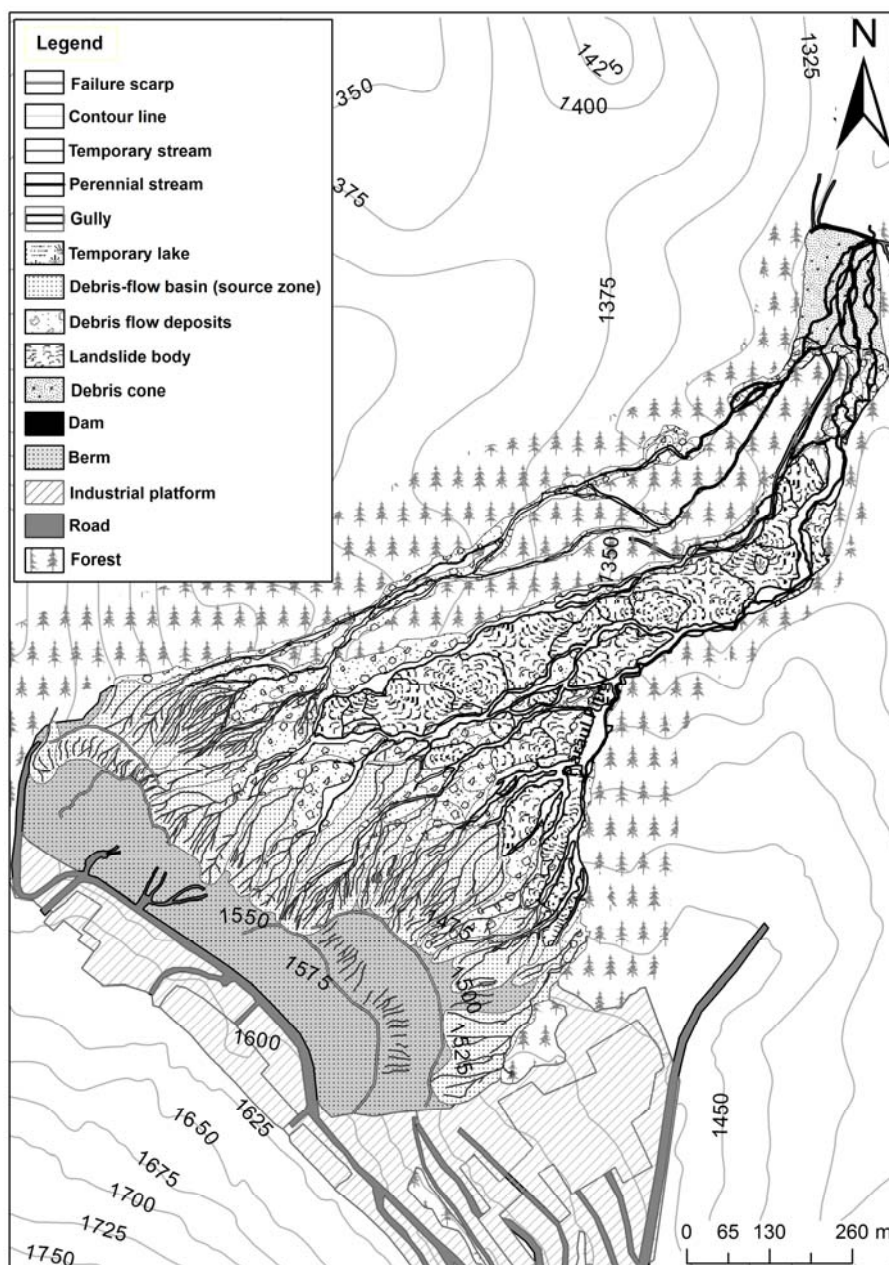


Figure 3. Geomorphological map of Pinul waste dump area



Figure 4. Reworked materials by geomorphological processes deposited in the former Pinul Valley



Figure 5. Hyperconcentrated and debris flow deposits accumulated behind the Pinul dam

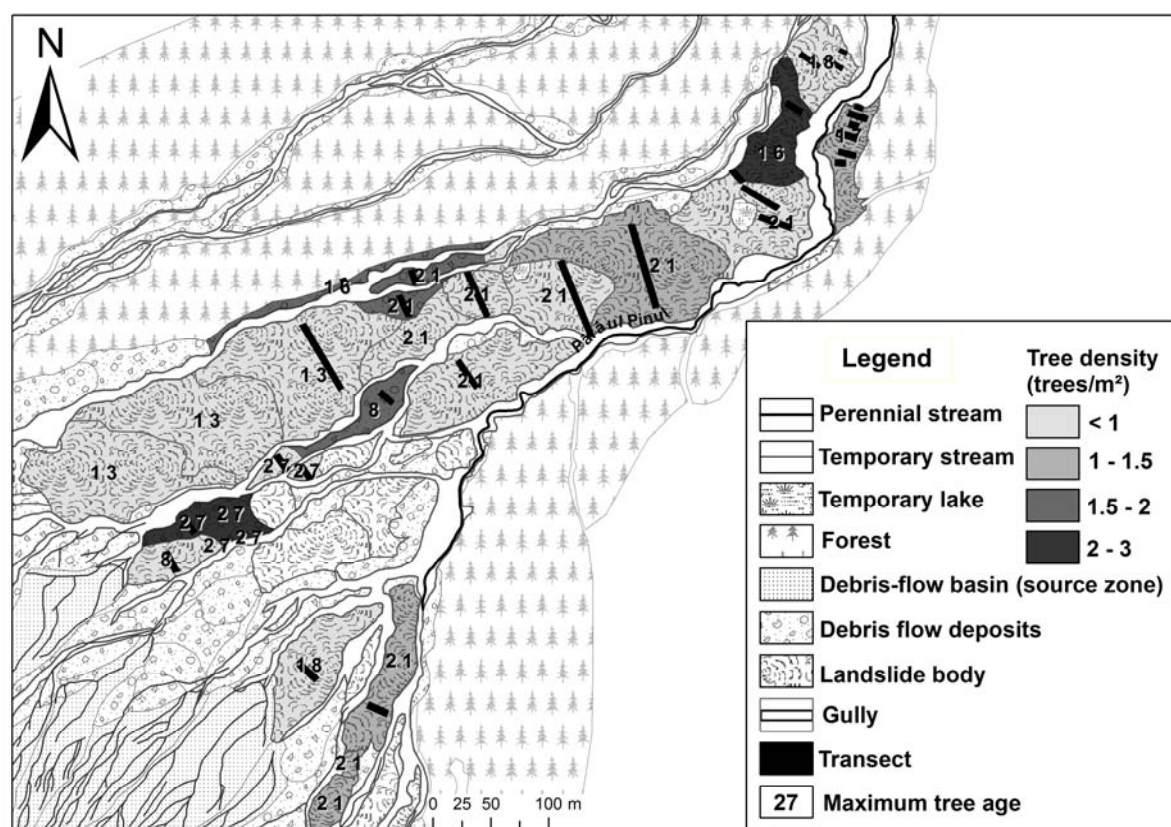


Figure 6. Map of the density of the trees and maximum tree age

Table 1. The total density values and maximum tree age

Study Plots	Maximum tree age	Density of trees (trees/m ²)	Density by species (trees/m ²)			
			Spruce	Birch	Poplar	Goat willow
1	13	1.87	1.73	0.13	0.00	0.00
2	16	0.85	0.85	0.00	0.00	0.00
3	17	1.15	0.95	0.05	0.15	0.00
4	14	2.29	2.21	0.05	0.00	0.03
5	14	1.40	1.24	0.16	0.00	0.00
6	14	1.49	1.49	0.00	0.00	0.00
7	18	4.75	4.75	0.00	0.00	0.00
8	16	0.94	0.94	0.00	0.00	0.00
9	17	0.75	0.75	0.00	0.00	0.00
10	17	1.16	1.11	0.04	0.00	0.00
11	17	0.73	0.69	0.03	0.00	0.00
12	15	1.27	1.23	0.04	0.01	0.00
13	21	1.27	1.23	0.04	0.01	0.00
14	21	0.87	0.85	0.02	0.00	0.00
15	21	0.87	0.84	0.02	0.00	0.00
16	21	0.87	0.84	0.02	0.00	0.00
17	21	0.49	0.41	0.07	0.01	0.00
18	21	0.49	0.41	0.07	0.01	0.00
19	21	0.42	0.25	0.15	0.01	0.00
20	8	1.89	0.32	1.57	0.00	0.00
21	13	1.62	1.12	0.49	0.00	0.00
22	16	1.82	0.10	1.72	0.00	0.00
23	27	0.90	0.73	0.09	0.06	0.03
24	27	0.90	0.72	0.09	0.06	0.03
25	27	0.89	0.72	0.09	0.06	0.03
26	8	1.03	0.14	0.89	0.00	0.00
27	18	0.83	0.24	0.47	0.12	0.00
28	21	0.31	0.27	0.03	0.01	0.00

5. Discussion

Analyzing the age of the trees which have colonized the slide bodies that resulted from the landsliding of Pinul waste dump during the 1970s- 80s, we observed their grouping into several categories. In the technical literature it is admitted that on a newly created surface with variable granulometry and depending on the stabilization of new surfaces, tree vegetation becomes installed after minimum of 2-3 years (Pierson, 2007). This phenomenon is apparent in our case too; the trees become established a few years after the stabilization of the micromorphology that resulted from the occurrence of the landslide and debris-flow processes.

For the two main morphologic types present in the study area, 5 age classes of age for the colonizing of trees could be established:

a. the 27 year-old age tree group contains the trees which colonized a debris-flow deposit, located in the central part of the valley, close to the Pinul waste dump. This deposit can be considered as stabilized only after 1978, when the last important debris flow process took place. In that period the debris-flow and landsliding could have transported materials which previously covered the initial morphology that resulted from the landsliding of the waste dump body. The first landsliding of the waste dump body affected only the upper part of the Pinul valley; one of them occurred before 1978 and the material mass dislocated by it was the source for the next group of geomorphic processes;

b. the 21 year-old age tree group is found on landslide and debris-flow deposits located in the middle part of the Pinul valley, following the morphology that stabilized about 30 years ago. Hence, in 1984, another landslide took place, which moved the material from where it has been before 1978. This process was accompanied by a debris-flow event in the western part of the Pinul valley. Another slide body, which was stabilized in 1984, lies in the south-eastern part of the valley, subsequently detaching itself from the Pinul waste dump;

c. the 16- 18 year-old age tree group is found within waste material deposits located in the lower part of the Pinul valley, close to the dam. These slide bodies were probably detached from those stabilized around 1984, their mobilization on the valley course taking place around: 1987-1989. During the same period, another mobilization of the waste dump body took place in its eastern part. On the course of the gully located in the western part of the study area, around 1989, successive debris flows and hyperconcentrated flows took place, which led

to the accumulation of sediment behind the Pinul dam. Topographic measurements taken in August 2007 in order to determine the volume of the materials accumulated behind the dam (POP et al., 2009) revealed that, up to that period, approximately 91110 m³ of material had been accumulated, resulting from the reworking of the materials within the Pinul waste dump;

d. the 13 year-old age tree group is found within landslide deposits located in the western part, close to the waste dump. Therefore, around 1992, the stabilization of a new landslide began, which firstly detached itself from the Pinul waste dump body;

e. the 8 year-old age tree group contains the trees located on the slide body in the central part of the waste dump. Therefore we can state that the last important landslide of the waste dump body occurred around 1997. Furthermore, during the same period, on the gully located in the central part of the Pinul waste dump there has been an intense activity of debris-flow processes.

Regarding the tree density on the morphological units within the Pinul valley, we can see a uniform distribution on similar age categories. An important difference appears within the slide bodies stabilized around 1984; the higher density (1.5-2 trees/m²) on the slide body located in the centre is probably due to detailed micromorphology and other conditions (granulometry, altitude, etc). Higher total densities are found on the debris-flow deposits. This fact could be due to the frequent reworking of the materials and a succession of incipient colonization by trees with little competition.

Ecologic rehabilitation work started in 2007 is intended to result in the natural colonization of the surfaces affected by mining activity and the areas around them. These works have not relied on detailed, long-term studies regarding the existing problems within this area. During the field survey, we estimated the possibility of stabilization by tree colonization, of the landslides and debris-flow forms downstream from Pinul dump. The different ages of colonizing trees show an intense geomorphic activity. This suggests that the ecological rehabilitation techniques would be inefficient in this case. The superficial root system does not allow the trees to stabilize the Pinul valley landforms because of the importance of the geomorphic processes. This restrictive factor adds up to the presence of a bare substratum, of sulphur derivatives which inhibit tree germination and growth. At this altitude, the presence of negative temperatures and snow cover (approx. 7 months a

year) are other inhibitory factors for tree colonization. That is why we consider the implementations of rehabilitation techniques based on reforestation by natural colonization as useless.

6. Conclusions

Within the study area, we have identified several landslide processes on the waste dump body. They occurred in stages, the last important event taking place around 1997. The largest landslides triggered between 1975 and 1992, created an extension of Pinul waste dump about 2 km along the Pinul valley.

The debris-flow processes were generally caused by heavy rainfall. In the case of Pinul waste dump, the debris-flow process could have been triggered by the mechanical overturning processes of the waste dump. The fine waste materials were successively reworked through hyperconcentrated flows and debris-flows, as deposited behind the dam downstream of the Pinul waste dump and thus threatening its stability. Continuous accumulation

and filling of the basin, would favor the crossing of the debris flow or hyperconcentrated flows, of some longer distances along Pinul Creek, because of a jumping board-effect which would appear in this situation. The downstream infrastructure (access road into the quarry, electricity network, buildings) and the forest near the study area, stay under the threat of the occurrence of geomorphic processes with negative effects, similar to those produced before 1992.

Our study revealed the fact that the total density and the ages of the trees which colonize the surfaces downstream from Pinul waste dump, are influenced by several geomorphic factors. Out of these, we can mainly distinguish the activity of landslide and debris-flow processes at the surface of the waste dump deposits and downstream of them.

Acknowledgments

This work was supported by CNCSIS-UEFISCSU, project number PN II-IDEI 2465/2008

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Evaluation of geoheritage in the Western part of Podyjí National Park, Czech Republic

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Abstract: The evaluation of geoheritage is one of the tools of geoconservation. For the geomorphological assessment it is possible to use the concept "geomorphosites" which includes both inventorying and evaluation and proposals for management and rational use of the sites. This concept was used for evaluating selected geomorphological sites in the western part of Podyjí National Park. Although the area is protected and conserved, geoheritage is not well promoted and managed. The results of the assessment can serve as a base for proposals for rational use and management. Other perspectives of the use of the geomorphologic assessment are outlined too.

Keywords: geoconservation, geoheritage, geomorphosites, Podyjí National Park, Czech Republic

1. Introduction

Evaluation and inventorying of geoheritage can serve as a tool for geoconservation and management of geoheritage and geodiversity. The concept of geodiversity was for the first time developed in Australian Natural Heritage Charter (2002) and the principles of geoconservation were defined in the same document. In general, we can define the geoconservation as an activity of humans that is oriented to the conservation of geoheritage. We consider geoheritage as a term which includes geological, geomorphological and pedological elements, landforms and processes worth of protection (SHARPLES, 2002). Conservation of geoheritage or geoconservation includes both management and strategies for rational use of this heritage.

The evaluation of geoheritage and geo(morpho)logic sites can be used for comparison between geo(morpho)logic sites themselves, for classification of the sites and also can be applied for management measurements and rational use for the sites.

The concept of "geomorphosites" seems to be an applicable tool for the evaluation of geoheritage. This concept was presented by PANIZZA (2001) and it is developed in various research institutions especially in Western and Southern Europe (for example Université de Lausanne, Switzerland, Università di Modena, Italy, Universidade do Minho, Portugal). Within the International

Association of Geomorphologists (IAG), the working group Geomorphosites exists and it is oriented on the development of methods of geomorphologic assessment, educational activities and geoconservation.

Under the geomorphosites concept, various methods of geomorphologic assessment exist. For the evaluation of geoheritage of the sites in western part of Podyjí National Park a modified method was proposed; this method comes out from methods that have already been used.

2. Methodological approach

Geomorphosites can be defined as landforms that have acquired a scientific, cultural/ historical, aesthetic and/or social/economic value due to human perception. Geomorphosites can be single geomorphologic objects or wider landscapes. These geomorphosites can be modified, damaged, and even destroyed by the impacts of human activities (PANIZZA, REYNARD, 2005).

The geomorphosites are classified by different points of view: 1) activity (in relation to presence or absence of current process): active or passive 2) dimensions: simple geoforms or geomorphologic landscapes or geomorphologic systems (REYNARD, E. (ed.), 2009).

As mentioned above, the geomorphosites can acquire different values. REYNARD et al. (2007) divide these values into two groups: 1) scientific

values that present an importance for understanding of a landform, a process or an evolution. Within the geomorphologic sites, the processes are considered one of the most important scientific values together with representativeness of the landform and process, uniqueness and palaeogeographical significance of the site, 2) additional values include cultural, aesthetical, economic/social and ecological values. Cultural value is represented by the archaeological or historical significance of the site and can both be influenced by the geomorphology of the site and can have an influence on the site. The perception of the aesthetic value is based on the colour contrast, structure of the space or heterogeneity of the site. For these reasons it is the most problematic value to describe. Economic or social value is related to the potential for use of the site especially for the geotourism. The ecological value of the site expresses the relation between geomorphologic elements of the site and biota and as well as cultural value can both be influenced by geomorphology of the site and can have an influence on the site.

Various methods are used for evaluation of geoheritage. PANIZZA (2001), CORATZA, GIUSTI (2005) proposed a method for geomorphologic assessment where especially scientific value is accented. Besides the scientific values (integrity, uniqueness and representativeness) the evaluation of some additional values is proposed. The methodology of GONZALES-TRUEBA (2006) comes out from the geomorphologic mapping and covers both scientific values and additional values. He also mentions the use of site for education and vulnerability. Universidade do Minho in Portugal uses the method of PEREIRA (2006). This method is based on the assessment of scientific and additional values and

takes into account the potential for use and protection of the locality. The method of REYNARD et al. (2007) comprises the assessment of scientific values (representativeness, integrity, palaeogeographical significance), additional values (historic, cultural, religious or symbolic values) and tries to evaluate the existence of the products that support the sites. Submitted methods of evaluation were particularly discussed and compared by KUBALÍKOVÁ, KIRCHNER (2010).

The above methods use different means of evaluation, both direct and indirect, for example expert's estimate or numerical evaluation. The majority of the methods are numerical which have an advantage of relative objectivity, but there are certain parameters that can be measured with difficulties and could be the source of disagreements. Another problem of the assessment process is subjectivity, especially in the evaluation of aesthetic and cultural aspects of the site, but also in evaluation of the scientific significance of the site.

The presented methodology for Podyjí National park (see Table 1) is based on the above-mentioned methods and keeps this procedure: 1) the identification of significant geomorphologic sites (based on the literature, maps and field survey), 2) a detailed inventory of selected sites (general information, geology, geomorphologic data – morphology and genesis, environmental conditions, a description of the cultural components of the site, aesthetic aspect, availability, background, presence services, current status of the site, potential threats and risks), 3) numerical evaluation of sites, 4) synthesis (classification of the sites, management proposals, possible use of the site, proposed legislative protection).

Table 1 The proposed methodology for evaluation of geoheritage in Podyjí National park

1. Scientific value		
number	criteria	score
1.a	Representativeness	0-1
0 – low representativeness of the form and process, 0,5 – medium representativeness, especially for scientists, 1 – high representativeness of the form and process, also for the laic public		
1.b	Integrity	0-1
0 – totally destroyed site, 0,25 – destroyed site but with the rests of geomorphologic features, 0,5 – disturbed site, but with the main geomorphologic features, 0,75 – only low destruction of the site, 1 – site without any destruction		
1.c	Exemplarity, pedagogical use	0-1
0 – very low exemplarity and pedagogical use of the form and process, 0,5 – existing exemplarity, but with limited pedagogical use, 1 – high exemplarity and high potential for pedagogical use, geodidactics and geotourism		
1.d	Number of similar sites in the area of interest	0-0,5
0 – more than 3, 0,25 – less than 3, 0,5 – unique site		

1.e	Number of similar sites in the country	0-1
	0 – more than 5, 0,5 – less than 5, 1 – unique site	
1.f	Mezofoms, microforms	0-1
	0 – no important or missing, 0,5 – presence of some mezo- and microforms, 1 – presence of some mezo- and microforms which are important for representativeness and exemplarity of the site	
1.g	Presence of geological and pedological features	0-1
	0 – no important or missing features, 0,5 – presence of geological and pedological features, 1 – presence and existing protection of the geological and pedological features	
1.h	Knowledge of the site, scientific articles	0-1
	0 – unknown site, 0,5 – some articles in the literature, 1 – high knowledge of the site, monographic studies about the site	
1.i	Importance for understanding to geological evolution	0-1
	0 – no important or missing, 0,5 – existing importance	
1.j	Paleogeographic importance (possibility of reconstruction of landscape, climate etc.)	0-1
	0 – no important, 0,5 – possibility for reconstructions but only at local scale, 1 – high paleogeographic importance	
1.k	Existing protection of the geo(morpho)logic features	0-1
	0 – no existing, 0,5 – existing protection, but not of the geo(morpho)logic features, 1 – existing protection of the geo(morpho)logic features	
Scientific value total score		max. 10
2. Additional values		
2.a	Aesthetic value	
	The number of colors	0-0,5
	0 – one color, 0,25 – two or three colors, 0,5 – more than 3 colors	
	Structure of the space	0-0,5
	0 – only one pattern, 0,25 – two or three patterns clearly distinguishable, 0,5 – more than 3 patterns	
	Global aesthetic value	0-1
	0 - low, 0,5 - medium, 1 - high	
2.b	Ecologic value	
	The influence of the geomorphologic feature on the ecologic feature	0-1
	0 – no important, 0,5 – existing influence but not so important, 1 – important influence of the geomorphologic feature on the ecologic feature	
	Presence of the protected species	0-0,5
	0 – missing, 0,5 - present	
	Existing protection of the ecologic features	0-0,5
	0 – no protection, 0,5 – existing protection	
2.c	Cultural value	
	Historical and archaeological importance	0-1
	0 – no historic and archaeological features, 0,5 – existing historic and archaeological features but without any relation to the geomorphology, 1 - existing historic and archaeological features with the strong relations to geomorphology	
	Religious and symbolical importance	0-1
	0 no religious and symbolical importance, 0,5 - existing religious and symbolical importance but without any relation to the geomorphology, 1 – existing religious and symbolical importance with the strong relations to the geomorphology	
	Literal and artistic importance	0-1
	0 - no literal and artistic importance, 0,5 - existing literal and artistic importance (paintings, legends etc.), 1 – site as strong inspiration of the artists	
2.d	Knowledge of the site due to its additional values	0-1
	0 – unknown site, 0,5 – local or regional knowledge, 1 – national or international knowledge of the additional values of the site	
Additional values total score		max. 8

3. Potential for the use		
3.a	Visibility	0-1
0 – only with special equipment (light, rope), 0,5 – good visibility, but necessity of walk around to see all, presence of the trees etc., 1 – very good visibility		
3.b	Accessibility	0-1
0 – more than 1000 m from the parking place, 0,5 - less than 1000 m from the parking place, 1 - more than 1000 m from the stop of public transport		
3.c	Infrastructure (tourist facilities)	0-1
0 - more than 10 km from the site existing tourist facilities, 0,5 – 5 – 10 km tourist facilities, 1 – less than 5 km tourist facilities		
3.d	Attendance, number of visitors	0-1
Depends on the data acquired. For example the rating: well attended, medium-attended, low attended.		
3.e	Current use of the geo(morpho)logic features of the site	0-1
0 – no use, 0,5 – existing use but not so important, 1 – existing and important use of the geo(morpho)logic features of the site		
3.f	Current use of the additional values of the site	0-1
0 - no use, 0,5 - existing use but not so important, 1 - existing and important use of the additional values of the site		
3.g	Total number of the possibility of the uses	0-1
0 – no use, 0,5 – 1 – 3 possibilities of the use, 1 – more than 3 possibilities of the use		
3.h	Limits of the use	0-1
0 – no accessible site, 0,25 – accessible only with guide, 0,5 – considerable limits, but good accessibility, 0,75 – good accessibility with small limits, 1 – no limits for the use		
3.i	Existing promotion of the site	0-1
0 – no promotion, 0,5 – postcards, leaflets etc., 1 – emblematic site for the region or town		
Potential for use total score		max. 8
4. Threats and vulnerability		
4.a	Existing and current threats	0-1,5
0 – high both natural and atrophic risks, 0,5 – existing risks that can disturb the site, 1 - existing risks that can disturb the geo(morpho)logic features of the site, 1,5 – practically no vulnerability of the site		
4.b	Potential threats (in the case of the more intensive use of the site)	0-1,5
0 – high both natural and athrophic risks, 0,5 – existing risks that can disturb the site, 1 - existing risks that can disturb the geo(morpho)logic features of the site, 1,5 – practically no vulnerability of the site		
4.c	Existence of the legal protection	0-1
0 – no protection, 0,5 – existence of the status of the site as Natural monument, Natural reservation or protected landscape area, 1 – existence of National Park		
Threats and vulnerability total score		max. 4
TOTAL SCORE		MAX. 30

This methodology was used for the assessment of selected geomorphosites in the western part of the NP Podyjí. The final part of the assessment was to present proposals for rational use of sites for their conservation and management.

3. Study area

National Park Podyjí is situated in the SW part of South-Moravian Region in Czech Republic (see Fig. 1). The deep incised, canyon-like valley of the Dyje River forms the axis of the National park between the towns of Znojmo in the East and the

town of Vranov nad Dyjí in the West. The relief strongly influenced the human activities in this particular area since the Neolithic. During the medieval time there were border castles built on steep slopes of the Dyje River (Hardegg in Austria, Vranov, Nový Hrádek in Czech Republic). On some slopes, the terraced crop fields and vineyards were situated. In the modern time several mills and paper mills used the waterpower of the Dyje River. Due to Iron Curtain established after World War II, the economic activities in the area were very limited, so the natural values of this area were protected and now the landscape is less damaged than in the other cultural landscapes of the Central Europe.

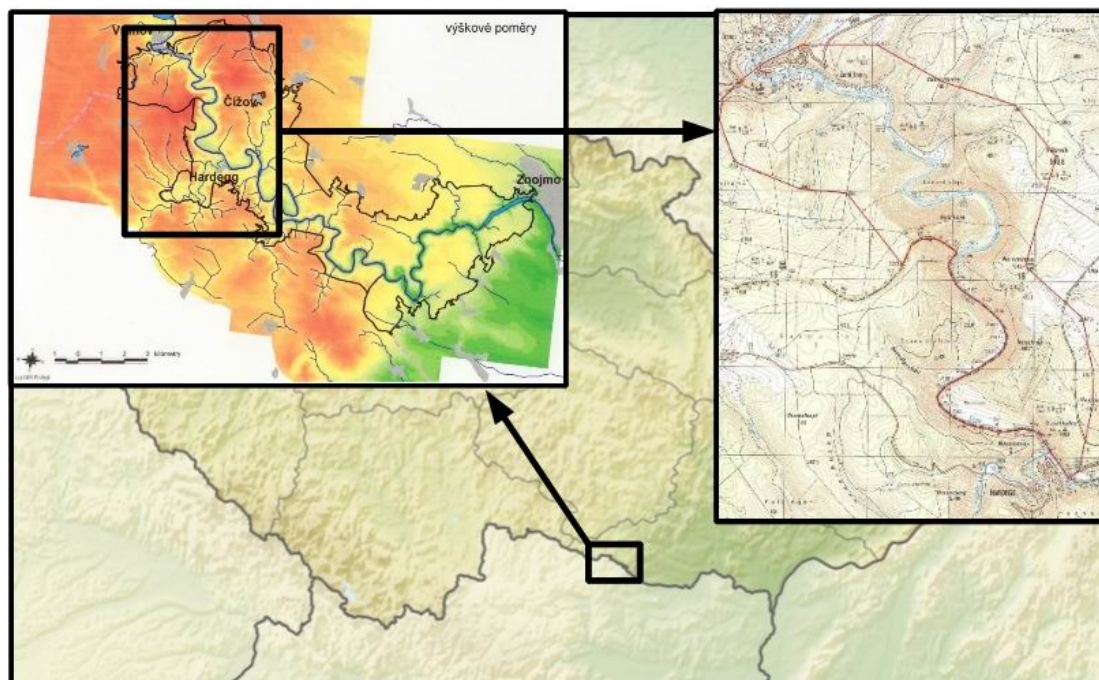


Fig. 1 The localization of study area (source: Administration of Podyjí NP, author)

Political changes in Europe since 1989 have brought the possibility of the evaluation of this area, so the National Park Podyjí was declared in 1991. The protected area of the NP Podyjí reaches 63 km². Natural forests cover about 84 % of the area. The high geodiversity and biodiversity (especially concerning plants and invertebrates) ranges the area among the most naturally valuable territories in the Central Europe.

Geologically, there are three main units in wider area. The Eastern part is created by the core of the Dyje dome, mainly of granite. The division between eastern and western parts makes the Lukov group formed by phylit and mica schist and in the Western part gneiss type Bíteš dominates (BATÍK, 2004).

The deep incised, canyon-like valley of the Dyje valley is the main and unique landscape feature of the National Park. The river enters the Podyjí NP close to the town of Vranov nad Dyjí in Czechia, flows through the town of Hardegk in Thayatal NP in Austria and it leaves the Podyjí NP close to the town of Znojmo in Czechia. The actual length of the Dyje valley on the territory of both Parks is 41.6 km. Three parts with different morphology were distinguished (IVAN, KIRCHNER 1994, KIRCHNER, IVAN, 1998):

- i) The W part incised in the Bíteš orthogneiss between the towns of Vranov nad Dyjí and Hardegk; it is the most incised part of the valley up to 235 m deep;
- ii) The central part which is incised in less resistant two-mica schist of the Lukov unit

(with the important intercalations of marbles); the valley is 120 to 150 m deep, but some slopes are less inclined in comparison with the first part;

- iii) The E part incised into granite of the Dyje Massif is almost 20 km long and the valley depth does not surpass 160 m; steep slopes with many tors and exfoliation forms are accompanied by large block fields, block streams and screes.

The study area itself corresponds with i). The main landformforms in the Western part of Dyje valley are incised meanders, alluvial plains and others typical fluvial landforms, the important feature of relief is also cryogenic relief with forms like large block fields, block streams and screes, rock towers and others. Important features of the relief are also the anthropogenic forms like water-gangs, vineyards, anthropogenic terraces etc. (KUBALÍKOVÁ, 2009).

Selection of significant geomorphologic sites was based on field survey and study of relevant literature. Seven geomorphologic sites were chosen: 1) Ice Caves, 2) Hardegk Lookout, 3) Rock City, 4) Hamry Folds, 5) Castle Rock, 6) Abandoned Meander, 7) Block accumulation at Braitava.

Site No. 1, Ice Caves is important especially for the occurrence of pseudokarst phenomena and extensive block accumulations, so it has a high scientific potential. The aesthetic value is represented by viewpoint near Obelisk that has certain cultural significance as well.

Hardegg Lookout, site No. 2, represents a site with high aesthetic and scenic value thanks to the existence of the valuable overview. It has also a very high potential for tourism because it is one of the best known sites of the western part of the National park.

On the contrary, the site No. 3, Rock City is known only within the researchers; it is situated out of the tourist paths and in fact the access is prohibited. The site is important due to existence of the range of cryogenic, pseudokarst and gravitational forms (torrs, block accumulations, rock towers).

Site No. 4 Hamry Folds is rather geological than geomorphologic site. The main reasons of protection are pygmatic folds of different scale.

Castle Rock, locality n. 5, is particularly significant because of its high aesthetic and cultural value. The castle situated on the rock is closely related to the geomorphologic form and in the past, its construction was conditioned by the existence of this landform.

Abandoned Meander, locality n. 6, represents fluvial landform that has a very high potential for pedagogic and educational activities. There is a risk of spreading of vegetation that can lead to a degradation of the site.

As the site No. 3, the site No. 7, Block accumulation at Braitava, is situated out of tourist paths, so it is practically unknown and non-visited. It has a high educational and scientific potential.

4. Results

The above-mentioned sites were evaluated, the final results shows Table 2. As can be seen, the Ice Caves (L1) reached a very high score both in scientific and additional values, so it became the most evaluated site within the area. The sites n. 4 and 6 also have an important scientific value, mainly due to its representativity and rarity. On the other side, the locality n. 5 (Castle Rock) does not have so high scientific value, but it has an important additional

value thanks to its historical and cultural importance and high potential for the use thanks to its accessibility. High potential for the use has also site n. 4 (Folds of Hamry) and Ice caves (L1) owing to the proximity of the tourist infrastructure. The less vulnerable are the localities n. 3 and 7 because they are situated out of the reach of the tourist path in the first zone of National Park.

The most evaluated geomorphological localities are L1 – Ice Caves and L4 – Folds of Hamry thanks to the high score of scientific and additional values and L5 – Castle rock thanks to its high potential for the use and high additional value.

On the basis of the inventorying, detailed description and assessment we can do a synthesis: alert to risks or threats, estimate the potential for use and present some proposals for management of the sites:

L1 – Ice Caves are very well preserved especially thanks to the fact that caves themselves are not accessible by public. This site has an extraordinary scientific and pedagogical potential, but in the case of possibility of access to the Caves, significant threats would appear. High potential for educational use can be employed during the organised excursion with a guide.

Aesthetically very valuable locality No. 2 Hardegg Lookout principally suffers from the movement of the tourists out of the marked path and from consecutive degradation of the soil and vegetation cover. This unwelcome phenomenon could be reduced for example by higher frequency of checks guard nature; however, the problem could be the financial possibilities of the National Park Administration.

Site No. 3, Rock City is probably one of the most preserved sites in the western part of the National Park thanks to its inaccessibility. The site has a high potential for educational activities and high scientific and cultural value, but it is relatively remote, so the design and creation of hiking trails would probably need certain financial resource.

Table 2. The evaluation of geoheritage in the Western part of Podyjí NP

Ranking	Scientific value	Additional values	Potential for the use	Threats and vulnerability	Total score
1	L1 (8,5)	L5 (7)	L5 (6,25)	L3 (4)	L1 (21,5)
2	L4 (8,5)	L1 (5,25)	L4 (5,75)	L7 (4)	L4 (20,75)
3	L6 (5,75)	L2 (4,5)	L1 (4,5)	L1 (3,5)	L5 (19)
4	L3 (5,25)	L4 (4)	L2 (4)	L2 (3)	L2 (16)
5	L7 (5,25)	L3 (3)	L6 (4)	L4 (2,5)	L6 (15,25)
6	L2 (4,5)	L6 (3)	L7 (2,25)	L6 (2,5)	L7 (14,25)
7	L5 (3,75)	L7 (2,75)	L3 (1,5)	L5 (2)	L3 (13,75)

The current usage of the site No. 4 (Hamry Folds) is sustainable, even if the existence of the road above the site may cause some problems. Another source of problems can be ingrowth vegetation, according to the Administration of NP this problem is already treated by elimination of undesirable vegetation. The pedagogical potential is supported by information panel so the locality can be used for the education of the public.

Castle Rock (site No. 5) is particularly important in terms of culture. That is why it is mainly used for these reasons (the visit of the Vranov castle). The scientific values of the site are not employed so much. Despite the situation of the site in the first zone of the national park there can be observed camping activities in this area. The solution could be similar as in the case of the site No. 2.

Despite its strong scientific and pedagogical potential value, the Abandoned Meander, site No. 6, is neglected and remains only a short stop on the way from Vranov to the Ice Caves. The reason may be, for example, that the geomorphologic features of the site are partially wiped and distinguished shape gradually overgrows with vegetation.

The locality No. 7, Block accumulation at Braitava offers a considerable educational potential, although it is one of many similar accumulations in the area of interest. It is situated in the inaccessible part of the first zone of the national park as well as Rock City. Given the relative proximity of these sites, there is a possibility to introduce a tourist path (see Fig. 2), or to use both sites for organized geomorphologic aimed guided tours.

In general, from a scientific perspective, the sites have been appreciated for its live component, non-living elements of nature in the context of conservation have not had such attention (there are no care plans for the geologic and geomorphologic sites, these sites are included in the management and care plan of the first zone of National Park). The above mentioned facts propose the question

whether the wider attention should be offered to the geo(morpho)logic components of the sites of interest. After all, it is the geomorphologic and geological component of the landscape, which usually determines all the other components of the landscape.

5. Discussion and conclusion

The proposed methodology for evaluation of geoheritage tried to assess the sites of a geo(morpho)logical interest. In the Western part of the Podyjí NP, the main objective of the inventorying and assessment itself was to evaluate the scientific and added values of the selected sites, to identify potential for use and to propose possible management of these sites. This synthesis was done and some proposals for rational use were presented, although these proposals may not meet with the understanding both the Administration of Podyjí NP and other researchers engaged in this area.

Despite the fact that it would be probably possible to use the proposed methodology to other territories, it should be noted, that in some respects there are some imperfections and defects (for example evaluation of aesthetic sites or objectivity in evaluating the scientific parameters of the site). Consequently, this methodology will be further refined and developed.

As mentioned above, the geomorphologic and geological components usually determines all the other components of the landscape, so they are very important and worthy of protection. Inventory and evaluation of geomorphosites and geoheritage in general may help identify these elements and appreciate its importance for both wildlife and the activities of human society and may thus significantly contribute to the understanding of the need to protect geoheritage.

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Land Vulnerability to Geomorphological Hazard Induced by Pluviometric Criteria (Romanian Plain)

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Land vulnerability to geomorphological hazard induced by pluviometric criteria (Romanian Plain). This study tries to bring a contribution to the motivation of the current geomorphological processes in terms of their genetic link with the climatic factor in general and the rainfall one in particular. One of the most used climatic index to determine the susceptibility of land to rainfall, with real and concrete applications in dynamic geomorphology, is the Angot index. The general objective of this study is to identify first the months, seasons or years with very high or very low susceptibility to erosion phenomena production of the banks and also the values of this index during the year, in order to identify the cumulation of the pluvial conditions which could induce, in general, the modeling processes. Applied to amounts of rainfall from Stolnici and Alexandria meteorological station for the period 1961-2000, Angot Index reveals that geomorphological processes along Vedeia valley and its tributaries are largely generated by the fallen precipitation amounts, plus other factors (petrographic, hydrogeological, morphometric, the use of the land, etc.).

Key Words: Angot Index, Romanian Plain, Vedeia basin, precipitation susceptibility.

Vulnerabilitatea terenurilor la hazarde geomorfologice după criteriul pluviometric (Câmpia Română). Prezentul studiu încearcă să aducă o contribuție la motivarea proceselor geomorfologice actuale prin prisma legăturii lor genetice cu factorul climatic, în general și cel pluviometric, în special. Unul dintre cei mai folosiți indici climatici pentru determinarea susceptibilității terenului la precipitațiile atmosferice, cu reale și concrete aplicații în geomorfologia dinamică, este indicele Angot. Obiectivul general al studiului îl constituie identificarea, pe de o parte a lunilor, sezonelor sau anilor cu o susceptibilitate foarte ridicată sau foarte coborâtă de producere a fenomenelor de dinamică a albiilor și torențialitate ca și variația valorilor acestui indice în cursul anului în vederea identificării cumului de condiții pluviometrice care ar putea induce, în general, procesele de modelare. Aplicat la cantitățile de precipitații de la stațiile meteorologice Stolnici și Alexandria, pentru perioada 1961-2000, Indicele Angot evidențiază faptul că procesele geomorfologice din lungul văii Vedeia și a afluenților acesteia (sunt generate într-o mare măsură de cantitățile de precipitații căzute, la care se adaugă și alți factori (petrografici, hidrogeologici, morfometricei, modul de utilizare al terenurilor etc).

Cuvinte cheie: Indicele Angot, Câmpia Română, Bazinul Vedeia, susceptibilitate la precipitații.

1. Introduction and objective

In the plain area, the appearance and intensity of the contemporary geomorphological processes are controlled by geology (type of deposits, thickness, granulometry), hydrogeology (depth of water table, water-level regime, flow direction, mineralization), human interventions (dams, dykes, irrigations), and especially by the climatic factor in general and the precipitation regime in particular (Grecu et. al, 2006; 2009)

One of the most widely used climatic index for determining the land susceptibility to atmospheric precipitation, with real and concrete applications in dynamic geomorphology, is the Angot index.

The precipitation is a major meteorological element that triggers, maintains and reactivates some geomorphological processes, thus acting as a shaping agent in the plain areas. This influence can be highlighted by quantifying the values of selected characteristic variables (duration, frequency and intensity), as well as by delimiting in time the individual and successive snapshots that present a certain degree of susceptibility (Dragota, 2006).

The general objective of this study is to identify first the months, seasons or years with very high or very low susceptibility to erosion phenomena production of the banks and also the values of this index during the year, in order to identify the cumulation of the pluvial conditions which could induce, in general, the modeling processes.

2. General Features about the Study Area

The Vedeia catchment lies in the central part of the Romanian Plain, where the climatic features, together with the geological and hydrogeological ones, may turn into vulnerability factors for the land (Fig. 1). In addition, the trunk river is allochthonous and it flows directly into the Danube.

From the hydrogeological point of view, the northern section of the catchment is represented by the piedmontane deposits, which have a flow regime imposed by the thickness and lithological characteristics of the Candesti Strata (Grecu et. al 2006, 2009). In the southern section, the presence of the Fratesti Strata (of Balcanic origin) at high depths and the specific features of the overlying loessoid deposits have imposed different underground and superficial flowing regimes (Liteanu, 1953,1969). Under the circumstances, precipitation becomes a major shaping agent for the triggering, maintaining and reactivation of the channel and slope processes.

Pluviometric regime. The mean multiannual amount of precipitation specific for the Vedeia catchment drops on the north-south direction, from

569.3 mm at Stolnici, in the piedmont area, to 520.3 mm at Alexandria (acording NMA). The maximum is recorded in August in the north (78.6.mm) and in July in the south (65.9 mm), whereas the minimum values are specific for January and February in the north (32.6 mm) and October in the south (28.2 mm).

Table no. 1 Vedeia drainage basin - morphometric parameters

Morphometric parameters		Vedeia basin/river
Altitude (m)	max	559
	min	20
Length of the river (km)		251 (200 in the plain)
Width of the basin (km)		54
Drainage area (km ²)		5266
Horton-Strahler hierarchy (Horton, 1945, Strahler, 1952).		7

The multiannual regime emphasizes considerable departures from the mean. Thus, the highest annual amounts may reach in the rainy years more than 700 mm, both at Stolnici (1966, 1971, 1972, 1979, 1980) and at Alexandria (1964, 1966, 1969, 1972), whereas the lowest amounts, below 400 mm, are specific for the dry years: at Stolnici in 1990 and 2000 and at Alexandria in 1965, 1985, 1990, 1996 and 2000.

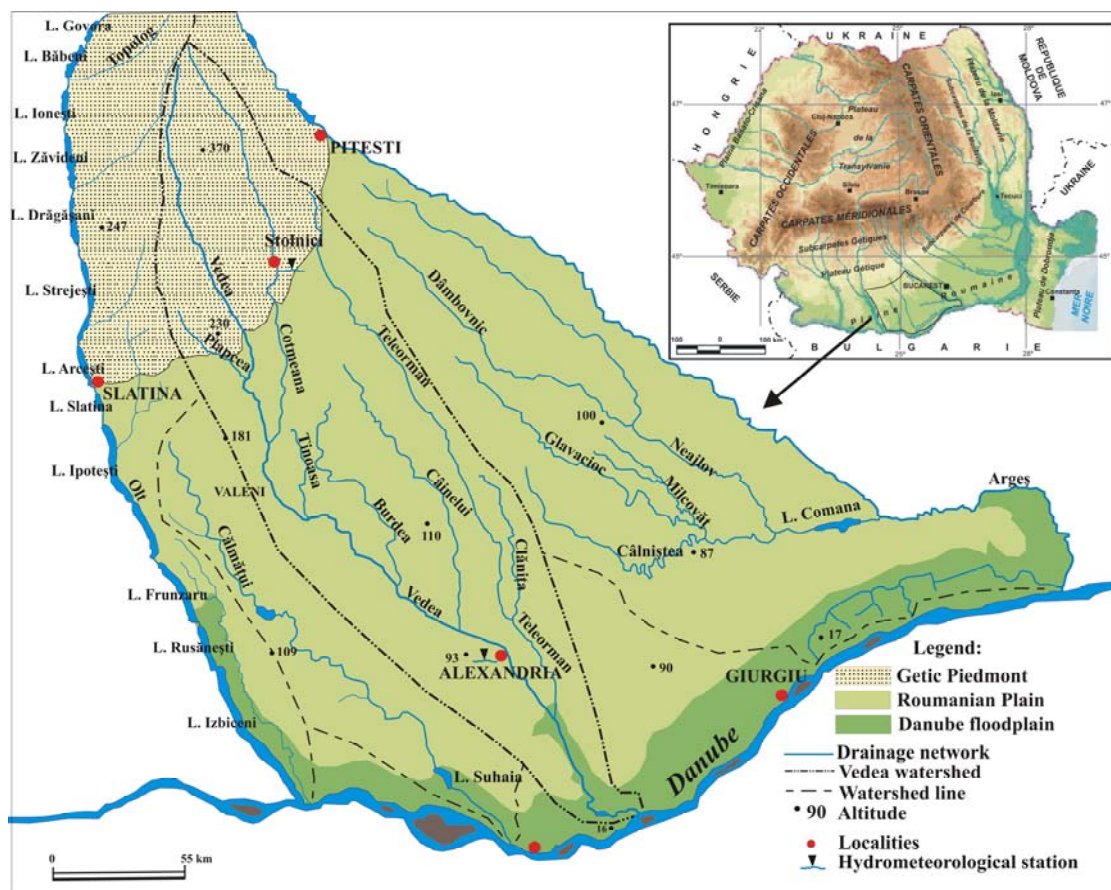


Fig. 1. Location of the Vedeia drainage basin and the weather station used in the study

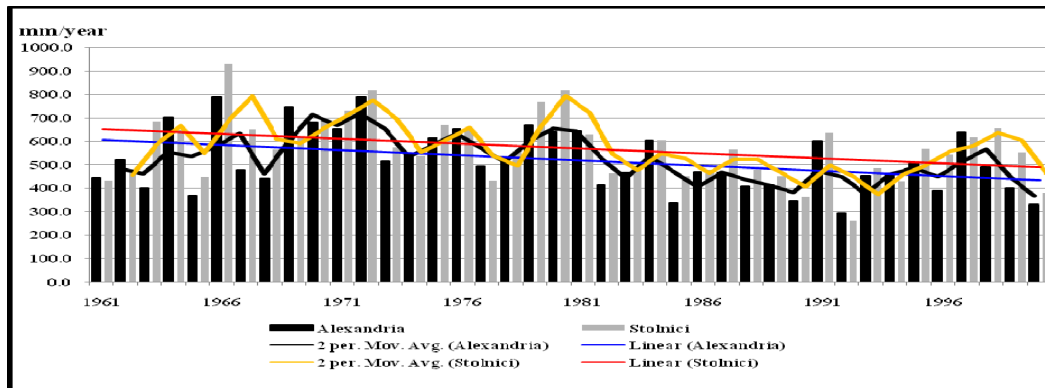


Fig. 2. Variability of annual quantities of precipitation and their trends
(Stolnici and Alexandria weather station) (1961-2000)

The precipitation shows a slight decreasing linear tendency both in the north and in the south. The polynomial trend line of degree six shows the following aspects: in the north the annual amounts of precipitation increased sharply from 1961 to 1966 and then dropped by 200-250 mm during the periods 1966-1967 and 1979-1980; between 1970 and 1972 and between 1976-1979 precipitation decreased; after 1979 until the year 2000 there was again a decrease, with a significant departure from the multiannual mean for the interval 1990-1995 and for the year 2000 (Fig. 2). The highest amount of precipitation was recorded in 1966, a year when floods were frequent and water table rose.

In the multi-annual regime, in 18.91% of the cases July was the wettest month of the year, while January and February were in 64.85% of the cases the driest months. Except for February, which is the driest month, all the other months of the year experienced during the investigated period maximum annual amounts, too. Thus, January was the wettest month of the year in 2.3% of the cases (a percent that is also specific for April and November), March, September and October in 4.7% of the cases, May and August in 9.3%, July in 16.3% and December in 11.5% of the cases. These monthly shares of the pluviometric regime determine the maximum range of temporal variability of this meteorological parameter, which influences the occurrence rate of geomorphological processes.

3. Data and Methods

The analysis of the pluviometric regime in the Vedeia catchment is based on the data recorded at the two weather stations in the area, namely

Stolnici, in the north of the catchment, and Alexandria, in the south. The stations are representative for the entire catchment both from the point of view of the territorial covering and from the point of view of the possibility to extend the datasets by calculation. The first station is representative for the upper section of the catchment and for most of its central part, that is for the piedmontane area and for the north of the plain. The second station is representative for the downstream part of the catchment lying entirely in the plain and drained by the Vedeia and its tributaries. The Angot index values have been computed for the interval 1961 – 2000.

1. The specific features of the pluviometric regimes of the Vedeia catchment influence the susceptibility to the contemporary geomorphological processes. In order to highlight this, the Angot index has been used, which is computed as follows:

$$I_{\text{Angot}} = (q/n)/Q/365$$

where q is the mean daily amount of precipitation for a given month; n is the number of days of the respective month (except for February, which is considered to have 28 days even in the leap years); Q is the mean multiannual amount of precipitation; and 365 is the number of days in a year (*Indici și metode cantitative utilizate în climatologie*, 2003).

This index shows the annual variability of precipitation and highlights the rainy ($I_{\text{Angot}} > 1$) and the dry ($I_{\text{Angot}} < 1$) intervals. Depending on the results, the susceptibility classes to the contemporary geomorphological processes are determined based on the amount of precipitation fallen to the ground (Table 2).

Tabel no. 2 - Susceptibility classes of precipitations to reactivating geomorphological processes based on Angot Pluvial Index attributes

Pluviometric attributes	Very dry	Dry	Normal	Rainy	Very rainy
Susceptibility classes	Very low	Low	Moderate	High	Very high
Angot Index value	<0.99	1.00 – 1.49	1.50 – 1.99	2.00 - 2.49	> 2.50

The computing formula of the Angot index has the advantage of characterizing the months of the year from the pluviometric point of view.

2. Cartographic data extracted from topographical maps (scales of 1:25.000 and 1:50000), ortophotos (scales 1:5000) and thematic maps (geologica, hydrogeological, climatic)

3. Climate data (precipitation) taken from different sources, mainly the Meteorological National Administration (MNA), Clima Romaniei (2008), for the weather stations in the investigation area (Alexandria, Stolnici). The analyzed periods are variable, between 1961-2006.

4. Data from field observation and measurements (topographic surveys).

4. Results

4.1. Angot Index analysis

For the Vedeia catchment, the Angot index values for the northern section of the catchment (Stolnici) are more than one all year round, with a maximum in July (2.5). In the lower section, at Alexandria, the maximum is reached in July (2.19), while in October the value is less than one (0.88) (Fig. 3). This index shows that in this area of the Romanian Plain the amount of precipitation is higher than in its eastern part, where the values more than one are specific only for the interval April – September. For instance, in the Mostistea catchment the maximum value of the Angot index is 1.47 in July (Ghita & Dragota, 2010). The index also emphasizes that the driest months belong to the cold season.

From the standpoint of the *multiannual regime*, in 83% of the cases July was the wettest month of the year, the maximum value of the Angot index reaching 6.32 in 1980. At Stolnici weather station, January, February, March and October experienced in more than 60% of the cases the lowest mean amounts of precipitation. With the exception of October, which displayed drastic water deficits in 1965, 1969 and 2000, when the values dropped to zero, all the other months of the year recorded maximum annual amounts during the period 1960 – 2000.

At Alexandria weather station, the situation was as follows: the wettest month (June) showed values

more than one in 95% of the cases, but values above 2 in only 20% of the cases. The driest month of the year (October) exhibited values less than one in 75% of the cases.

At both weather stations, January was the wettest month of the year in 6% of the cases, a percent specific also for February and October. March, April, November and December were the wettest in 7% of the cases, and May, June, July and August in more than 10% of the cases (July 13.5% and June 12.5%). These monthly percentages determine for the study area the maximum range of temporal variability of precipitation, which in its turn influences the occurrence of geomorphological processes all year round. It is worth mentioning that despite the fact that on a multiannual scale October is the driest month, in 1972, under exceptional conditions, it displayed the highest values of the Angot index (9.2 at Stolnici and 5.61 at Alexandria).

The determination of the annual pluviometric features based on the annual values (K) of the Angot index.

During the interval 1961 – 2000, there was only one year (2000) when the pluvial regime did not offer favorable conditions for the triggering of the contemporary geomorphological processes. This situation was emphasized by the Angot index value, which was lower than 0.99.

The driest years do not create favorable conditions for the triggering of geomorphological processes, because of the weak pluvial impact. At Stolnici station, there are 14 years when the Angot index values did not exceed 1.5. Of the previously mentioned interval, the driest year was 1992, when the Angot Pluvial Index was less than one.

At Alexandria weather station, 12 years with values less than 1.2 are considered dry. These years are: 1961, 1963, 1965, 1982, 1985, 1988, 1989, 1990, 1992, 1996, 1999 și 2000. In the southern part of the catchment, the year 1985 showed Angot index values less than 1.2 for each month, while the values for 1990, 1992 and 2000 were less than one. Every year has a certain prevalence of the months with moisture deficit.

Table no 3. The driest 2 years ($K < 1$) over 1961-2000 (Vedeia catchment)

Weather station	The driest year $K < 0.99$							
	Year	Pp. annual (mm)	No. of month	Dry months	% of months	Rainy months	No. of months	% of months
Stolnici	1992	261.9	10	I, II, III, V, VII, VIII, IX, X, XI, XII	83	IV, V	2	
Alexandria	2000	330.2	8	II, III, V, VII, VIII, X, XI, XII	66.6	I, IV, VI, IX	4	33.3

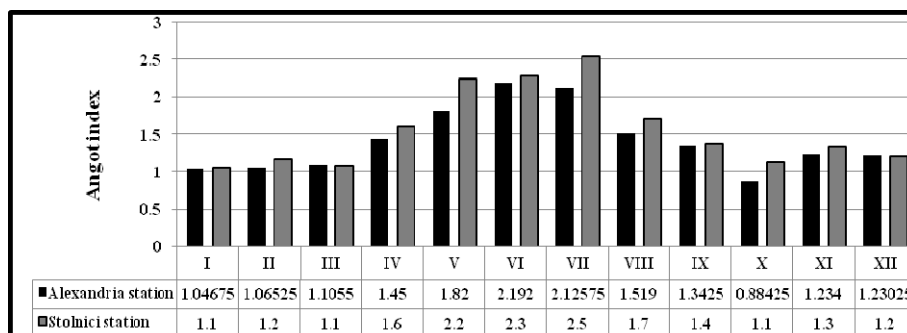


Fig. 3. Variation of monthly rainfall index Angot - Vedeia catchment (1961-2000)

At Stolnici station, the situation is the following: in the 14 years considered dry, the months with pluviometric deficit vary between 7 and 10 cases (a frequency of 58% and 83% respectively). For Alexandria weather station, the number of dry months ranges from 8 to 12, that is from 67% to 100%. The prevailing dry months with Angot index values less than 1.5 occur frequently during the periods January – April and September – December. In the case of the dry years, the rainy months differ in the north in comparison with the south of the catchment. At Stolnici station, the frequency of the months with pluviometric surplus varies between 2 and 5 (25% and 42% respectively) and the occurrence intervals are May – August and, rarely, December. At Alexandria, the number of rainy months of the dry years is between 0 and 4, that is a frequency of 0 and 33%.

By contrast, the Angot index values have allowed the separation of some rainy years, when K was greater than 2, which means the respective years had a high susceptibility of the landscape to the pluvial factor (table 4). The Stolnici station lying in the north of the catchment has a long series of years when the land was exposed to the pluvial factor, as follows: 1966, 1971, 1972, 1979 and 1980. As far as Alexandria station is concerned, the datasets include only three rainy years, namely 1966 (July – 128.8 mm), 1969 (June – 165.8 mm) and 1972 (July – 114.5 mm) (according to Dragota, 2006 and *Clima Romaniei*, 2008). One should note that for both weather stations 1966 and 1972 were very wet years (table 4), which demonstrates that precipitation regime was the same over the entire Vedeia catchment.

In the north, at Stolnici weather station, only four months in 1972 (May, August, September and October) exceeded the index value of 2 units, whereas in the south, at Alexandria, only five months were wet (May, July, August, September and October). For both weather stations, the highest

Angot index values were recorded in October 1972 (9.2 at Stolnici and 5.61 at Alexandria), which explains the high floods that plagued that year. At Stolnici station, in the five years designated as having a maximum susceptibility to precipitation the rainy months ranged from 4 to 8, that is between 33% and 67% of the year. Generally, the precipitation fell during the warm season, with the exception of 1966 and 1980 when the wettest months occurred in the cold season. At Alexandria, the number of rainy months in the three years considered very susceptible to the pluvial factor was between 5 and 6, that is 42% to 50% of the year. A special situation occurred in 1966, when most of the months having an Angot index greater than 2 belonged to the cold season.

On a *monthly scale*, of the 960 possible cases (the total number of months in the 37 investigated years) the highest frequency (40%) is held by the very low susceptibility class, followed by the low susceptibility one (18%). In 159 cases (3.15%) the land susceptibility to contemporary geomorphological processes was very high.

In the cold semester, the very low and low susceptibility values are prevalent, while the relative frequencies of the high and very high classes are low.

In the warm semester, the very high and high susceptibility classes prevail, but the medium class has a significant relative frequency.

4.2. Vulnerability

In order to get a comprehensive picture of the degree of influence of the amount of precipitation on the hydromorphological processes the study has also taken into account the monthly frequency of the susceptibility classes for the Mostitea catchment, which lies in the eastern section of the Romanian Plain and experiences different climatic conditions (Ghita, Dragota, 2010).

Table no 4. The rainiest 2 years ($K > 2$) over 1961-2000 (Vedea catchment)

Weather station	The rainiest year $K > 2$							
	Year	Pp. annual (mm)	No. of month	Dry months	% of months	Rainy months	No. of month	% of months
Stolnici	1972	817.4	4	V, VI, IX, X	33.3	I, III, IV, VI, VII, VIII, XI, XII	8	67
Alexandria	1966	787.7	6	II, IV, V, VI, IX, X	50	I, IV, VI, IX	6	50

By analyzing the values in Table 5 one can see that 40% of the cumulated precipitation do not have a significant impact on the landscape ($K < 0.99$) in terms of triggering or reactivating the geomorphological processes. With irrelevant exceptions, this situation is specific for the winter months, which in this area are generally dry.

At the same time, 18% of the monthly amounts of precipitation, which lead to Angot index values between 1.00 and 1.49, impose a low susceptibility to the land. These precipitations are distributed all year round, with some differences introduced by the interval of the year when they occur. At Stolnici, only January has 10 cases, whereas at Alexandria there are 15 cases in April and 10 in November.

The occurrence probability below 20% affects the entire catchment all year round, while the values higher than 20% are recorded only in January, April and November. The moderate susceptibility classes (III and IV), which show the considerable impact of precipitation on the landscape through the triggering of geomorphological processes have an annual occurrence probability of 14%. However, the role of precipitation must be weighted by taking into account the properties of loess deposits that cover the south of the catchment, the hydrogeological and morphological properties, as well as the land use in the region. One should note that in the warm season the K values are clustered.

The upper susceptibility classes, with monthly values greater than 2 or 2.5, which encourage the most the dynamics of the channel and slope

processes, and especially the floods, are mainly specific for the warmest months of the year (the interval May – July). Higher amounts of precipitation are recorded in June and July, both in the north (with 19 and 18 cases) and in the south (with 11 and 17 cases respectively). The occurrence probability of some intense geomorphological processes is specific for May, June and July, when the frequency exceeds 30%.

High values of the Angot index ($K = 2.00-2.49$), which prove the land is very susceptible to precipitation and floods, have been observed especially in the south during the decade 1961-1970 (in 1966 and 1969 the K values being 2.16 and 2.04 respectively). The most important decade from this point of view is 1971-1980, both in the north and in the south. The year 1972 is common for the entire catchment, with K values of 2.20 in the north and 2.16 in the south, whereas 1971, 1979 and 1980 are rainy years only for the southern part of the catchment, with K values varying between 2.00 and 2.20. In this case, the occurrence probability is between 10% and 25%.

The highest annual amounts of precipitation define the very high susceptibility class ($K > 2.50$). In an interval of 40 years, only in 1966 the K value reached 2.60. This happened in the north of the catchment, where the impact of precipitation on the land is obvious, especially on the slopes with higher gradients, which encourage the formation of gullies and torrents.

Table no. 5 Frequency of susceptibility classes monthly quantities of precipitation (Stolnici, Alexandria and Fundulea weather station)

Susceptibility classes	K index values (Angot)	Absolute frequency (no. of cases)		Cumulative frequency (no. of cases)		Relative frequency (%)	
		Vedea	Mostistea (Ghita, Dragota, 2010)	Vedea	Mostistea (Ghita, Dragota, 2010)	Vedea	Mostistea (Ghita, Dragota, 2010)
I - very low	< 0.99	386	348	960	444	40	78,3
II - low	1.00 - 1.49	246	74	574	96	18	16,6
III - moderate	1.50 - 1.99	139	16	399	22	14	3,6
IV - high	2.00 - 2.49	101	5	260	6	11	1,12
V - Very high	> 2.50	159	1	159	1	17	0,22

If we take into account that for the entire investigated period of time there were 8 cases with moisture surplus ($K > 2.00$), representing a frequency of about 17%, we may contend that at least in the north of the Vedeia catchment (where $K > 2.5$) geomorphological processes are to a great extent the result of the high amounts of precipitation. The amplest of these processes are triggered only in the rainy years and especially in the areas with maximum vulnerability.

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In comparison with the eastern section of the Romanian Plain (the Mostistea catchment) one can note, however, higher values of the moderate and high susceptibility of the land (17% and 11% respectively, in comparison with 1.12% and 0.22%) (Ghita C., Dragota C-S., 2010). These are mainly encouraged by the amounts of precipitation and the hydrogeological conditions of the territory (the presence of the piedmontane deposits close to the surface – the Candesti Strata in the north and the Fratesti Strata in the south). Under the circumstances, the drainage density has acquired high values, while torrential, channel and slope processes are common (Grecu et al., 2006) (Fig. 4).

A very good example that mirrors the influence of the Angot Pluvial Index and the specific susceptibility classes is the confluence of the Vedeia and Teleorman rivers (the Benceni – Smardioasa reach), where the channel dynamics has suffered

significant changes over an interval of 36 years (Grecu et. all, 2009, 2010) (Fig. 4). One can see a shortening of the Vedeia channel by approximately 2.5 km, on the one hand because of the stream piracy and the migration downstream of some meander loops and on the other hand because of the engineering works accomplished in the last 30 years.

Likewise, the extreme pluviometric events that are mirrored by the land susceptibility to erosion have brought about significant changes in a short period of time. We can mention in this respect the very high values of the monthly Angot index ($K > 2.5$) at Alexandria, when the abundant precipitation made the Vedeia River overflow its banks. Such repeated events led to significant changes of the river channels (lateral erosion, stream piracy and accumulation) and to the weakening of the dams built across the Vedeia River and its tributaries.

5. Conclusions

The susceptibility of the Vedeia catchment to the contemporary geomorphological processes, encouraged by the precipitation amounts (grouped in several susceptibility classes depending on the Angot index values) is predominantly low and moderate. In comparison with the eastern section of the Romanian Plain (the Mostistea catchment), the Angot index values point at a moderate, high and very high susceptibility. The pluviometric events have turned into an important imbalance in the general dynamics of the Vedeia morphohydrographic system. The pluvial factor plays an important part in the present dynamics of the topography and together with the local land use and the hydrogeological features, it is responsible for the accelerated dynamics of the landscape.

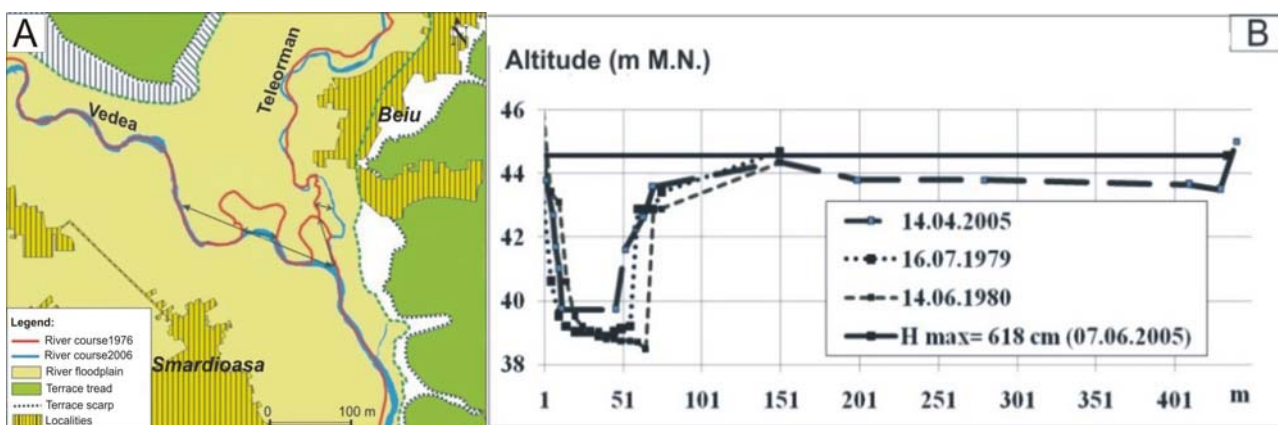


Fig. 4. The Vedeia riverbed dynamics at Teleorman junction (in plans - A and cross section - B) (downstream Alexandria weather station) (after A.N.A.R. – D.A.A.V, 2008, with modifications)

This work was supported by CNCIS – UEFISCDI, project number PNII – IDEI code 1954/2008 - "The hydrogeomorphological system in the concepts of geomorphometry and of modern morphological theories. Applications to hazard and risk diagnosis in areas of Romanian Plain" (Director, prof. univ. dr. Grecu Florina).

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Geomorphological impact of floods in the Bâsca Catchment (Romania)

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Abstract. The purpose of the current study is to analyse the floods and their impact on the dynamics of river channels and slopes in the Bâsca Catchment. Floods analyses are based on processing statistical data on maximum monthly and annually discharge of the Bâsca River at the closing hydrometric station, Bâsca Roziliei (period 1960 – 2007). It underlines specific aspects regarding the variability of the maximum flow (at multiannual scale and during the year) and the flood potential. The frequency analysis of the maximum monthly discharge indicates that the month with the highest flood potential is June followed by July. The consequences of the floods on the Bâsca river channel, consist on fluvial processes amplification: river bank erosion (e.g. upstream auto-station Varlaam), and channel aggradation or degradation. Therefore floods, by actioning on the river banks, imbalance slopes, determining landslides and rockfalls.

Key words: floods, maximum discharge, geomorphological effects, Bâsca Catchment

Rezumat. Prezenta lucrare are drept scop analiza viiturilor și a impactului acestora asupra dinamicii albiilor și versanților în bazinul hidrografic al râului Bâsca. Analiza viiturilor se bazează pe prelucrarea statistică a datelor privind debitele maxime lunare și anuale de la stația hidrometrică de închidere Bâsca Roziliei, în perioada 1960 - 2007. Sunt relevate aspecte privind variabilitatea scurgerii maxime (la scară multianuală și în timpul anului) și potențialul de viitură. Din analiza frecvenței de producere a debitelor maxime lunare reiese că luna cu cel mai mare potențial de viitură este iunie urmată de iulie. Consecințele geomorfologice induse de viituri asupra albiei râului Bâsca constau în amplificarea proceselor fluviale, prin accentuarea eroziunii laterale (de exemplu amonte stația automată Varlaam) și agradarea albiei. În același timp, viiturile, prin acțiunea asupra malurilor, afectează stabilitatea versanților, favorizând prăbușirile și alunecările de teren.

Introduction

Floods are natural risk phenomena with socio-economic and environmental consequences, multiple and complex, both direct and indirect. Through their erosive and transport power, floods act on the river bed, accelerating its vertical and horizontal dynamics. Floods action on the river banks determines imbalance slopes, generating landslides and rockfalls. Short or long term, geomorphological processes induced by floods can cause significant human and material damage. In order to minimize their impact, measures are necessary, and appropriate protection works against floods and geomorphological processes associated with them.

The present paper analyzes the floods and their impact on the dynamics of river channels and slopes, and identifies the engineering works necessary to mitigate the floods consequences in the Bâsca Catchment. Positioned in the external region of the Curvature Carpathians, the Bâsca Catchment (Fig. 1) has a surface of 785.1 sq km. It lies at a medium altitude of 1,081 m between the Lăcăuți

Peak (1,777 m a.s.l.) and the confluence whit Buzău River (385 m a.s.l.). The Bâsca River (length = 81 km) is one the main tributary of the Buzău River.

Zaharia (2004) showed the importance of knowing the characteristics of the maximum discharge for building and exploitation of hydrotechnical works, stream improvement, territorial planning, management of water resources, as well as for estimating the risk induced by floods.

The results of the present study complement and update specific information on some parameters like maximum discharge and floods from the Bâsca River Catchment, published in hydrologic papers and synthesis about Romania (*Râurile României. Monografie hidrologică*, 1971; Ujvári, 1972) and at regional scale (*Monografia hidrologică a bazinului hidrografic al râului Siret*, 1967; Diaconu, 2005; Zaharia, 2004, 2005; Chendeș, 2007, etc.).

Regarding the dynamics of geomorphological and hydromorphological processes in the Bâsca River Catchment, basic information on them are presented mainly in the papers written by Ielenicz (1984), Rădoane et al., (1991).

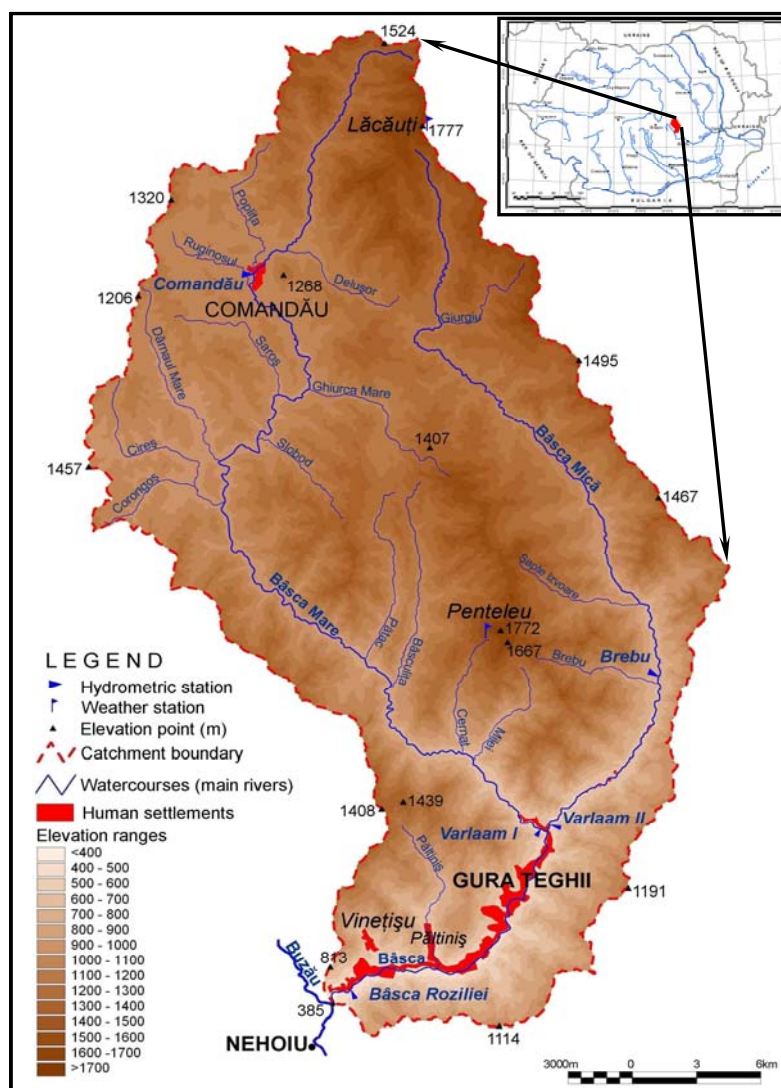


Fig. 1. The Bâsca Catchment and its location in Romania

Source: data processed from topographic maps, scale 1:25,000, MTD, 1982

1. Database and methodology

In the analysis we used following types of data: cartographic (topographic maps scale 1:25,000 by Military Topographic Department -MTD, 1982); climatic parameters: temperature and precipitation (average monthly & annual) at the Lăcăuți (1960-2000) and Penteleu (1988-2007) weather stations (w.s), provided by the Regional Meteorological Center Muntenia (Buzău); hydrological data: maximum monthly and annual discharges of the Bâsca river at the Bâsca Roziliei hydrometric station (h.s.) (1960 - 2007); discharges during the main floods (the hydrological data were provided by the "Romanian Waters" National Administration, Buzău – Ialomița Water Basin Administration -BI BWA- and the National Institute of Hydrology and Water Management – NIHWM).

The main methods used are: spatial analysis using GIS techniques (ArcView Gis 3.3 and ArcGis 9.3) and statistical analysis of hydrological and climatic data.

2. Favourable factors of floods and hydrogeomorphological processes

Floods genesis is a highly non-linear process that depends on favourable factors such as the geological and morphometrical features (e.g. lithology, slopes, energy relief and drainage density), pluviometric regime, vegetation, soils and antecedent conditions of the catchment (e.g. land use).

From the geological point of view, the Bâsca Catchment overlaps the orogenic unit of the Eastern Carpathians, where the external Paleogene flysch is predominant, including: sandstones (Tarcău sandstones Facies), marls, conglomerates (Fig. 2.a).

This area is characterised by tectonic uplift and by severe seismicity related to the Vrancea Epicentral Area, being affected by deep-seated landslides (Ielenicz, 1984). Lithology is dominated by the presence of the hardest and hard rocks, covering 96.7% of the catchment surface (Table 1).

In the Bâsca Catchment slopes declivity is frequently between 10 and 20° (44.3%) followed by classes 20-30° (23.8%), 0-3° (14.5%), 3-10° (7.52%), with the highest values exceeding locally 30° (9.77%) (Fig. 2.b).

The slopes significantly influence the concentration time of precipitation on slopes and therefore velocity in the genesis and transmission of floods.

The slopes have a very important role on the genesis and propagation of floods. The average slope

of the Bâsca River is 13.3 m/km, but its main tributaries have slopes exceeding 90 – 100 m/km: Păltiniș = 94.4 m/km (where linear human settlements are presents), Cernat = 122.6 m/km, Brebu = 111.4 m/km (Table 2).

Drainage density shows values up to 5.21 km/km² (Table 2), being another favourable factor for the concentration and production of flows and floods. Confluence and convergence hydrographic areas have an increased flooding risk. Similar areas were identified in the human settlements perimeters: Comandău (where Bâsca receives main tributaries Delușor, Poplița Rivers), Varlaam (where Bâsca confluence with Bâsca Mică) and Păltiniș (at confluence of the Bâsca and Păltiniș River).

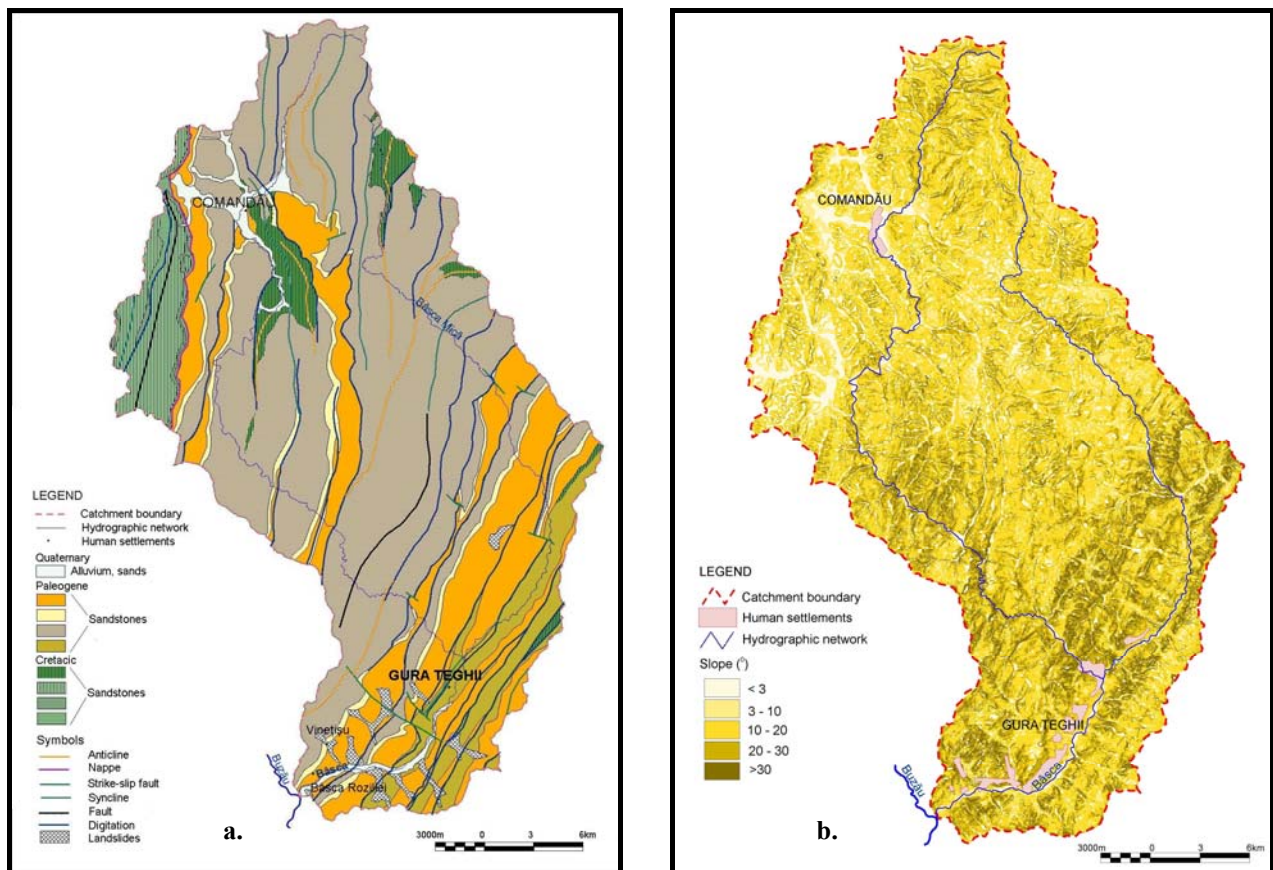


Fig. 2. Geological (a) and slopes (b) maps of the Bâsca Catchment

Sources: data processed from geological map (scale 1:200,000) and topographic maps (scale 1:25,000)

Table 1. Rocks classification according to their perforation resistance* in the Bâsca Catchment

Rocks hardness	Coefficient of resistance	Physical-mechanics characteristics	Geological formations	P (%)
Hardest	15 -17	consolidated rocks	Siliceous sandstone	96.77
Hard	10-12	reduced alteration, well-cemented	solid sandstone	
	7-8		sandstone, marls	3.23
Soft	1-2	unconsolidated rocks	alluvial, sands	

* According to Geological Committee of Romania (Zăvoianu, 1985)

Table 2. A summary of the significant morphometrical features of the Bâsca Catchment

River	RIVER CHANNEL LENGTH (KM)	Drainage area (km ²)	Drainage density (km/km ²)	Sub-basin			Slope (m/km)	Channel slope (m/km)
				Elevation (m)				
				H*	H**	H***		
Bâsca Mare	64.2	440	3.65	1.148,5	1.777	520	30.4	14.7
Bâsca Mică	46.5	238	3.63	1.148,5	1.777	520	30.4	21.5
Bâsculița	11.5	40	4.01	1.278,5	1.772	785	124.6	46.3
Poplița	9.29	22.4	3.37	1.198	1.387	1.009	112.5	22.2
Cireș	11.1	19.6	3.61	1.114	1.193	1.035	140.8	6.8
Păltiniș	9.69	25.1	4.61	937	1.439	435	112.5	94.4
Ghiurca Mare	9.59	23.3	3.76	1.283	1.601	965	162.2	58.8
Dârnăul Mare	10.6	21.5	4.20	1.081	1.219	943	115.1	16.7
Delușor	6.88	20.9	3.65	1.323	1.618	1.028	231.1	32.3
Pătac	10.0	18.5	2.90	1.144	1.479	809	134.1	45.2
Giurgiu	6.48	16.2	3.98	1.440	1.720	1.160	267.8	57.9
Șapte Izvoare	6.62	15.6	4.72	1.271	1.772	770	247.3	95.2
Milei	6.43	15.8	5.21	1.119,5	1.604	635	176.3	95.6
Saroș	7.84	14.9	4.02	1.154,5	1.244	1.065	169.3	14.9
Corongoș	5.32	12.8	3.98	1.094	1.250	938	214.6	20.1
Brebu	6.55	11.1	5.15	1.100	1.520	680	178.7	111.5
Ruginosul	5.14	11.8	3.81	1.107,5	1.206	1.009	219.1	42.0
Cernat	6.69	11.1	4.50	1.213,5	1.772	655	193.0	122.6
Slobod	6.18	9.22	4.11	1.187	1.429	945	193.1	67.2
Bâsca	81	785.1	3.69	1.081	1.777	385	22.3	13.3

*- mean altitude, **- maximum altitude, *** - minimum altitude; bold values are maximum values of each variable while italics indicate the minimum values.

Data are obtained from processed GIS after topographic maps (scale 1:25,000)

The climate of the Bâsca Catchment is temperate-continental. Föhn phenomena moderate the characteristics parameters of climatic elements (e.g. amounts reduced of precipitations and moderate value of air temperature).

The average multiannual temperature in the study area ranges between 1.2°C at Lăcăuți w.s. (1961 – 2006) and 2.4°C at Penteleu w.s. (1988-2007). In the mentioned periods, the average annual amount of precipitations recorded at Lăcăuți w.s. were 827.3 mm and 664.3 mm at Penteleu.

During the considered periods, the annual precipitations varied between 308.9 mm (in 1990 at Penteleu w.s.), and 1,319.9 mm (in 1972 at Lăcăuți w.s.). At both meteorological stations, summer is the wettest season, with 45% of the yearly amount

of precipitation, followed by spring and autumn with comparable amounts (23%, and 18% respectively), whilst winter is the driest, with 14% of the total annual amount of precipitation (Minea, 2009).

The pluviometric regime has a summer torrential character, being favourable to flow genesis and evolution. The most humid month is July (117.4 mm to Penteleu and 127.2 mm to Lăcăuți w.s.), followed by June (Fig. 3.a). Under these circumstances, these months have the highest flood potential. In floods genesis an important role is represented by the 24 hours rainfalls. At Lăcăuți w.s., in summer months, they exceed 80 mm (Fig. 3.b), which favours flash-floods and explain the high frequency of floods in the summer period.

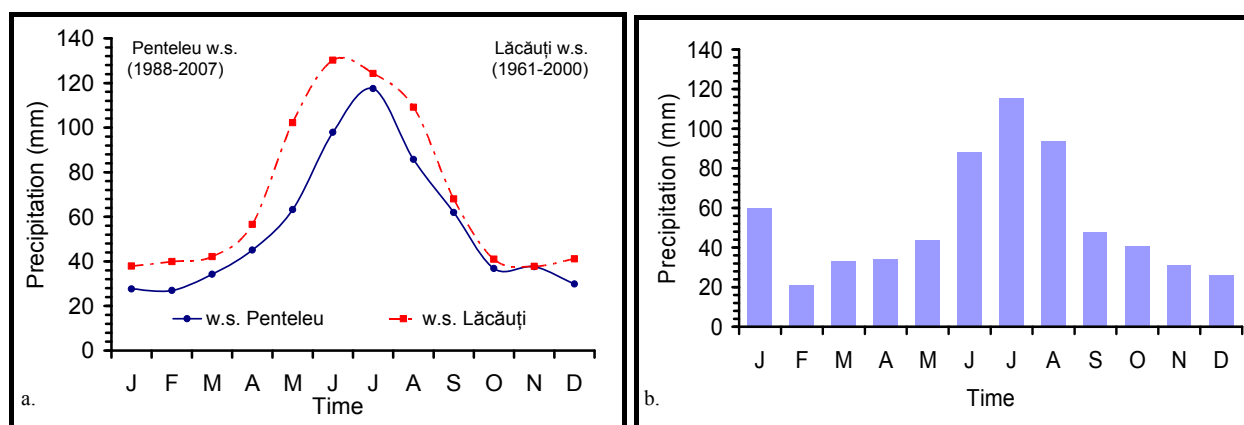


Fig. 3. a. Pluviometric regime in the Bâsca Catchment. b. Maximum amounts of precipitation in 24h at Lăcăuți w.s. (1961–2000)
Source: data process from Regional Meteorological Center Muntenia (Buzău) and *Clima României*, 2008

Land cover. According to the Corine Land Cover 2006 classification, the main category of land use in the Bâsca River Catchment is category 3, represented by forests and semi-natural areas (92.6% from catchment area). The catchment, in general shows a high forestation degree (83.4%), which constitutes a moderator factor of superficial flow on slopes. The forests include the following subdivisions: beech forests (102 sq km), mixed forests (280 sq km) and coniferous forests (273 sq km) (Minea & Vişan, 2010). In some areas, is encountered concentrated cutting of forests (e.g. Cernat Catchment, where is private forestry management: *Ocolul Silvic Penteleu*), which led to escape favouring the runoff on slopes.

3. Floods: potential and features

Floods analyses are based on processing statistical data on maximum monthly and annually discharge of the Bâsca River at the closing hydrometric station Bâsca Roziliei (period 1960 – 2007). Discharges during the main floods were also used. In the considered period, the annual maximum flow of the Bâsca River varied between 39.4 m³/s (year 1986) and 960 m³/s (year 1975) (Fig. 4). Exceptionally floods were recorded in the years: 1975 (960 m³/s), 1969 (697 m³/s), 1991 (530 m³/s) and 1985 (515 m³/s). Multiannual average discharge at this station is about 12 m³/s.

A particular year for this catchment was 1975 when at Bâsca Roziliei, in 24 hours fell 135,2 mm of rainfall, resulting a flood with a peak discharge of 960 m³/s (on July 2) (BI BWA, 2009). It was the historical maximum discharge recorded on the Bâsca River at Bâsca Roziliei h.s. The parameters of this flood were: time to peak - 24 hours, recession time - 99 hours, total time - 123 hours), volume - 75.8 mil.m³. Socio -

economical impact was dramatically and generated serious damages (Zăvoianu & Podani, 1977).

Most floods have pluvial causes, occurring mainly in the warm season. Monthly frequency analysis of production of the largest floods indicates that the greatest potential for flood is encountered in the months from May to July. Thus, from the total of 59 major floods identified (were considered cases in which maximum discharge monthly of values were above average annual maximum discharge), 13 (22.0%) occurred in June and each 10 (16.9%) in May and July (55.9%) (Fig. 5).

As a result of specific physico – geographical conditions from the catchment, some floods may be flash-floods. Heavy rainfall and deforestations have increased the incidence of flash-floods and landslide (Bălteanu *et al.*, 2010).

4. Geomorphological floods impact and its economic consequences

Associated with floods is a rich alluvial transport, due to high erosive force of water acting on the river bed and river banks. If the multiannual mean suspended sediment load of the Bâsca River at Bâsca Roziliei h.s. is 9.267 kg/s, during the major floods the suspended sediment load exceeded 10,000 kg/s: 19,800 kg/s (18.VII.1991), 16,400 kg/s (2.VII.1975), 10,045 kg/s (2.VII.1971), (according to the data from BI BWA, 2009).

An important geomorphological impact of floods is the growth of channel processes: lateral erosion (Fig. 6.a), degradation and aggradation (Fig. 6.b). As a consequence of the historical flood in 2nd July 1975, the channel and floodplain morphology of the Bâsca River have been strongly modified both by erosion and by aggradation. On the river bed, sand and rubble sediments were deposited with a thickness of 0.5-1.5 m, which generated stretched stairs of 50-100 m and wide of 10-25 m (Ielenicz, 1984).

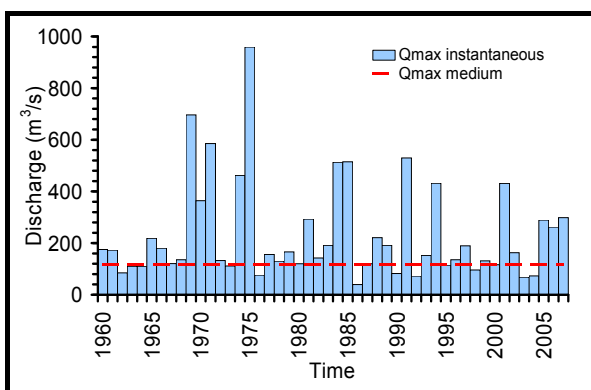


Fig. 4. Multiannual variability of the maximum discharges of the Bâsca River at Bâsca Roziliei h.s. (1960-2007)
Source: data process from BI BWA, 2009

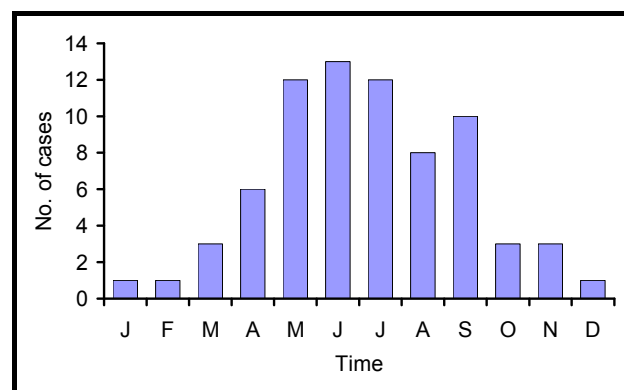


Fig. 5. Monthly distribution of major floods at the Bâsca Roziliei h.s. (1960-2007)
Source: data process from BI BWA, 2009



Fig. 6. Geomorphological effects of floods on the Bâsca River channel: river bank erosion (a) and alluvial processes (b)
(Photo: Minea, November 2009).

The erosion action of the floods on the river banks favors slopes destabilization and mass wasting (falls, landslides) (Grecu, 2008). These are also caused by the infiltration and the down-slope flow, the geological features (alternation of different deposits and rocks, presence of faults) and the high slopes (76 sq km of the Bâsca Catchment has slopes exceeding 30°).

Changes of the Bâsca River channel and its tributaries due to processes of erosion and accumulation have been identified in several locations. In some cases they have caused economic damages, such as:

- deterioration of the forest railway embankment (after 1969 it was out of service);
- undercutting and detachment of engineering techniques (for example along the Păltiniș River) (Fig. 7.a) and degradation of the county and departmental roads: DJ203K, DC178 at

auto-station Varlaam (Fig. 7 b), DC173 and DC66.

5. Hydrotechnical works for reducing the geomorphological effects of floods

For prevention and mitigation of the floods effects and their geomorphological impact, engineering techniques were made in the Bâsca River Catchment. These include longitudinal and transversal in-stream structures for bank and bed protection: revetments (gabions, lining with concrete etc.), grade control structures (weirs, sills), re-sectioning and realignment (Aquaproiect, 2006). Engineering works for slope protection and consolidation were also made in areas vulnerable to falls and landslides, due to fluvial erosion on the slope base.



Fig. 7. Economic damages caused by the fluvial dynamics processes: a – degradation of hydrotechnical works in the Păltiniș River channel; b - erosion and crumble of the departmental road DC178 near auto-station Varlaam)
(Photo: Minea, November and July 2009).

The destructive stream power during the floods associated with neotectonic process by uplift movements with rates of $+5 \text{ mm/year}$ Buzău Mountains (Polonic, 2006) and seismicity, affected in time the hydrotechnical works. In figure no. 8 we present the hydrotechnical works from the middle and lower parts of the Catchment (where are positioned the human settlements: Vadu Oii, Varlaam, Gura Teghii, Nemertea, Furtunești, Păltiniș, Vinețișu and Bâsca Roziliei), and their physical status.

After 2007, for reducing the destructive impact of the floods in the lower sector of the Bâsca River, Buzău – Ialomița Water Basin Administration started new hydrotechnical works (gabion baskets).

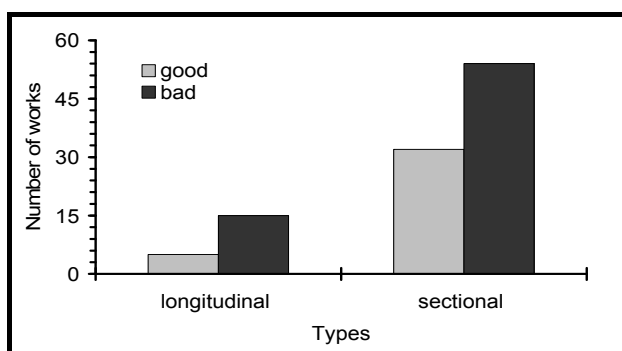


Fig. 8. Physical status of hydrotechnical works in the middle and lower part of the Bâsca Catchment
Source: data process from ICAS, 1996

Conclusions

Floods in the Bâsca River Catchment are common risks phenomena, favoured by physical and

geographical conditions of the catchment: high proportion of impermeable rocks, high slopes and river slope, energy relief and the torrential regime of rainfalls.

The floods are characteristic in the warm period, especially between May and July, with a maximum flood potential in June. Floods cause quick changes to river bed, in vertical and horizontal profile, through enhanced erosion and accumulation processes. Also, trough erosion actions on river banks are favoured and slope processes amplified (rockfalls, landslides).

Such phenomena have been identified in several sectors along the main river and on its tributaries and cause economic damages (deterioration of roads and hydrotechnical works).

Although there are hydrotechnical works to protect against floods and geomorphological processes associated with them, these works are degraded at a rate of 65%, requiring rehabilitation, and development of new hydrotechnical works.

ACKNOWLEDGMENTS

The research was accomplished within the doctoral training programme and supported by a POSDRU grant, financed by the Social European Fund (SEF). Thanks to Professor Florina Grecu make-up editors of the *Revista de Geomorfologie*, for the final form of this scientific paper.

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Landslides in the Plain Sector of the Jiu Valley

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Abstract. This sector of the Jiu valley lays downstream of Craiova, where the unit evolved asymmetrically on a width over 10 kilometres and to a depth of maximum 120 meters at Craiova. The right slope is steep and has a very active dynamic, while the left one has a step-up section and the alluvial plain has an average width of 4-5 kilometres. These general features of the section challenged a lot of researchers and in the literature there are given dispersed and succinct explanations in works that study the neighbouring regions.

The development of a piedmont plain in the north of the Oltenian Plain and of a terrace plain in the south, the erosion of the piedmont structures and the formation of a terrace plain occurred on the background of Pleistocene climatic changes, neotectonic movements and due to the deviation of the Danube to the right and the lowering of the base level.

Therefore, there are five terraces, the upper ones are covered by loess and yellow-reddish loessial deposits, while the bottom terraces and the alluvial plain have a complex morphology and which is covered by sand dunes.

All the events and the changes studied lead to a reconstruction of the formation stages and allow a synchronization of the morpho-hydro-climatic events as a premise for the present geomorphological processes.

Key words: landslides, slope, vulnerability, the Jiu valley

Rezumat. Acest sector al văii Jiului se desfășoară aval de Craiova, unde valea s-a dezvoltat asimetric pe o lățime de peste 10 km și adâncime de maxim 120 m la Craiova. Versantul drept este abrupt și are o dinamică foarte activă, versantul stâng are un profil în trepte, iar lunca are lățime de 4-5 km în medie. Aceste trăsături generale ale profilului văii au trezit curiozitatea a numeroși cercetători, iar în literatura de specialitate sunt explicate dispart și succint în lucrări ce vizează regiuni vecine.

Dezvoltarea unei câmpii piemontane în nordul Câmpiei Olteniei și a unei câmpii de terase în sud, erodarea structurilor piemontane și formarea unei câmpii de terase s-a produs pe fondul oscilațiilor climatice pleistocene, mișcărilor neotectonice, abaterii Dunării spre dreapta și coborârii nivelului de bază.

Astfel există cinci terase, cele superioare sunt acoperite cu o cuvertură de loess și depozite loessoide de culoare gălbuie-roșcată, iar terasele inferioare și lunca au o morfologie complicată și camuflată de nisipuri și dune.

Toate evenimentele și transformările studiate conduc la o reconstituire a etapelor de formare și permit o sincronizare a evenimentelor morfohidroclimatice, ca premisă a proceselor geomorfologice actuale.

Introduction

The plain sector of the Jiu valley lays downstream of Craiova, separating the Băilești Plain and the Romanați Plain, here the valley evolved asymmetrically on a width of 5-8 kilometres and a depth of maximum 120 metres (at Craiova). Thus, the right slope stays steep and has a very active dynamic, the left side generally occupies half of the width of the valley – having a step-up section and the alluvial plain sometimes exceeds the sum of the length of the riversides.

In the Romanian special literature landslides were studied more in the mountain and hilly regions with a high risk to mass movements and less into the plain areas where they are not so frequent. The studies treated morphological and morphodynamic aspects, the distribution, classification and the dependency

regarding the land use, earthquakes, quantity of precipitations (Surdeanu, 1975, 1990, 1994, 1998, Badea & Bălțeanu, 1977, Bălțeanu, 1983, 1999, Bălțeanu et.al 2010, Ichim & Rădoane, 1986, Surdeanu & Zemianschi, 1990, Vespremeanu-Stroe et al., 2006, Cioacă, 1996, Grecu, F. 1996, Ielenicz et al. 1999, Armaș et al., 2003, Boengiu et al. 2009).

In this sector, the palogeographic evolution lead to the formation of a piedmont plain in the north of the Oltenia Plain and of a terrace plain in the south. The erosion of the piedmont structures and the formation of a terrace plain occurred on the background of the Pleistocene climatic changes, neotectonic movements, the deviation of the Danube to the right and the lowering of the base level. Therefore, there are five terraces with a continuous outlay, the upper ones being covered by a loess layer and yellow-reddish loess deposits,

while the bottom terraces and the alluvial plain are covered by sands and dunes.

In the plain sector, the Jiu valley has two equal sections in length: the northern one between the Sâlcuța and Leu-Rotunda piedmont plains; the south sector developed within the terrace plain.

In the north sector, the terrace system of the Jiu developed on one side, and in the south sector it has a bilateral terrace system. This fact suggests the direction of the influence under which they evolved (Fig. 1).

On the left slope, in the north sector, there are 5 terraces located at the following relative altitudes: the Rojișteța terrace (T_1 5-12 metres), the Malu Mare terrace (T_2 15-22 metres), the Bârza terrace (T_3 30-40 metres), the Șimnic terrace (T_4 40-60 metres), the Cârcea terrace (T_5 70-90 metres). They generally have a continuous outlay and they lose in the Danube terraces downstream of Padea-Mârșani (Coteț P., 1957), where the south sector of the Jiu valley was carved in the detriment of the Danube terraces. In figure 1 the Jiu terraces are represented with the absolute altitude.

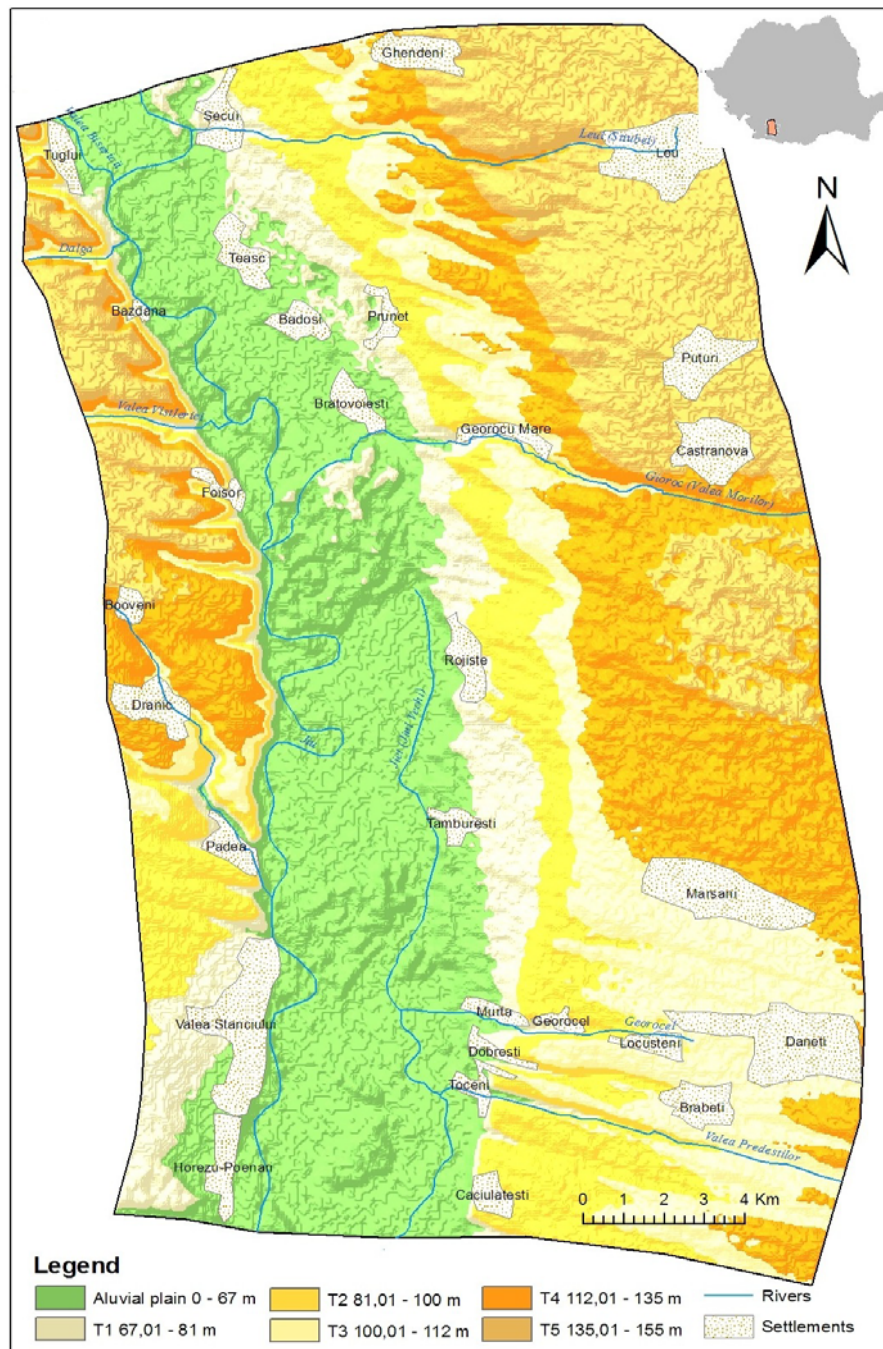


Fig. 1 The morphological map of the Jiu valley in the plain sector

The alluvial plain has an average width of 4-5 kilometres, is dominated by the terrace scarp of 5-12 metres on the left, and on the right side by steep slopes of 50-60 metres.

The general course of the Jiu is to build up the alluvial plain on the left side and to destroy the right side by lateral erosion. It has a monotone morphology, except for the sectors with old courses filled with alluvia or swampy areas and pluvial banks.

The altitude increases with 2-3 metres due to the presence of the alluvial cones and sand dunes. Downstream of Rojiște, on the left side of the Jiu can be easily noticed an old course of the Jiu river – the Jieț stream.

Data and methods

The plain sector is 80 kilometres long, developing between the Podari – Cârcea line and the confluence with the Danube, having a share of 8% (800 km²) from the surface of the basin and a slope of 0,3-1‰ (Savin C., 1990).

The neotectonic movements from the Pasadena phase (Middle Pleistocene) reactivated the Balș – Leu – Rotunda ascension, which interposed between the domain from the east and west of this ascension. This phenomenon forced the Jiu river to take its course to south and to slowly lower to south-west, leaving terraces only on the left side of the valley (Boengiu, 2009).

For the analysis of the present geomorphologic processes we evaluated the morphological, morphometrical and hydrographic features.

The relief was analyzed based on the topographic maps 1:25000, 1:50000, 1:100000 and SRTM DTM la 30 metres, the maps from the general studies of forestry management, the Corine Land Cover data and a series of Landsat 2000 satellite images in GIS, to which were added the ortophotoplans (1:5.000) for critical areas.

For the analysis of the climatic influence we used the values of the annual precipitations registered during the period 1961 – 2006 (Boengiu, 2009).

The observations made in the field tried to clarify and add new details that had not been surprised by the maps regarding the actual stage by mapping in the representative areas.

Results and discussions

The present geomorphologic processes within the studied sector can be grouped in processes that

affect the slopes and processes that affect the alluvial plain. The slope processes are represented by landslides with areas only on the right side and aeolian processes manifested only on the left side. The bed and aeolian processes have a great occurrence in the alluvial plain.

During the entire stage of formation of the alluvial plain, up to its present stage, the Jiu river changed several times its flow direction, the present one being of a historic age. These discontinuities in the evolution of the Jiu course and alluvial plain have been, of course, the result of the climatic changes rebounded in the hydrological regime of the Jiu river, to which were associated the influence of the neotectonic movements (Curcan et al. 2009).

The Jiu river is now in a process of strong alluviation. In its minor course, the river bed is, on some sections, at higher levels compared to large surfaces from the alluvial plain.

The right side of the Jiu river, between Podari and up to south of Padea, is affected by landslides on several sections (Podari, Bâzdâna, Dâlga, Foișor, Drânic, Padea, Valea Stanciului, Horezu-Poenari), but the landslides from Bâzdâna and Drânic are among the most representative ones (Photo 1).



Photo 1. The upper part of the Bâzdâna landslide

This slope has altitudes between 140-110 metres on its upper side (Bâzdâna Hill – 146,1 metres and La Izlaz Hill – 111,7 metres) and 60-40 metres at the bottom, resulting an altitudinal difference of 80 to 70 metres for the hill having the character of a cuesta. The permanent erosional action of the Jiu and the Romanian-Pleistocene deposits consisting of clays, marls and sands lead to the maintenance of a very steep slope with a slope over 65° that is very vulnerable to landslides.

The Bâzdâna landslide

The landslide is located on the area of the village with the same name and has two sections divided by the Bâzdâna stream (Fig. 2).

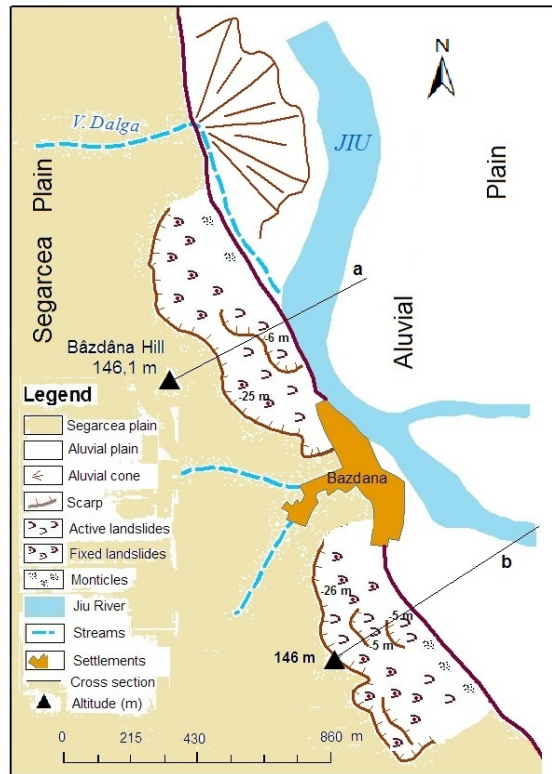


Fig. 2. The sketch of the Bâzdâna landslide

The landslide evolved on a general west-east movement direction, starting from 140 metres and reaching up to the minor river bed of the Jiu river at 60 metres, where it is perpendicular on the convexity of a meander of the Jiu. In the north part, the Jiu river was pushed toward east by the alluvial cone of the Dâlga stream, but the immediate return of the Jiu river under the slope determines the landslide to have a rhythmic evolution depending on the dynamic of the river bed. As the lateral erosion evacuates higher quantities of materials, the landslide is more active, these episodes being strongly correlated with the

river flow synchronized with the excessive humectation of the deposits from the landslide steps.

The landslide is not unitary, in the north part having two steps outlined by the two scarps (Fig. 3, 4). The first scarp is 22-25 metres high, 940 metres long and 80-95 metres width (Photo 2), the movement of this step being performed almost without deranging the structure. The second scarp has 6-4,5 metres in height and is kept only on a length of 380 metres, because in the spring of 2006, the front part of the landslide was reactivated and important quantities of material were consumed by the Jiu river.

In the south part, the landslide has three steps very well evidenced by three scarps (Fig. 4), the first one being 26-22 metres, high and the second and the third one of 5 metres. The first scarp is 840 metres long and a width of maximum, the other two steps had been destroyed during the same spring in 2006 due to some complex reactivations.

Generally, the upper steps are structurally deranged only by inclination, while the bottom steps are strongly disordered and in the scarp of the landslide they have the aspect of a monticle.



Photo 2. The scarp of the Bâzdâna landslide

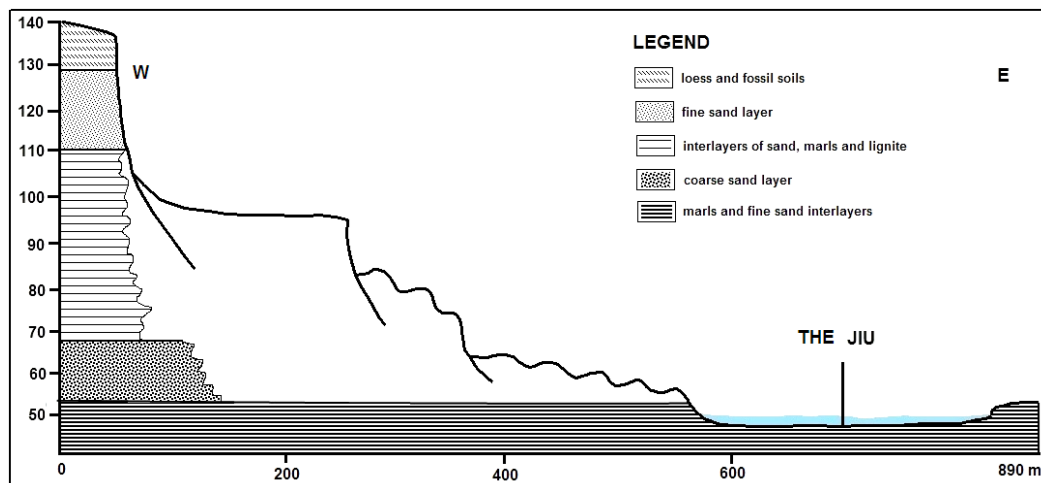


Fig. 3. Cross section (a) in the north part of the Bâzdâna landslide

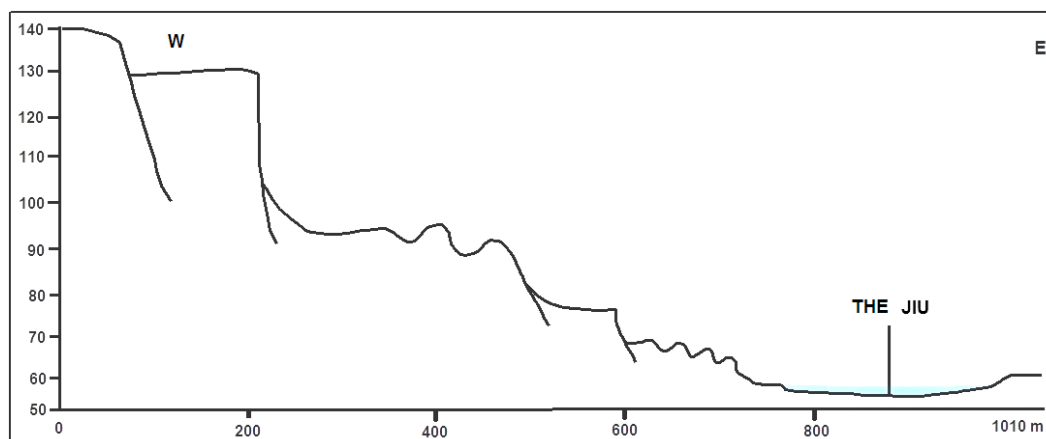


Fig. 4. Cross section (b) in the south part of the Bâzdâna landslide

The Drănic landslide

This landslide is located on the area of the Drănic commune in front of Padea village. The landslide evolved on a general west-east movement direction, starting from 111 metres and reaching the minor river bed of the Jiu at 40 metres (Fig. 5, 6). It has a single scarp in the shape of a semicircle, approximate 1,800 meters long and a width of 20-30 metres (Photo 3). The in the central part of the landslide the width reaches 210 metres and decreases constantly toward north and south. The mass of the landslide is entirely deranged structurally and moves rhythmically as small steps, furrows and monticles toward the Jiu riverbed where it is being consumed.

This landslide of great dimension is due to the intensification of the lateral erosion performed by the Jiu river upon the right slope because of the decrease of the flowing slope.

Upstream of this landslide, the Jiu has two ample meanders in the shape of the letter *m* which indicate a strong aggradation of the bed due to the river reduced power of transportation.



Photo 3. The Drănic landslide

In front of this landslide of almost 2 kilometres, the minor river bed has the tendency to unplat, in the present having three branches with smaller and smaller flows to the face of the landslide.

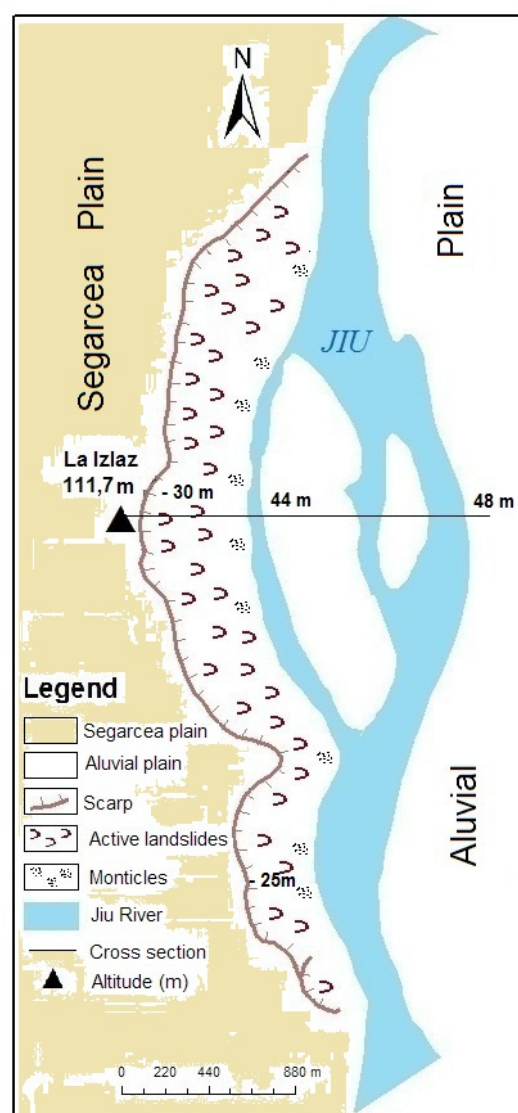


Fig. 5. Sketch of the Drănic landslide

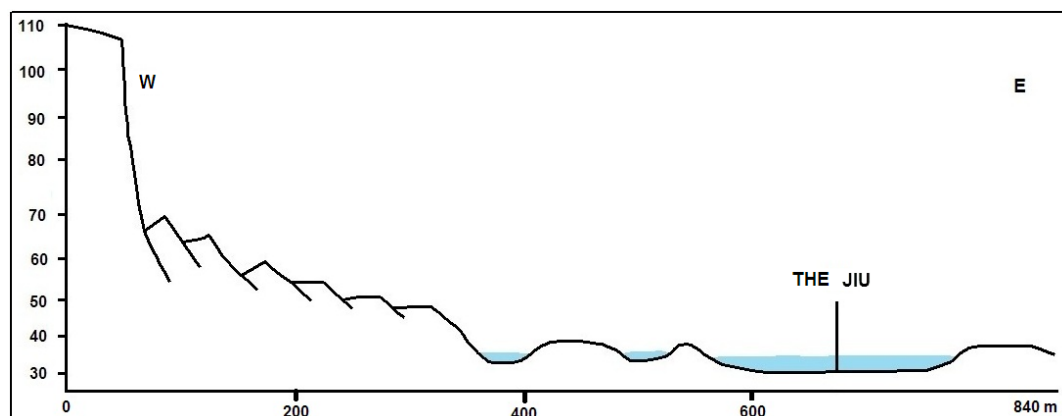


Fig. 6. Cross section of the Drănic landslide

Conclusions

The neotectonic movements of various directions and the climatic changes are indicated by the tendency of the Jiu river to go west, a direction kept also in the present. During the most part of the Holocene, the Jiu river strongly eroded the terraces on its left side. In a subsequent stage, the river left its old bed – the Jieț river flows nowadays on this course – and began to flow on the right part of the alluvial plain. In the initial stage, when the alluvial plain of the Danube was formed, the erosion performed by the Danube river on the left side was strong enough. Thus, the bottom terraces had been eroded especially downstream of the confluence. After leaving the old course, the scenario changed and the river strongly eroded the right side, destroying all the terraces that were surely also present here. The violent erosion of the right side caused the total transformation of the geomorphologic systems mainly by increasing the energy of the slope, cutting the confluent valleys (Boengiu S., 2008) and by lowering the river bed under the level of the Romanian clays and grey marls.

Nowadays, the entire slope is affected by mass movements (collapses and landslides) following a commune mechanism: where the convex part of the meander gets close to the slope, its vulnerability is increased and produces collapses and landslides,

and where the slope is farther from the river course or it is near the concave part of the mender, the vulnerability is reduced and the at the base of the slope, where the transported debris is accumulated are formed glacises.

Most of the times, the Jiu river gets away from the right slope in front of the confluences with the tributaries on this side and immediately returns close to the slope.

This slope is under the direct influence of the Jiu river which, in the conditions mentioned above, periodically unbalances the slope maintaining an accelerate dynamics of the slope.

Acknowledgements

The authors would like to thank professors Tomescu Viorica, Pleniceanu Vasile and Savin Constantin, from the Department of Geography, the University of Craiova for their suggestions on the studied phenomena. We mention that this study benefited by material and logistic support from the project *Vulnerability of slopes and landslides in the Bălăcița Piedmont. The use of G.I.S. and the achievement of digital maps of vulnerability*, CNCSIS code 2005/2008.

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Cryo-nival modeling system.

Case study: Făgăraș and Piatra Craiului Mountains

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Laura COMĂNESCU, Robert DOBRE

Cryo-nival modeling system. Case study: Făgăraș Mountains and Piatra Craiului Mountains. During Upper Pleistocene, the study areas were lying below the snow line, where periglacial processes were extremely active. Supporting evidence in this respect is given by the presence of old periglacial deposits, most of them stabilized by soils and vegetation. These deposits are accompanied by scarps present at all elevations, from the alpine and subalpine zones to the forest altitudinal belts. The high mountain steps, generally lying above 1800 m altitude, represent a specific morphosculptural area. The most obvious relief forms which are present here are the Borascu erosion level, with a large extension, as well as the glacial cirques, troughs and arêtes situated around the main peaks (Moldoveanu, Vanatoarea lui Buteanu, Negoiu) and on the sides of the ridges that connect them. This study has employed topographic maps of the region at 1:25000 and 1:50000 scales, aerial photographs at 1:50000 scale, the Negoiu, Cumpăna, Zărnești geological maps at 1:50000 scale, as well as satellite imagery. At the same time, relief forms have been mapped in the field and simple measurements of slope processes that develop above tree line have been undertaken. As far as the climatic data are concerned these have been provided by the nearest weather stations: Balea, Cumpăna, Curtea de Argeș and Omu Peak.

Key words: cryo-nival modeling system, castellated rocks, gelifractions, solifluction, striated soils, Făgăraș Mountains, Piatra Craiului Mountains.

1. Introductory and methodological aspects

During the Upper Pleistocene, the study area was lying below the snow line and consequently periglacial processes were prevailing. The most obvious traces of their morphogenetic activity are the scarps that develop at various altitudinal levels, as well as the old periglacial deposits, stabilized by soils and vegetation, which are found in the Făgăraș Mountains (talus slopes, deluviums, eluviums, patterned grounds and striated soils). But the appearance of Carpathian periglacial province has suffered significant alterations during postglacial era. Thus, the forest has climbed by more than 1000 m, with local variations imposed by topography and soils. At more than 1750-1800 m altitude, above the climatic tree line (within the province of alpine and subalpine grasslands and rocky lands), a cryonival level has come into existence (Bălțanu, Călin, 1996). Here, the climate is cold (although the temperatures are not as low as during the Pleistocene) and one can notice the existence of two seasons (Niculescu, 2005). Under the circumstances, cryonival processes discussed above occur at lower altitudes, but without being dominant. For instance, gelifraction brings its

contribution to the formation of some local lithological scarps within the forest level, whereas solifluction is active only above 1500 m. This altitude is roughly followed by the annual isotherm of 3°C, which is considered not only the lower limit of these processes (Urdea, 2000), but also the upper climatic limit of beech tree (Nedelea, Oprea et. al., 2009).

The study relies on the analysis and interpretation of the information coming from various sources: topographic maps of scales 1:25000 and 1:50000, aerial photographs of scale 1:5000, geological maps of scale 1:50000 (the sheets Negoiu, Cumpăna and Zărnești) (1972, 1985) and the climatic data recorded at several weather stations (Balea, Cumpăna, Curtea de Argeș, Omu Peak). At the same time, various mappings of terrain features have been accomplished in the field, as well as some measurements regarding the slope processes that carry on above the tree line.

2. Factors controlling landform development

The direct or indirect climate impact on morphogenesis is capital and it manifests itself

towards the direction of the intensity of time and space association of the intensity of some processes. Therefore it is considered that of all climate parameters the temperature and the precipitations are playing a primordial role. Fagaras and Iezer Mountains are characterized by a high erosive dynamics for many reasons:

- the region is characterized by massive rainfall and low temperatures, but the massive snowfalls;
- the instability of the region is tightly bound to the sloping grounds, the type of rock, but mostly by the climatic conditions, water and snow being the important agents;
- once with the growing of altitude the frost/defrost alternancy rhythm grows in intensity and in frequency; few summer or autumn shower rains enrich the water contribution from the superficial formations and cause slope processes;
- the wet snow avalanches have the most important role in the dynamic of the versants in this sector and they begin in April at 1800 m on the Southern slopes and in May on the Northern slopes; on the Southern slopes they correspond to the frequency of the frost /defrost alternation while on the Northern ones they correspond to the maximum quantity of precipitations;
- high declivity and long length of the versants lead to a vertical zonality of the morphodynamic processes, in this way inevitably conditioning the morphogenesis;
- in the mountain periglacial environment, the morphogenesis is commanded by the action of the cold; tant than the versant's declivity, which doesn't have to be very high to allow the appearance of periglacial processes; the cold inhibates the chemical processes and favors the mechanical ones;
- the slope influences the efficacy of the freezing, thus, the more powerful the cold and the slope are, the fastest the transportation processes approach the slide rocks flow passing through the stages of gelicreeping and gelifluction;
- high on the ridges we need to take in account the shape and the display of the walls in regard with the changes of the wind;
- the absence of the vegetal carpet can lead to the appearance of cryoturbation, gelifluction and gelifluction processes;
- the nature of human activities also influences the erosive dynamics

The ridges, plateaus and high peaks lying above 1800 m make up a distinct morphostructural area. This includes the Borascu erosion surface (2000-2200 m), the glacial cirques and troughs (specific for the Fagaras Mountains) (Chardon, 1984) and the ridges that come off the main peaks (Moldoveanu, Vanatoarea lui Buteanu, Piscul Baciului, Vf. Ascutit).

The present climate of alpine grasslands is milder than it used to be during the Pleistocene. However, in comparison with the lower areas it is harsh and humid, with annual average temperatures of 0°C , or even lower (-0.2°C at Balea Lake and -2.5°C at Omu Peak), in the high areas and on the main summits (Nedelea, Oprea et. al., 2009) (fig.1). Precipitation reaches more than 1200 mm per year, almost half of the amount falling in solid form. The number of frost days depends on the altitude. For instance, at Balea Lake weather station are recorded on an average about 200 frost days per year, while at Omu Peak, which lies higher, the number grows to 260 days per year. The freeze-thaw cycles, more frequent during transition seasons, and the daily temperature variations are responsible for landscape degradation by frost shattering processes. The detached blocks accumulate at the base of the slopes as screes or aprons of debris (Caldarea Pietroasa, Marele Grohotis, Martoiu, Funduri).

The prolonged duration of snow layer (between slightly more than 120 days per year at Balea Lake and 217 days per year at Omu Peak) brings its contribution to the shaping of land, especially on the lee sides, that is opposite to the prevailing winds directions (west, northwest, and southwest). The snow settling at the base of the cliffs that surround the catchment areas of the valleys (Podragu, Podul Giurgiului, Doamnele, Fundul Caprei, Lancii, Urzicii, Padina Inchisa, Martoiu, Padinile Frumose) has resulted in the formation of nival cirques and niches. The rocks are represented by gneisses, paragneisses, micaschists, crystalline limestones, limestones and conglomerates. These are rather fissured, which explains why they are so prone to frost shattering. At the same time, the rocky bare lands lying on peaks and ridges (Podragu Ridge, Arpaselul Ridge, Balea Ridge, South Ridge, Timbalelor Ridge, etc.) encourage land degradation. In addition, local topography is also shaped by denudation processes with recurrent character. Thus, beside the cryonival processes one can also notice gravitational processes, surface erosion, gully and torrentiality.

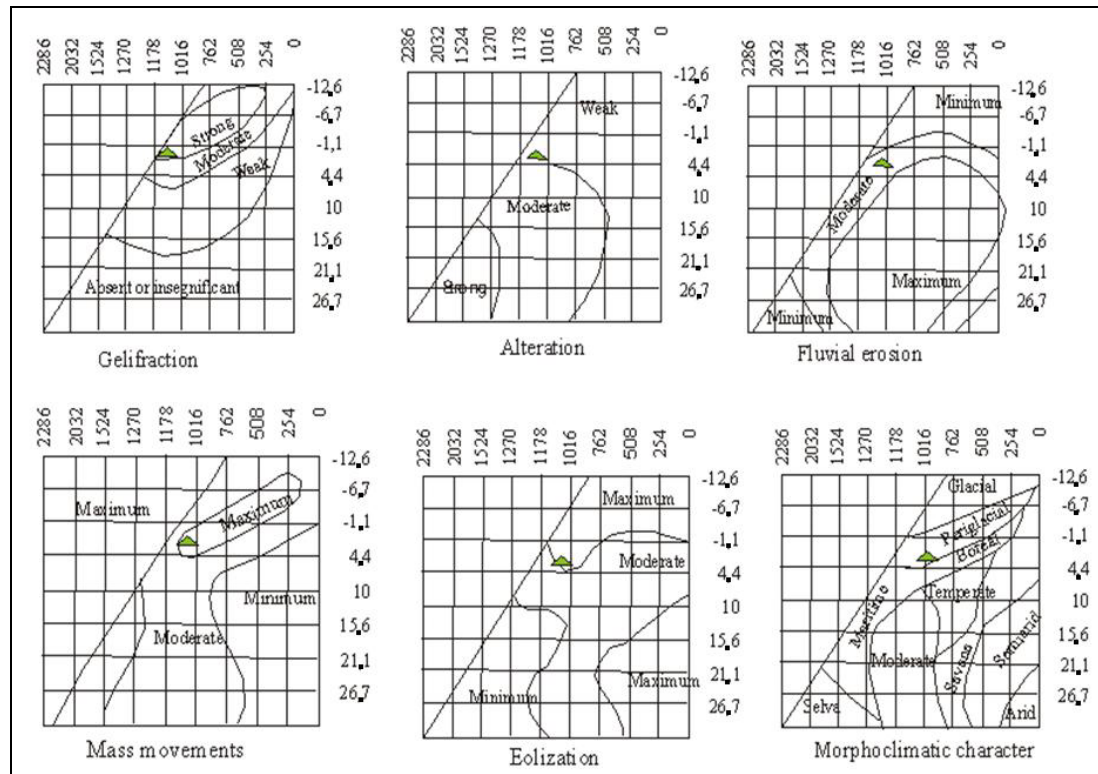


Figure 1 Peltier diagrams for Bâlea meteo station (Cristea and Gheorghe, 2009)

3. Cryonival processes and the resulting landforms

Above climatic tree line, all the ridges and slopes stay most of the year under the influence of freeze-thaw action, nivation and aeolization. The analysis of climate data from the Lacauti weather station (1776 m) shows that with the exception of

the last decade of July and the first half of August the rest of the year is under the influence of periglacial processes (Popescu, Ielenicz, 1981). Thus, glacial-nival processes are specific for the last decade of November, the whole December, January and February and the first two decades of March, while the dry gelival regime is common for the remaining intervals.

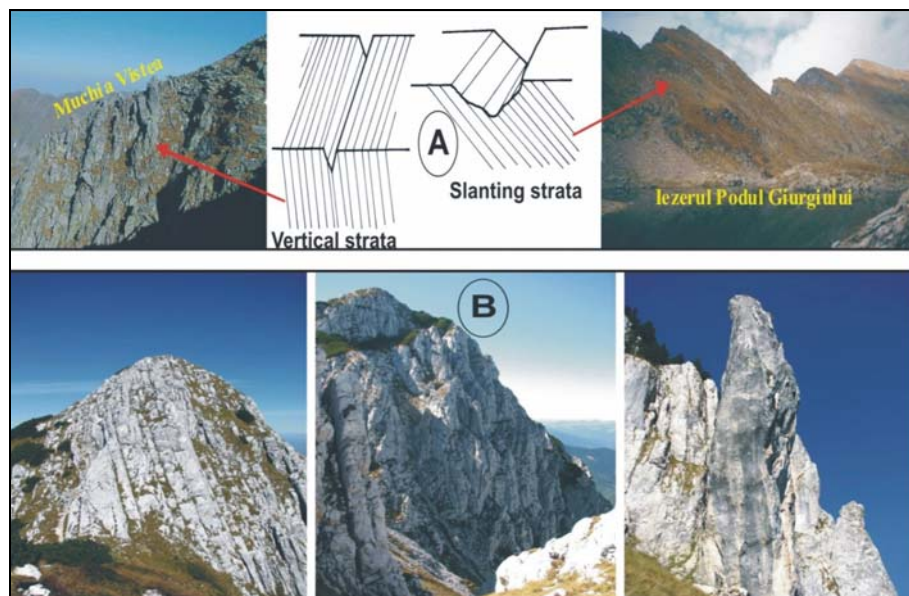


Figure 2 a, b Castellated relief in the Fagaras (a) and Piatra Craiului (b) mountains

3.1. The landforms created by freeze-thaw processes. The castellated relief is represented by prominent landforms (Figure 2 a, b) developed mainly in the area of gelival cirques, especially in the November-April interval or even until May. Beside the freeze-thaw action, the aeolization also plays an important part in their formation. These landforms can be grouped into two categories: on the one hand the periglacial edges, ridges and arêtes (Arpaselul Ridge, Vistea Edge, Padina Popii Edge, Trei Tancuri Edge, Sunny Edge) and on the other hand the crags and needles (Raiosului Crags, Crapaturii Needle, the Crag from the Pulpit, Goat Crag). An important part in the carving of landforms is played by the bedrock. Thus, in the Fagaras Mountains the gelival rocks (quartzitic micaschists, ocular gneisses, highly faulted and fissured crystalline limestones) and the steep grades of geological strata, brought to a vertical position within the main ridge, encourage the gelifraction processes (Nedelea, 2005). In the Piatra Craiului Mountains, the needles and crags show a considerable density on the western, northwestern and northern slopes, especially because of the stratigraphic differentiations and the vertical position of limestone strata (Constantinescu, 1994).

In the Fagaras Mts., *scree*s are found mainly inside the glacial cirques, at the base of steep slopes and retreat scarps. The most important scree deposits are lying at the base of the south-facing scarps (the side of the Arpaselului Ridge to the Fundul Caprei, where the scree is 980 m long), southeasterly-facing ones (the side of the Raioșului ridge to the Raioșu valley, where the scree is 1.3 km

long) and east-facing slopes (under the Lespezi peak, to the Caltun valley). These scree are made up of big angular blocks of micaschists and limestones detached through the widening of faults and joints. The deposits are organized in various forms (Figure 3 a): mobile scree, rock streams, specific for the sharp ridges that separate glacial cirques, as well as old and fossilized scree of periglacial origin. On the lands slanting $25 - 45^\circ$ scree particles move by rolling, while on steep slopes where declivity exceeds 45° they simply collapse. At gradients less than $30 - 35^\circ$, the scree begin to acquire a stable poise.

The scree in the Piatra Craiului massif (Figure 3 b) are spread on vast areas. They are made up especially of limestone fragments of various sizes. The most important alignment of such scree, which lies on the Western Side of the mountains, is 20 km long and develops on a northeast-southwest direction, between Piatra Mica and Pietricica. The maximum width of approximately 2 km is specific for the section lying between the Ursilor and Crapaturii valleys. Nearly 80% of these scree are stabilized by soils and vegetation. To the west, about 60% of the scree are loose and extremely active, especially in the area of the Marele Grohotis (*The Big Scree*) (Figure 4). As far as the Eastern Side is concerned, one can see a train of debris developed at the foot of the slopes underlain by limestones. This rests upon the conglomerates, being stabilized to a large extent by soils and vegetation. On the limestones lying at the base of the slopes debris cones develop, whereas along the valleys rock streams are present.

Figure 3 a, b Scree on the northeastern side of the Izvorul Caprei massif (a). Marele Grohotis (*The Big Scree*) in the Piatra Craiului Mts. (b)

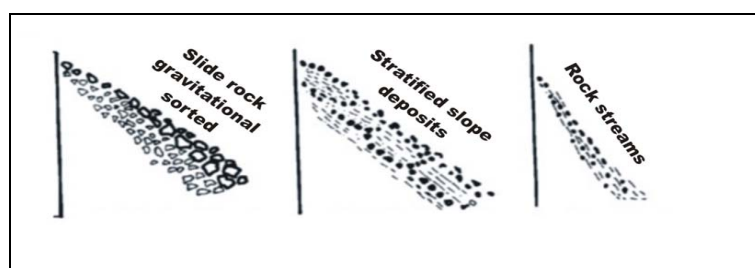


Figure 4 Mobile scree

The study of gelifractions has emphasized only the dynamics of surface deposits (Munteanu, 2009). On the eastern slope, gelifractions have a lower dynamics in comparison with the western slope, excepting the upper part of the talus cones and the gelifractions that have been carried away by avalanches. In the central part of the slope, one can notice approximately the same features, the only differences being represented by the extension of headwaters section, which increases from north to south, according to the development of the whole macroslope. The highest complexity and the biggest fragments are specific for the areas affected by transverse faults (Martoiu, Grind, Funduri). On the west, the areas occupied by Quaternary deposits are much more extensive, due to the presence of vertical strata that form the very steep and highly dissected calcareous monolith of the western flank of the syncline. The screes are longer, predominantly looking like rock streams along the valleys and talus cones at the base of the slopes. Their common feature is that they show a vast talus at the lithological contact. The differentiations that exist between the two macroslopes are conspicuous on the long profiles, too, which exhibit clearly different lengths and gradients of the transportation sectors: on the east they are long, with grades of approximately 30° , while on the west they are short and steep, with gradients higher than 45° .

One of the biggest scree accumulations on the northeastern side of the Piatra Craiului Mts. is the Hornul Gainii (*The Chicken Chimney*). In fact, these area shelters four main chimneys and several

secondary ones, which dissect the limestones. Around them rises the gelifractions detachment zone, for which the chimneys represent the transportation paths (Figure 5). Hornul Gainii is situated in the Curmătura catchment, at altitudes ranging from 1600 m to more than 1900 m. It stretches 300 m from east to west and another 200 m from north to south. The gradients range from 10° in the ridge area to 90° in the middle part, where calcareous slope lies. The scree deposit in the Hornul Gainii area covers $13,555 \text{ m}^2$, of which active screes occupy $4,800 \text{ m}^2$, the stabilized ones $8,500 \text{ m}^2$ and the semi-stabilized screes 155 m^2 (Munteanu, 2009).

The deposit, which develops at the base of the calcareous slope, is made up of rock fragments fallen from above. In fact, this is a talus cone, narrow in the upper part and growing larger downstream. Its narrowness in the upper part is explained by the presence of two calcareous edges that flank the scree deposit. Upstream of these edges there are several chimneys that shelter scree accumulations along their talwegs, which in the end join the talus slope lying downstream. The southern chimney (141 m long) is dominated by semi-stabilized talus slopes, while the northern one (51 m long from the top to the confluence) by active screes. However, both chimneys have gradients that average 45° . The active talus lies in the central part of the main cone. It has an elongated appearance, narrower in the upper part, wider in the middle, and narrow again to the base. Due to its high mobility, vegetation is absent.

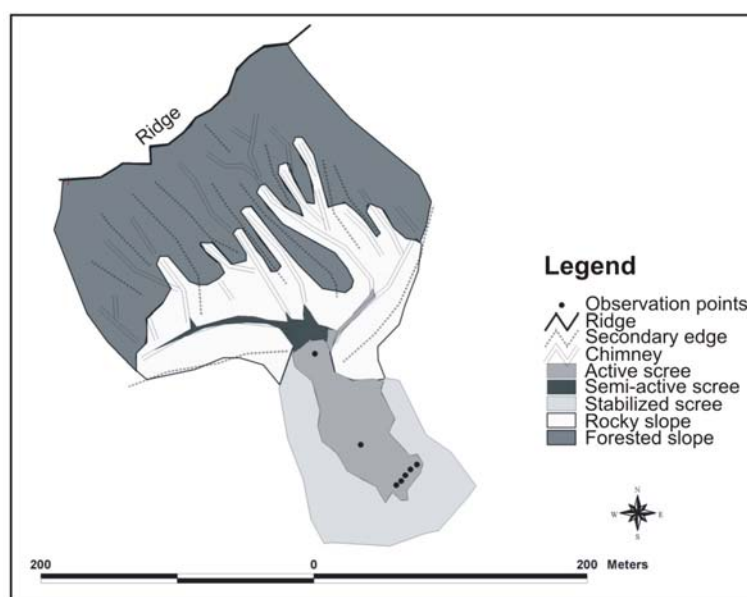


Figure 5 Scree distribution in the Hornul Gainii
(*The Chicken Chimney*)(Piatra Craiului Mts.)

Other periglacial microforms common for the two mountain massifs are the solifluction trails and earth hummocks. *Solifluction* occurs in the areas delimited by the annual isotherm of 3°C (usually lying above 1500 m altitude), on surfaces trending from 3° to more than 30° , which are underlain by thicker regolith and deeper soils. In the Capra and Buda catchments, such relief microforms are found above the tree line, generally on slopes with easterly, westerly and southerly aspect. *Earth hummocks* are circular mounds, 0.2 – 0.5 m high and 0.5 – 1 m in diameter. Their development is due to vertical displacement of soil by frost heaving (Figure 6), under wet and cold conditions that seasonally encourage ice formation. This seasonal ice deeply penetrates the earth hummocks and the lateral pressure of the ice combined with the existing vegetation (usually tufts of *Nardus stricta*) (Bălăceanu, 1970) exacerbates or maintains these forms from one year to another. In the Fagaras Mts., they are spread on the Paltinu plateau, the Naneasa and Raiosu – Museteica summits, the western side of the Vistea Mare – Moldoveanu peaks, as well as on Coastele Mt. and the eastern slopes of the Tarata, Corabia and Buda peaks (Nedelea, 2005). In the Piatra Craiului Mts. solifluction trails and earth hummocks can be seen on the southern slope of the Pietricica Ridge (Plaiul Nou, Plaiul Mic), in the glades lying along the syncline axis and on the southern slope of Piatra Mica (Munteanu, 2009). As far as the Fagaras Mts. are concerned, periglacial microforms also include striated soils (in the Orzaneaua Mare cirque) and patterned grounds (in the Raiosul and Orzaneaua Mare cirques).

3.2. The landforms created by snow action.

Nivation is defined as the complex action exerted by the snow on the surfaces on which it accumulates over a long period of time. Through its weight, the snow puts great pressure on the land and when begins to move will erode its surface. More than that, the platform or slope deposits will settle under the pressure exerted by the long stagnation of snow layer and, with the active contribution of dissolution processes, microdepressions, as well as nival niches and cirques, come into existence. Their

occurrence is encouraged by the previously existence of some negative microforms. The best conditions for the development of nivation processes are found on the shadow slopes (with northern and northeastern aspect), where snow can last longer, more often than not from year to year. The occurrence of snow avalanches is possible especially in the February-April interval, when snow layer thickness is significant and snow cohesion is weakened by the rising temperatures. All escarpments are scarred by avalanche chutes on which the snow persists until April or even longer (as in the case of the north-facing slopes). During the year, the action of avalanches alternates with torrential erosion.

Nival microdepressions develop at the base of gently inclined slopes, in talus deposits, saddles and torrential catchment areas or on interfluvial surfaces with low declivities. In the Fagaras Mountains such microforms have been spotted on the Borascu Platform (under the Ciocanul, Piscul Negru and Podragu ridges) and on the bottom of glacial cirques and troughs (Capra, Caltun, Paltinu, Izvorul Moldoveanu). *Nival niches* are placed both on slopes and within torrential catchment areas (which seasonally function as avalanche chutes) at elevations that usually exceed 1600 m. They come into existence due to the long stagnation of snow cover over the respective areas. Nival niches show steep slopes and bottoms frequently capped by mobile scree, which indicate the presence of gelivation processes and suggest the intensity of their action (Nedelea, Oprea et al., 2009). Such forms can be seen on the headwaters of some streams in the Fagaras Mts., such as the Izvorul Moldoveanu, Orzaneaua Mare and Orzaneaua Mica, Buda, Izvorul Podul Giurguiului and Fundul Caprei. In the Piatra Craiului Mts., one can see nival depressions lying at the confluence of several valleys, both on the western side (Hotarului, Sindrileriei, Padina lui Raie, Padina lui Calinet, Vladusca, Spirlea, Valcelul Urzicii) and on the eastern one (Padinele Frumoase, Padina Brusturetului, Martoiu, Vladusca, Grind). Likewise, the presence of avalanche chutes and deposits cannot pass unnoticed (Munteanu, 2009).



Figure 6 Frost heaving

4. Conclusions

The investigations undertaken in the Fagaras and Piatra Craiului mountains have led to several conclusions regarding the cryonival shaping system. Thus, slope instability is correlated with the gradient systems, climatic and lithological conditions and human impact. The maximum frequency of cryoclastic processes is reached above 1800 m altitude, where screes are very active. As far as the movement of snow masses is concerned, the prime role in the slope dynamics is played by wet snow avalanches. These begin in April on the sunny and semi-sunny slopes and in May on the shadow and semi-shadow ones. On the sunny slopes the avalanches are somewhat linked to the frequency of gelival cycles, while on the shadow

slopes they correlate with the pluviometric maximum. The high declivities of the rocky walls encourage both gelifraction processes and the accumulation of screes in the subalpine and even in the mountain levels.

Acknowledgements

This work was supported by the project: "Evaluation and Monitoring of Avalanche Risk in the Context of Mountain Environment Organising and Planning. Case Study – Fagaras and Piatra Craiului Mountains", financed by CNSIS, category IDEI, project manager Alexandru Nedelea. The contributions of the all author is the same.

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Planation surfaces in the Bistricioara catchment (Eastern Carpathians)

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Abstract: The study reveals the spatial distribution, the absolute and relative altitude, as well as the present state of conservation of five planation surfaces identified in the Bistricioara catchment (Eastern Carpathians). At the same time, we have attempted to draw a parallel between the absolute age of these planation surfaces and of the erosion levels in the study area, on the one hand, and the geochronological timescales proposed by other researchers (David, 1945; Posea, 2002) for areas lying closer to or farther from the Romanian Carpathians, on the other hand. It is important to say that these timescales also take into account the sequence of orogenic phases on the Romanian territory in the second half of the Mesozoic.

Keywords: Bistricioara catchment, planation surfaces, valley shoulders, spatial distribution, geochronological timescale

Rezumat. În studiu sunt redate distribuția spațială a celor cinci suprafețe de nivelare identificate în bazinul hidrografic Bistricioara (Carpații Orientali), altitudinea absolută și relativă la care acestea se desfășoară, gradul de conservare în care acestea se află în prezent. De asemenea, s-a încercat o paralelă între vârsta absolută a suprafețelor de nivelare și a nivelelor de eroziune de pe teritoriul analizat și schemele geocronologice încercate de alți cercetători (M. David, 1945, Gr. Posea, 2002) pentru zone mai apropiate sau mai îndepărtate din Carpații Românești, ținând cont și de succesiunea fazelor orogenetice de pe teritoriul României în a doua jumătate a Neozoicului.

1. Location and general data

The Bistricioara catchment lies in the central-northern part of the Eastern Carpathians and covers an area of 781.3 km².

The geological structure is dominated by old epi- and mesometamorphic crystalline rocks, which are found on 73.1% of the area. These are followed by Cretaceous flysch (sandstones, clay schists and marly limestones accounting for 13.5%), Pliocene sedimentary rocks (sands and clays amounting to 4.42%), Neogene volcanic rocks (especially andesites, with a share of 3.2%) and the Mesozoic sedimentary formations of the metamorphic unit (dolomites, sandstones and wildflysch, spread on 2.91% of the territory). As far as the present and Quaternary alluvial deposits are concerned these account for 2.8% of the area.

2. Planation surfaces

The careful analysis of topographic maps, geomorphologic profiles and panoramic photos, as well as the investigations conducted in the field have allowed us to separate in the catchment five planation surfaces and two valley shoulders, which

are shown on the geomorphologic units map (Fig. nr. 5).

In order to identify the planation surfaces we have used both figures and names, the latter borrowed from the areas where these surfaces are most conspicuous: S₁ (*Grintieșu Mare*, lying at 1650-1750 m), S₂ (*Harlagia*, 1500-1600 m), S₃ (*Făget-Mezovești*, 1200-1450 m), S₄ (*Malnaș-Dosu Cheosrezului*, 1000-1250 m) and S₅ (*Frasinul*, 850-1050 m altitude).

As for the valley erosion levels, these have been divided into two categories: the upper shoulders (140-250 m relative altitude) and the lower shoulders (80-130 m).

Our analysis reveals that the planation surfaces identified by us are closest to the model proposed by David (1949) for the Bistrita Mts.: *Poiana Ciungilor* surface, of Helvetian age, lying at 1500-1600 m, corresponding to S₂; *Băda* surface, of Sarmatian age, lying at 1300-1450 m, matching our third surface; *Dornelor*, of Pontian age, lying at 1150-1280 m, corresponding to S₄; and, particularly for the Borsec-Bilbor area, the Pliocene levels *Hazanez*, at 1150-1250 m, also corresponding to S₄, and *Verofeny*. The altitude of the latter has not been mentioned, but it has been credited with a large extension on a mountain ridge developing east of

Borsec. This erosion level, which tilts to the east and lies at 930-1050 m, corresponds to our fifth surface (S_5).

Beside the aforementioned surfaces one must also take into account the *Grințieșu Mare* surface, found only in the massif it was named after, at 1650-1750 m altitude. It corresponds, at least in terms of altimetry, to „ S_1 ” (equivalent to the „Borascu” surface in the Southern Carpathians), which, according to Posea (1997), cuts the Paleogene crystalline massifs except the Rodna Mts. at elevations of 1600-1800 m.

As far as the age of the mapped planation surfaces is concerned, for the moment we prefer to rely on the parallel made with the datings accomplished by David (1949) and Posea (1997).

The only places where we could venture to date a planation surface are the Văcăria Mts., lying north-northwest of Bilbor, and the northern and northwestern parts of Mount Șapte Izvoare, which is in the Borsecul de Sus area. As it results from geological map scale 1:200000 (Comitetul de Stat, Institutul Geologic, 1968), in the Văcăria Mts. the S_4 surface seems to cut the biotite, amphibole and pyroxene andesites, which belong to the Upper Pliocene, or, according to the map's authors, even to Lower Quaternary.

If the large quasi-horizontal surface that develops in the Văcăria Mts. between 1100 and 1260 m were the result of a leveling process, then the corresponding S_4 surface would seem to belong to Lower Post-Quaternary. However, this is hardly possible because during Quaternary Era the Carpathians witnessed the deepening and branching of the river systems to the detriment of the existing planation surfaces. Therefore, the issue is still debatable, at least until a geological map of scale greater than 1:50000 for the Bilbor area is published, which will make possible to decide whether the northern branch of the planation surface in the Văcăria Mts. was shaped on crystalline schists or on biotite, amphibole and pyroxene andesites.

If the surface were shaped on andesites, we would deal with a volcanic structural surface, but if it were shaped on crystalline schists then things get complicated. This happens because S_4 (developing on crystalline rocks, according to the geological map scale 1:200000) passes without any break of slope into the quasi-horizontal surface shaped on the biotite, amphibole and pyroxene andesites of the Văcăria Mts. This would mean that the respective level was cut after the andesite formation, i.e. in the Quaternary Era.

Another dating can be accomplished to the north of the Mount Șapte Izvoare, where the Pliocene molasse from the Borsecul de Sus, settled

during the Dacian period, fossilizes the S_5 surface, which should therefore be older. This is a very interesting thing in case we admit the Pontian age of the S_4 surface, according to the David's model (1949). Consequently, it would result that S_4 and S_5 were formed during the same interval (Pontian), which seems rather odd, and therefore it would be wiser to consider that S_4 must be a little bit older (for the time being its age has not been thoroughly established).

Grințieșu Mare surface (S_1) is found, as mentioned before, only in Mount Grințieșu Mare, at elevations of 1640-1750 m, having the appearance of long ridges that stem from Grințieșu Mare peak running to the west, southeast (with rougher relief) and north (quasi-horizontal and very expressive). Given the high altitude and the limited extension it is likely that S_1 (*Grințieșu Mare*) is a simple altiplanation step, which remains to explain later. If it were a planation surface, then, according to the scheme presented further, it was shaped in Oligocene-Aquitania.

Harlagia surface (S_2) appears only on the northern water divide of the Bistricioara catchment, in three places: the Harlagia, Bâta Verde and Stârca mountains. The greatest development, however, and the most conspicuous appearance are specific for the Harlagia summit, where its genesis through planation processes is undeniable. At this locality, it unfolds between 1500 and 1587 m, on a length of 4.7 km, having widths ranging from 150 to 700 m and a remarkable flatness – fig. nr. 1.

To the east, in Mount Bâta Verde, S_2 is also very expressive (a remarkable flatness), stretching along 2.5 km and having a width of 100-250 m, while in altitude it climbs from 1500 to 1611 m.

On the southwestern side of Mount Grințieșu Mare (Mount Stejei-Stârca) S_2 develops between 1580 and 1632 m altitude, keeping its remarkable flatness. Here, the length is 1.8 km, whereas the width ranges from 60 to 250 m.

In all the above cases, S_2 develops on crystalline schists.

In Mount Măgura (made up of calcareo-dolomitic rocks) one can see a small smooth area developing to the northeast of the Magura peak (1548 m) at 1500-1530 m altitude, slightly tilting from southwest to northeast. It is likely that this area were an altiplanation or a lithological surface. In Mount Comarnic (made up of limestones) one can notice a small plain (7.3 hectares) lying at elevations of 1500-1520 m. Here, too, it is possible to be in the presence of a lithological surface. Speaking of age, we might consider it Miocene and therefore most likely shaped between the Styrian (Burdigalian) and Moldavian (Sarmatian) uplifts.

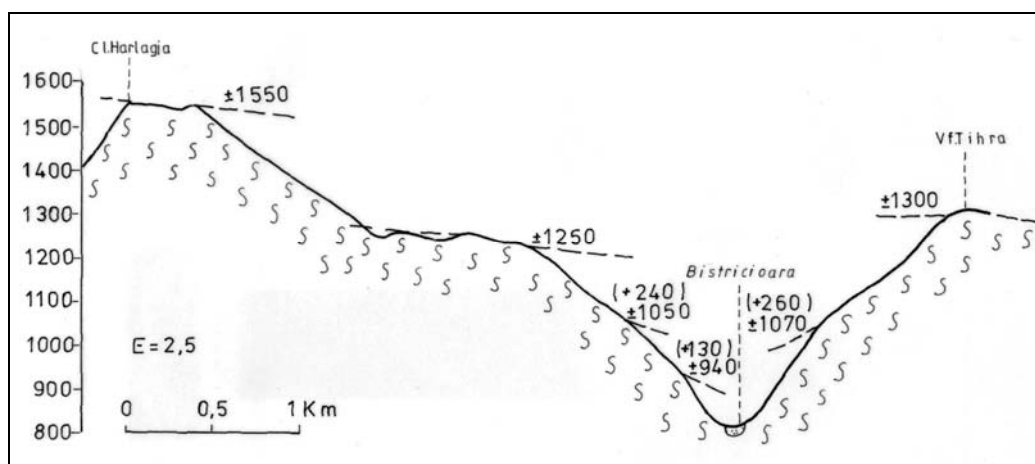


Fig. 1. Surfaces S_2 and S_3 in the Harlagia-Mezovești sector

Făget-Mezovești (S_3) surface knows the greatest development in the Bistricioara catchment, as it is also the case of S_4 (Malnaș-Dosu Cheosrezului). In many cases, it is the highest surface (towering over the surrounding areas), but sometimes it is dominated by other summits or peaks. The most typical development is in the Arcoza-Făget-Mezovești ridge, where it resembles a genuine water divide plateau, rising above the neighboring areas, and ranging in width from 250 to 650 m. In this massif, the surface climbs from 1160 m in southwest to 1337 m in the extreme north-northeast (Mezovești peak), probably due to the more accelerated neotectonic uplifts that affected the area.

This surface dominates other areas as well, such as Mount Alunișu Mare (from a height of 1420-1447 m), Mount Vamanu (from 1360-1418 m), and especially the ridge between Vamanu and Harlagia mountains (from 1260-1440 m), a place where it is wider than 1 km.

S_3 also appears as a dominant step in the following mountains: Mount Batca Arsurilor (calcareo-dolomitic), where it lies at 1340-1384 m, having a lithological character and exhibiting

similar features with the surface belonging to Mount Comarnic (uplifted plain); Mount Sitaru, where it lies at 1200-1317 m, developing on crystalline rocks; Preluca Ursului ridge (at 1320-1439 m), developing on the crystalline rocks and sienites that underlie the mountains situated at the headwaters of the Corbul and Rezul Mare rivers; Mount Cheosrezul Mare (at 1280-1491 m), particularly the ridge that branches off to the northeast and the mountain lying west of the Făgetel peak (1382 m), partly developed on sienites; Mount Făgetel and the ridges that stem from it to northeast and east, where the surface lying at 1180-1382 m has an extensive development especially to the east of Făgetel peak – fig. nr. 2; Piciorul Cuților (at 1200-1367 m); Muntele Nou-Vf. Deșelat ridge (at 1300-1482 m), lying exclusively on sienites and exhibiting an almost perfect flatness; Vf. Deșelat-Hedieș ridge (at 1380-1450 m); Șumuleu-Călugărul Mic interfluv (at 1220-1320 m); Mount Câmpul Bârsanului (east of Mount Făgetel), at 1220-1293 m, with a clear development (which explains the determinative *Câmpul*, meaning flat land); and Mount Cal (at 1220-1319 m), where the surface develops on Cretaceous sandstone flysch.



Fig. 2 – S_3 and S_4 in the area of Mount Făgetel

S₃ appears as a subordinate step (towered by ridges or peaks belonging or not to higher planation surfaces) in many areas, such as: Mount Piatra Lăptăriei (at 1230-1400 m), the secondary ridges that stem to the west from Mount Lupăria (at 1200-1280 m, with clear development), the ridges descending to the southeast from the eastern extremity of Mount Harlagia (at 1200-1370 m), some ridges branching off from Mount Vithavaş (at 1200-1380 m), the ridge that stems to the west from Harduga peak (at 1260-1300 m) cutting the Bistra strata (sandstone flysch), the Grinţiesu Mare–Preluca Dreptului summit (at 1340-1402 m), very conspicuous and developed on crystalline rocks and partly on porphiroide gneisses, etc.

The age of the third surface is probably post-Moldavian (post-Sarmatian), but surely younger than the Attic orogenic phase.

Malnaş - Dosu Cheosrezului surface (S₄) is well developed in the Bistricioara catchment and, as we have already seen, it is comparable in extent to S₃. Unlike S₃, however, it covers large areas in the flysch sector, too, but is seldom dominant. Such places where S₄ is dominant are the following: Preluca–Capu Corbului summit (Vin–Corbu interfluve), where the surface cuts the epimetamorphic crystalline rocks at 1120-1178 m altitude and shows distinctive features and a remarkable flatness; Corbu–Asod interfluve, where it is less conspicuous than in the previous case and develops at 1000-1187 m; Bărbântii peak area, where the surface lies at 1160-1263 m resembling rather an intervening ridge (even though the respective summits have an almost ideal degree of flatness); Văcăria Mts., situated north of Bilbor, where S₄ develops at 1060-1230 m on mesometamorphic crystalline rocks connecting farther with the large structural surface coming from the south, which is underlain by biotite, amphibole and pyroxene andesites; Piciorul

Bilborului (The Bilbor Spur), where the surface develops also on crystalline rocks, at about 1120-1169 m, being extremely flat and smooth; and Răchitiş summit, where the surface is 1100-1159 m high, being well developed on epimetamorphic crystalline rocks.

Otherwise, one can say that S₄ occurs as a subordinate altimetric level. It can be seen as valley shoulders at the Bistricioara headwaters, on the left of the stream (at 1200-1260 m), in the form of longer or shorter summits gently descending from Mount Harlagia to the southwest and south (having an expressive look on the left side of the Huruba), but staying at altitudes of 1220-1250 m (Fig. nr. 1).

S₄ appears as well in the extreme east of the Mezoveşti Ridge (at 1180-1268 m), being well developed and expressive, on the summit that separates Cupaş 1 and Cupaş 2 streams (at 1020-1099 m), where it is also very conspicuous, and on some short spurs that descend from the Arcoza-Făget summit to southeast (at 960-1180 m) – fig. nr. 3.

However, the clearest development of this planation surface is specific for the Malnaş–Dosu Cheosrezului summit (from which it derives its name), where it looks like a long (more than 3 km) and remarkably smooth table land, shaped entirely on epimetamorphic crystalline rocks, with widths ranging from 100 m to 1 km. The whole surface dips gently on a south–north direction from 1283 to 1080 m.

Between Corbu and Rezu Mare, S₄ occurs sporadically and on limited areas, except for the Asod–Putna interfluve (southeast of the Tulghes–Centru), where it looks typical and expressive, developing on mesometamorphic crystalline rocks at 1040-1173 m altitude.

S₄ is well developed on the Rezu Mare–Putna interfluve as well, cutting the crystalline rocks at 1120-1236 m, where it resembles a slightly rounded and long summit (called Culmea Putnei).



Fig. 3 – Planation surface complex in the Cupelor catchment

In the Putna's upper catchment (including the entire basin of the Putna Întunecoasă) S_4 appears at elevations ranging from 1100 to 1280 m in the form of headlands (or spurs), shaped in sienites on the southwest and in epi- and mesometamorphic crystalline rocks on the rest of the territory.

It can also be seen, having approximately the same features, on the spurs descending from Mount Vithavaş to the west, northwest and north, at 1070-1185 m altitude. North of the Şumuleu, it occurs in scattered and small-size patches lying at 1040-1140 m on the Şumuleu-Călugarul Mic interfluve and at 1000-1040 m on the Balaj-Marcu interfluve, as well as on the summits lying north of the Marcu. Throughout this area, it is very difficult to make a clear distinction between S_4 and S_5 , because the difference in elevation between the two is only several tens of meters.

The flatness of some spurs lying between 840 and 1000 m, which dip gently from east to west (towards the Putna) in the Marcu-Sumuleu sector, on the right side of the mentioned river, and from southeast to northwest in the region lying southwest of the Rezu Mare-Putna junction, allows us, however, to delimit the S_5 surface. As a matter of fact, it is found at rather similar elevations throughout the entire catchment.

S_4 also appears on the southeastern divide of the Pintec catchment and in the high extremity of the Piciorul Sandului, at 1040-1139 m, cutting the flysch formations represented by the Sinaia strata. Here, the features of a planation surface are more obvious, unlike the sector Obcina Târşoasei-Obcina Boiştei (shaped on the Sinaia strata, too), where, although it comes out in quasi-horizontal summits, those summits are in fact intervening ridges, which remind us of the so-called "lower lithological level" of the Ceahlau Mts. identified by Stănescu (1980). In the Obcinele Târşoasei and Boiştei the surface lies at 1060-1112 m in the surroundings of the Rotunda peak, and at 1100-1200 m, farther to the south (Obcina Târşoasei).

North of the Rotunda peak (1112 m), i.e. within the Obcina Boiştei, even though the summit is quasi-horizontal and long (hence the name of *obcina*) it cannot be considered a planation surface, but rather an intervening ridge (the so-called *gipfel* mentioned by Sârcu in 1958).

Between Muncelul and Valea Seacă S_4 appears as spurs, often highly inclined ($10-15^\circ$) and lying at an altitude of 1000-1200 m, which proves its advanced degree of degradation.

From Valea Seacă eastward (north of the Bistricioara), both in the Crystalline-Mesozoic and in the flysch domains, S_4 occurs (as it has been the

case with the previous sector) as small-size patches, lying at an altitude of 1000-1240 m. In this area, although it is dominated by peaks like Magura (1548 m) and Hurduga (1384), S_4 occupies in many cases the main interfluves, which are the highest in the flysch unit. Consequently, it is found at 1020-1200 m on Pietrele Vinete, Smida Grasului, Mount Răchitiş, Grinţieşu Mare-Grinţieşu Mic interfluve and the Măluşteţul summit, in the latter case being well developed (180-200 m wide and 1.35 km long).

As for the age of this surface we consider it post-Meotian, but no older than the Rhodanic phase (Romanian).

Frasinul surface (S_5) has a limited extension in comparison with S_3 and S_4 , developing pre-eminently in the flysch area, i.e. in the Pintec and Putna catchments, in the territory situated north of Borsec and, sporadically, on both sides of the Bistricioara, along the stretch between the Valea Seacă and Putna rivers.

S_5 has an almost ideal development (at an elevation of 880-948 m) on the interfluve lying upstream the Bistricioara-Pintec, a long (1.3 km) but narrow (80-120 m) crystalline summit, and also in the Pintec catchment (on Piciorul Sandului, at 900-1000 m). In the latter case, it cuts the Sinaia strata generating a tableland that continues upstream, passing through a slight break of slope into S_4 .

In the lower stretch of the Bistricioara catchment (downstream of the Pintec), S_5 occurs frequently as an erosion level (Posea, 1968; Ielenicz, 2004). This happens on Dealul Bradului (at 860-960 m), on Culmea Răchitiş (at 830-930 m), on Dealul Frasinul (at 850-940 m), on the right interfluve of the Pârâul Duruitorul (at 900-940 m), on the left interfluve of the same creek (at 820-940 m), and on the last eastern spur of the Bistricioara catchment, which descends from Culmea Măluşteţu (at 800-900 m) – fig. nr. 4.



Fig. 4 – Frasinul surface (S_5) on Dealul Bradului

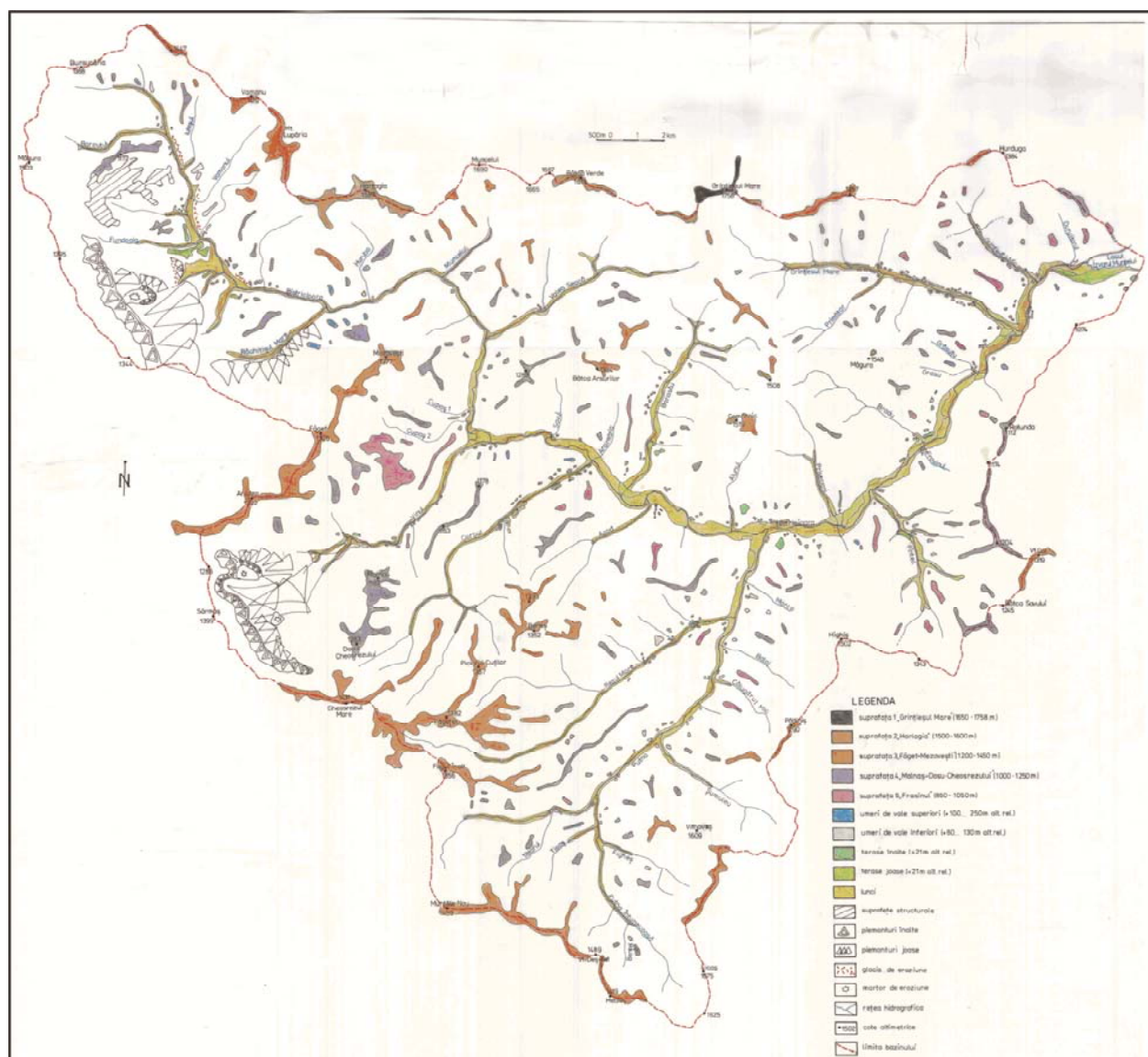


Fig. 5 – The Bistricioara catchment – Geomorphologic units map

In the first three cases, it has the appearance of gently inclined tablelands, which get slightly wider downstream (especially on Dealul Bradului and Dealul Frasinul). On Dealul Frasinul, it is better developed upstream, on a length of 1.3 km, getting increasingly narrow in the same direction. On the right interfluve of the Pârâu Duruitorul it takes the shape of a suspended bridge, remarkably smooth and flat, while in the last two cases it appears as relatively steep spurs ($10-20^\circ$), which descend from Culmea Măluștețu to the Bistricioara river.

In all these cases, S_5 makes the connection between the planation surfaces and the erosion shoulders, being itself in some areas a level of erosion shoulders (Posea, 1986; Ielenicz, 2004).

In our opinion, this surface was shaped during the interval between the Rhodanic and Wallachian orogenic phases.

The erosion shoulders (or valley shoulders) are an undeniable presence on most major valleys.

The geomorphologic units map shows only those shoulders that are clearly expressed in the landscape. Occasionally, we have experienced difficulties in separating the valley shoulders from the high terraces, as it has been the case with the terraces of 120-150 m and 200-240 m from Tulgheș-Centru. However, taking into account their morphology (well developed tops), we have decided to consider them terraces.

The valley shoulders in the study area can be grouped into two categories: the upper shoulders (designated by „ U_1 ” on the map), with a relative altitude of 140-250 m, and the lower shoulders („ U_2 ”), hanging at 80-130 m above the streams.

Most likely, the valley shoulders in the investigated area belong to Lower Quaternary.

3. Conclusions

The planation surfaces in the Bistricioara catchment are better developed in the western part of the territory. This is due to the generally hard metamorphic rocks, but mostly to the delay of erosion occurrence, which depends on the base level represented by the Bistrița River that flows in the extreme northeast. Of the five planation surfaces the most developed are S_3 (at 1200-1400 m) and S_4 (at 1000-1200 m). These can be seen in massifs such as Cheosrezul Mare-Făgetel, Arcoza-Făget-Mezovești, Harlagia-Vamanul, Muntele Nou-Vf. Deșelat etc., where they resemble large vaulted

domes. On the flysch formations on the east the best preserved surface is S_5 (Frasinul), lying at 800-900 m. Finally, the Bistricioara catchment shelters two levels of valley shoulders, at relative altitudes of 140-250 m and 80-130 m, respectively.

By drawing a parallel between the datings accomplished by other researchers and the sequence of orogenic phases of the last part of the Mesozoic, one can adopt the following timescale: S_1 – Oligocene–Aquitainian, S_2 – Miocene, S_3 – Meotian, S_4 – Upper Pliocene, S_5 – Villafranchian, while the valley shoulders belong to the Quaternary, which brings them closer to terraces.

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On periglacial processes and landforms in the Brodina River Basin (Obcinele Bucovinei)

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Abstract. Situated in the north-eastern part of the Eastern Carpathians, Obcinele Bucovinei are characterised by a strong parallelism of the main ridges, following a NW-SE direction, with altitudes decreasing from 1400-1500 m in the west to 800-900 in the east. Due to their altitude and localisation in the Romanian Northern Carpathians, the moulding of Obcinele Bucovinei started with the installation of glaciations by processes characteristic to permafrost. While dividing the periglacial units in the Pleistocene, Posea & coll. (1974) include the most part of the Mountains Obcinele Bucovinei in the north-central periglacial province, the Carpathian region, the detritic periglacial layer and the crionival sublayer (between 700 and 1500 metres), while the high segment of the mountain Obcina Mestecăniș (up to 1500 metres) belongs to the nivo-cryogenic sublayer. Dividing among regional morphogenetic periglacial *Würmian* units Ichim (1983) situates the same mountains in the *Carpathian periglacial domain*, where he identifies two altitudinal levels: the level of cryoplanation and intense weathering (above 1000 metres) and the level of solifluctions (600-1000 metres). Morphogenetically speaking, the periglacial area is characterised by a series of specific phenomena and processes determined by various agents such as gravitation, surface runoff water and groundwater, snow and wind. These are closely related to the characteristics of the thermal regime. The main processes typical to the periglacial morphology are: freeze-thaw cycles, nivation, eolisation, and, subsequently, gelifluviation. Thus, the alternation between glacial stadial and interstadial periods alternately placed the mountains Obcinele Bucovinei in the zone of either the continuous or discontinuous permafrost. In the cold stadial periods, the dominant processes gelifraction and nivation generated large debris slopes, residual peaks and wind generated microforms. The transition to the interstadial periods is morphologically marked by the intensification of solifluidal processes and torrent erosion. The specific landforms resulted from such processes are: residual forms (ridges, cliffs), debris deposits, rhythmically stratified slope waste deposits, altoplanation terraces, solifluctions, nival niches, eologlyptolites etc.

The Brodina River is the main right-side tributary of the superior segment of the Suceava river. It is 31 kilometres long and its basin is 153 km². Geostructurally speaking, the catchment completely covers the external flysh, in the west, the Audia Thrust Sheet for about 48 km², and the central and eastern part the Tarcău Thrust Sheet, for about 103 km². The lithologic variety characteristic to the flysh is reflected in the different reaction to the action of periglacial processes. Therefore, petrographic areas rich in marlstone and clay were mainly affected by eluvial and solifluidal processes while gelifraction was a process specific to areas dominated by limestone, sandstones and conglomerates. Periglacial processes and phenomena generated in the morphology of the river catchment both periglacial deposits – debris deposits, some of them still active (on the Vejul Mare – Hrebeni Ridge), solifluidal deposits (the periglacial deposit identified upstream from the Brodina-Ehrește junction), involutions, and erosive landforms – residual ridges (Vejul Mare), slopes and terraces of cryoplanation, eologlyptolites.

Key words: periglacial, frost-heaving, involution, cryoplanation, eologlyptolite

Rezumat. Asupra unor procese și forme periglaciare în bazinul hidrografic Brodina (Obcinele Bucovinei). Situate în nord-estul Carpaților Orientali, Obcinele Bucovinei se caracterizează printr-un accentuat paralelism al culmilor principale, orientate NV-SE, cu altitudini ce scad de la vest (1400-1500 m) la est (800-900m). Prin altitudinile sale și localizarea în nordul Carpaților românești Obcinele au fost modelate odată cu instalarea glaciațiunilor prin procese caracteristice permafrostului. În regionarea unităților periglaciare Pleistocene Posea și colab. (1974) situează aproape integral Obcinele Bucovinei în *provincia periglaciara central-nordică, regiunea carpatică, etajul periglaciara detritic, subetajul crionival* (700-1500m), doar partea înaltă din Obcina Mestecăniș fiind încadrată *subetajului nivo-criogen* (>1500m). Ichim (1983) într-o regionare a unităților morfogenetice periglaciare wurmiene din România, situează aceleași Obcine în *domeniul periglaciara carpatic*, în care identifică altitudinal două etaje: etajul crioplaneției și al dezagregărilor intense (peste 1000 m alt.) și etajul solifluxiunilor (600-1000 m). Din punct de vedere morfogenetic periglaciara este caracterizat de o serie de procese și fenomene specifice, determinate de diverși agenți – gravitația, apa de șiroire și infiltrație, zăpadă, vânt. Aceștia evoluează strâns dependent de caracteristicile regimului termic. Principalele procese ce se caracterizează morfologia periglaciara sunt: ciclurile gelive, nivația, eolizația și secundar gelifluviația. Astfel alternanța stadialelor și interstadialelor glaciare plasau periodic Obcinele Bucovinei când în zona permafrostului continuu când în cea a celui discontinuu. În răcirile stadiale procesele dominante, gelifracția și nivația, au generat marile

pânze de grohotișuri care acoperă versanții, martori și microforme eoliene. Trecerea către interstadiale este marcată morfologic de intensificarea proceselor solifluidale și a celor de eroziune torențială. Formele specifice sunt: formele reziduale (creste, țăncuri etc.), grohotișurile, depozitele de versant ritmic stratificate, terasele de altiplanație, solifluxiunile, nișele nivale, eoliglotoliții etc.

Râul Brodina este principalul afluent de dreapta al Sucevei superioare. Are o lungime de circa 31 km și se dezvoltă pe o suprafață bazinală de peste 153 km². Geostructural, bazinul se suprapune în întregime flîșului extern, la vest pe Pânza de Audia (cca 48 kmp), iar partea centrală și estică pe Pânza de Tarcău (cca 103 kmp). Varietatea litologică specifică flîșului se reflectă în comportamentul diferit al acestora la acțiunea proceselor periglaciare. Astfel arilor petrografice preponderent marnoase și argiloase le-au fost specifice procesele eluviale și solifluidale, iar celor dominate de gresii, calcare și conglomerate procesele de gelifracție. Procesele și fenomenele periglaciare au generat în morfologia bazinului atât depozite periglaciare – grohotișuri, unele chiar active (Culmea Veju Mare – Hrebeni), depozite solifluidale (depozitul periglaciare identificat amonte de confluența Brodina-Ehrește), involuții, cât și forme distructiv-erozive – creste reziduale (Veju Mare), versanți și terase de crioplaneție, marmite de eolizație (eoliglotoliți).

Cuvinte cheie: periglaciare, elevație periglaciară, involuție, crioplaneție, eoliglotoliți

Introduction

Situated in the north-eastern part of the Eastern Carpathians the mountains Obcinele Bucovinei are characterised by a strong parallelism of the main ridges, following a NW-SE direction, with altitudes decreasing from 1400-1500 m in the west to 800-900, in the east. The glaciations determined by the Quaternary temperature decrease resulted in the extension of the ice sheet towards lower latitudes. In the Carpathians, mountain glaciers appear and grow above 1800 m. Practically, above the snowline and the limit of frost action phenomena and under the altitude of 1800 metres can be identified the conditions of periglacial moulding, mainly by processes related to gelivation and also, especially under the snow line, by processes of nivation, solifluction and eolisation. These work on a permanently frozen layer, the permafrost. The term was introduced by Muller in 1943 and it is an abbreviation of the expression *permanently frozen*.

By their altitude and localisation in the Romanian Northern Carpathians, the moulding of Obcinele Bucovinei started with the installation of glaciations by processes characteristic to permafrost.

While dividing the periglacial units in the Pleistocene, Posea & coll. (1974) included the most part of the Mountains Obcinele Bucovinei in the north-central periglacial province, the Carpathian region, the detritic periglacial layer and the crinival sublayer (between 700 and 1500 metres), while the high segment of the mountain Obcina Mestecăniș (up to 1500 metres) was included to the nivo-cryogenic sublayer. The authors consider gelifraction as the dominant process in the moulding of landforms. As a consequence, especially in the case of frost shattering rocks (sandstone, limestone and magmatic rocks),

downslope and at the bottom of the mountains will be found large debris deposits and important eluvial materials covers on horizontal and sub-horizontal surfaces. The other processes are also present but they are of secondary importance.

Dividing among regional morphogenetic periglacial *Würmian* units, Ichim (1983) placed the same mountains in the *Carpathian periglacial domain*, where he identifies two altitudinal levels: the level of cryoplanation and intense weathering (above 1000 metres) and the level of solifluctions (600-1000 metres).

Morphogenetically speaking, the periglacial area is characterised by a series of specific phenomena and processes determined by various agents such as gravitation, surface runoff water, groundwater, snow and wind. These are closely related to the characteristics of the thermal regime. The main processes typical to the periglacial morphology are: freeze-thaw cycles, nivation, eolisation, and, secondarily, gelifluviation. The specific land forms resulted from such processes are: residual forms (ridges, cliffs), debris, rhythmically stratified slope waste deposits, altiplanation terraces, solifluctions, nival niches, eoliglotolites, etc.

The identification of landforms that can be attributed to the periglacial morphogenesis in the Brodina hydrographic river catchment completes the image of the complex pleistocene moulding of the Obcine. The eolisation and the erosion, the elevation and the vertical separation of gelifracsts, the cryoplanation and the results of its action, periglacial deposits and structures are all proofs of a morphology that has been poorly exemplified in the geomorphological literature attributed to this mountain unity.

Aspects of the periglacial morphogenesis and morphology in the north-eastern part of the Eastern Carpathians

The identification and characterisation of the various periglacial landforms is made by Donisă, 1968 (Bistrița Valley), Barbu, 1976 (Obcinele Bucovinei), Ichim, 1979 (The Stânișoara Mountains) and Rusu, 2002 (The Rarău Massif).

According to his research, Ichim asserted that in the Eastern Carpathians the periglacial morphology is represented by deposits, structures and landforms resulted from the dynamics of various specific processes. He also identified the main periglacial processes that moulded the lower mountains in the Pleistocene, gelifraction and solifluctions, but he does not dismiss the effects of nivation and cryoplanation. He classified the discovered periglacial deposits according to J. Dylik's opinion, in either erosive or weathering, the first type including debris, solifluction deposits and rhythmically stratified deposits while the second category includes periglacial eluvial deposits.

Debris deposits cover the slopes to altitudes lower than 1000 metres, their formation depending on the structure and extension of flyschoid gelive rocks as sandstones, limestones and conglomerates under the impact of freeze-thaw cycles. These are now fossilized and fixed by vegetation. There are also forms of moving debris deposits determined by the morphometrical features of the relief (slope, energy etc.) and lack of vegetation.

Solifluidal deposits are frequent on slopes, below the 1000 metres level. These are difficult to identify in the landscape and are sometimes revealed by lateral erosive fluvial processes that bring to daylight soil slip mounds 10-15 metres in length and up to four metres thick. Some were described by Ichim in the proluvial cones and the terraces of the hydrographic network of Stânișoara Mountains and by Donisă in the terraces of the river Bistrița, in the mountain area.

Rhythmically stratified slope deposits are successions of alternate structures that point out different conditions of the periglacial morphogenesis. These deposits are made of bigger gelifractions separated by horizons of smaller gelifractions and horizons of sand and clay. Such deposits are identified on the Bistrița Valley at Roseni (Donisă, 1968) and on the valleys of the streams Negrileasa, Voroneț and Sălătruc in the Stânișoara Mountains.

Periglacial eluvial deposits were formed in interfluvial areas but also appear on gentler slopes. Are constituted of fine deposits but also sometimes by coarse deposits, strictly dependent on lithology.

I. Ichim (1979) notes in Stânișoara Mountains the dependence of the granulometric structure by the slope and by the petrographic typology.

Periglacial structures include cryostatic structures and periglacial ice wedges.

Cryoturbations or periglacial involutions are isolated deformed structures occurring in the deposit layers as a result of thermal changes. These are present both in terrace deposits and in solifluidal slope deposits. I. Ichim exemplifies these microforms for the mentioned deposits on the Largu, Cucalea, Cracău Vallies in Stânișoara Mountains.

Ice wedges are less mentioned, slightly atypical structures that could be the consequence of a deformation of superior layers rather than the result of ice intrusion into the bedrock or into other deposits. The author signals such a possible structure in the influx point of the Rotaru creek in the Izvorul Muntelui lake.

The landforms resulted from the action of periglacial processes are among the most important topics in geomorphological research. *Gelifraction* is mainly revealed by sedimentary deposits, like debris, but above 1000 metres residual landforms can also occur (Barbu N., 1976) – sharp ridges (narrow peaks), tower or needle-like shaped peaks, pyramidal peaks etc.

Solifluctions generated various landforms, like solifluction glacises, valleys and slopes. This process was facilitated by certain slope gradients and by the thickness of the layer exposed to the cyclic action of a thermal fluctuating regime. The most frequent forms of patterned ground are circles and solifluction lobes; sheets are less frequent, the only form of this kind being identified by Ichim (1970) on the Sălătruc valley.

Nivation occurred secondarily in the North-Eastern Carpathians above 1000-1200 metres, altitudes that marked the lower limit of perennial snows (Péwé, cited by Ichim, 1979). The result of nivation are nival hollows with their lower limit is represented by stripes resulted by debris accumulation. I. Ichim identified such landforms on the Țiflea Mountain, in the Fărcașa riverbasin (The Stânișoara Mountains), above 1500 metres. Rusu considers that *nival hollows* are not representative for the Rarău Mountain but he doesn't reject the possibility that some smaller sinks in the eastern part of the plateau and north-east of Piatra Zimbrului, should have periglacial origin.

Cryoplanation or altiplanation is a complex process that combines gelifraction, nivation and frost creep and generates the terraces of altiplanation. These are gently inclined surfaces that occur on mountain tops or on the upper part of

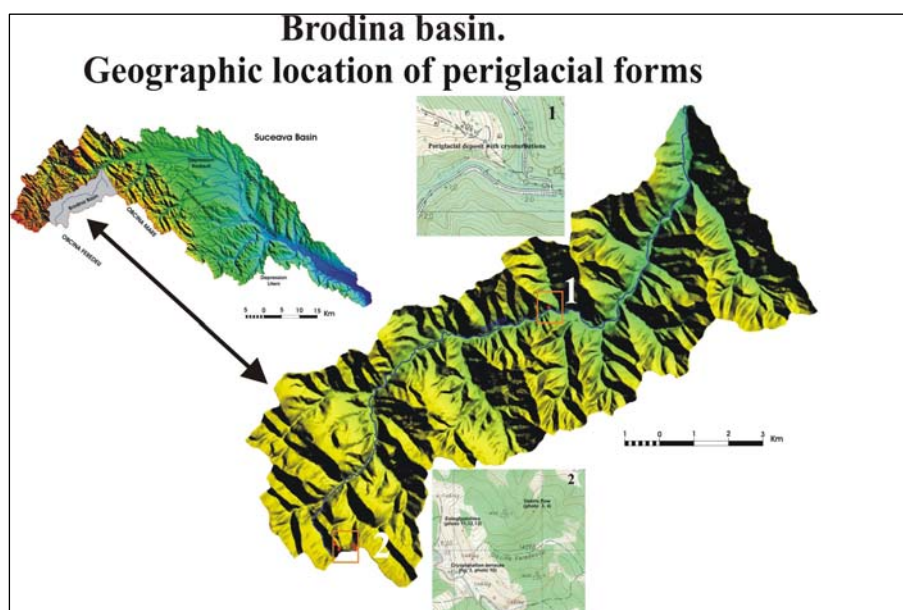


Fig. 1. The geographic position of the Brodina river basin and location of periglacial forms

mountain slopes as a result of the above mentioned processes. Such forms were also identified and described by Ichim (1973) in the Stânișoara Mountains (Ostra, Hăcigosu, Migovan) at about 1400-1500 metres, after they had previously been mapped and described in the Rodna Mountains (Morariu, 1940) and in the Călimani Mountains (Ichim, 1972).

Eolization or wind erosion, created microforms such as small wind hollows in rock, named by I. Ichim – eologlyptolites. In the Stânișoara Mountains he identified a series of such forms that can have up to 80-90 centimetres in diameter. Hollows that are less than 10-15 centimetres wide and up to 5-8 centimetres deep are the most frequent. He also indicates the presence of some rills, considered to be the result of both eolization and surface runoff.

Presentation of the studied area and of the work method

The Brodina River is the main right-side tributary of the superior segment of the Suceava river. It is 31 kilometres long and its catchment is 153 km². Geostructurally speaking, the catchment completely covers the external flysch, in the west, the Audia Thrust Sheet for about 48 km², and the central and eastern part the Tarcău Thrust Sheet, for another 103 km². The characteristic lithology for the flysch is made of a rhythmic alternance of conglomerates, sandstones, clay and marl arranged in a structure whose complexity grows towards east. From a

structural point of view, the Audia Thrust Sheet transgresses the Tarcău Thrust Sheet in a large overthrust.

The structural and lithologic details give a special note to the landform. One can see an obvious parallelism of the peaks oriented prevalingly towards NW-SE. This feature determines in Brodina valley a succession of narrowing and depression sectors grafted on hard and erosive rocks. The minimal altitude is located at the junction with Suceava, almost 580 m, and the maximal altitudes are located in SW of the superior basin on the hard horizons of the quartz-feldspatic stone of Tomnatic-Prisaca: Vejul Mare (1494 m), Vejul Mic (1421 m), Feredeul (1429 m), Hrebeni (1406 m)

In what climate is concerned, the studied area belongs to the continental moderate climate of medium and low mountains having east influences of the excessive continental climate west influences of the humid continental climate and north-west Baltic influences. The thermic values decrease according to altitude from about 6° on the bottom of the valleys to 2° on the highs of over 1300 m. The rain fall increase according to altitude. The empirically determined values according to an algorithm made by Apostol L. and his co-workers (1985) vary between 800 mm on the bottom of the valley and 1100 mm / year at over 1400 m. In the warm season occur 70 – 75% of rain, a fact reflected in water run-off. The river flow stands at an average value of about 1,85 mc/s, that indicates a liquid flow of about 13 l/s/kmp. The turbidity stands

at low values explained by the lithologic characteristics and by the structure of the land use. According to the data offered by the Corine Land Cover 2000 European programme, the hydrographic basin is covered about 79% by natural vegetation (coniferous, mixt woods, bush areas, secondary pastures). About 20% are agriculture lands, spontaneous vegetation and only 1 % bould area and complex cultures. The forest prevalence in Brodina hydrographic basin (71%) covering even the highest peaks makes somehow difficult the identification and the observation of the periglacial landform features mainly fossilized by the vegetation emerged at the beginning of Holocene.

The recognized forms attributed to the periglacial morphology appear on maps and are expeditively measured. Fix landmarks are placed on the debris deposits for the purpose of the actual dynamics display.

Periglacial elements in the Brodina River Basin

In a study regarding the mountains Obcinele Bucovinei, Barbu (1976) discussed the morphogenetic conditions of the Pleistocene periglacial period, considered to have an important role for the actual morphology. He considers gelifraction and solifluction as the most important of the dominant slope shaping processes. According to him, mountain slopes evolved towards a decrease in altitude (a process similar to the mechanism of peneplanation) and disagrees with the regressive and parallel retreat of the slopes theory (the mechanism of pedimentation). The periods with periglacial conditions were dominated by slope processes, while the interperiglacial was characterised by an increased hydrologic competence of rivers that evacuated the sediments accumulated on the valley floors. Taking into consideration the idea of alternative processes, Barbu believes it is highly unlikely that the deposits

of the first periglacial morphogenesis should have remained unaltered, with the possible exception of some accumulations in some Prewürmian terrace deposits. In consequence, considers that slope deposits and debris belong to the transition period from the Würm to the Holocene.

He admits the existence of different types of periglacial deposits and, for the residual landforms, he exemplifies the gelifraction moulded peaks – Creasta Vejului, Creasta Hrebenilor, Creasta Huțanului, Obcina Mare, cone-shaped or pyramidal peaks (Lucina, Tatarca, Tâmpa, Feredeul etc.). He also admits the existence of ruiniform elements – Piatra Fuscului, Piatra Vânăță, does not locate other periglacial landforms, but he does not exclude that they may exist.

Same author admits the existence various types of periglacial deposits and gives examples of residual ridges moulded by gelifraction: Vejului Ridge, Hrebenilor Ridge, Huțanului Ridge, Obcina Mare Ridge and also mentioned some examples of residual peaks such as Piatra Fuscului and Piatra Vânăță. He does not identify other periglacial landforms but he does not exclude the possibility that such forms should exist. The lithologic variety characteristic to the flysh is reflected in the different reaction to the action of periglacial processes. Therefore areas rich in marls and clay were mainly affected by eluvial and solifluidal processes while gelifraction was a process specific to areas dominated by limestone, sandstone and conglomerates.

Periglacial deposits. In the Brodina River catchment debris deposits are to a large extent fossilised and fixed by vegetation.

These can consist either of large blocks as can be seen above Poiana Solovan, at the upper part of the Hepa Mountain or of smaller size gelifractions (10-20 centimetres), similar to those from the northern side of the Veju Mare Ridge. (Photo 1, 2).



Photo 1, 2.
Debris flow and
terraces in the
body of gelifractions

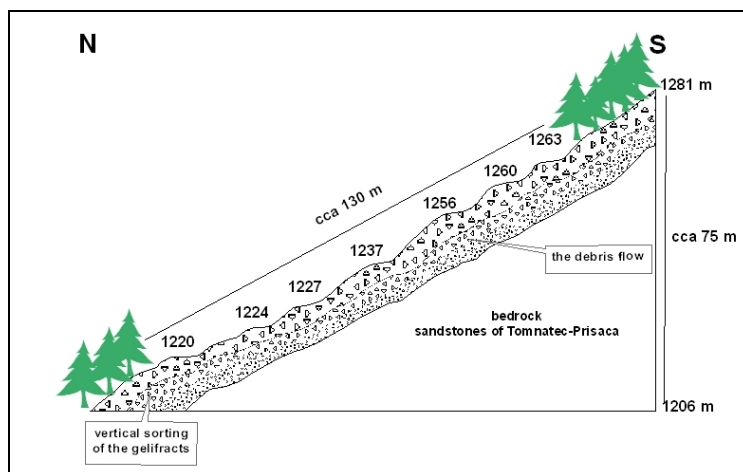


Fig. 2 Cross-section. The debris flow on the northern slope of the Vehu Mare Ridge

Morphometric and morphological observations on the debris flow that covers the northern slopes of the Vejul Mare Ridge revealed a succession of small terraces up to 0.6-0.8 metres wide (fig. 2), that were about 130 metres long at a level difference of about 75 metres. The analysed debris surface is at an altitude mainly between 1200-1290 metres.

The succession of these small terraces seems interesting. Genetically speaking, they could be associated with the rock creep, a process similar to the river flow that generates a succession of riffles and pools along the riverbed. We can't also exclude the biogenic origin of such terraces, given their similarity to the more frequent *pied du vache*. The terraces were marked with the purpose of periodic survey in order to identify the genetic process.

If we consider the position of the gelifraacts on a vertical profile (photo 3, 4), their vertical sorting becomes evident, consequence of frost-heaving. Bigger size gelifraacts are thus pushed upwards due to the larger area exposed to the action of interstitial ice formed during numerous annual or even daily cycles. It is possible that these periglacial processes, frost – heaving and frost – thrusting, should also be active today.

Upstream from the junction of the rivers Brodina and Ehrește, at an altitude of about 750 metres, in the sediments of the 6-8 metres high terrace was identified a periglacial deposit that might cover an area of about 35 metres. This structure could not be observed on its entire length; an area of only 2 metres wide on the entire height of the profile was accessible for analysis (photo 5, 6).

Photo 3, 4.
Vertical sorting
of the gelifraacts



Photo 5, 6.
The identification
of the terrace
profile and its
uncovering

We could thus notice a series of layers of sand and clay whose color and content suggest their sedimentation occurred in different morphogenetical conditions. (Photo 7).

Some layers contain centimetric angular rock elements that are indicative of slope transport. These are, most probably, colluvial solifluidal deposits subjected further to cryoturbation processes.

In the successive structure of the layers one can observe small folds that can be associated with some cryostructures – involutions, and also small lenticular structures (Photo 8, 9).

Despite the few available profiles, the presence of the periglacial deposits in Obcinele Bucovinei is obvious. By comparison, residual forms are less evident, barely identifiable.

The process of cryoplanation is a debatable subject among the authors that studied the periglacial landforms in the Eastern Carpathians. In a study on the periglacial in the Călimani Massif, Ichim (1972) identified such landforms in the area

of the Rețiș, Negoii Ungureșc – Pietrosul Peaks and in the area of the Drăguș Plateau. Morphologically speaking the terraces of altiplanation are small plateaus delimited by escarpments or small scree slopes of 2-8 metres. The presence of debris both on the top and at the bottom of the scarps suggests a parallel retreat of the slope due to gelifraction processes. In Călimani this process was favoured by lithologic and structural characteristics – the alternation of andesitic lava with volcanic agglomerates.

Towards the Brodina River's springs, on the right (Western) side of the Bursucul stream (the western end of the Vejul Mare, 1493m – Obcina Feredeului 1429 m Ridge), a series of residual peaks – and small terraces can be interpreted as results of the process of cryoplanation (Fig. 3, Photo 10). In the profile curvature of the slope one can identify two steps marked by two residual heights delimited by 3-4 metre scarps at the bottom of which occur grass-covered gelifracts.

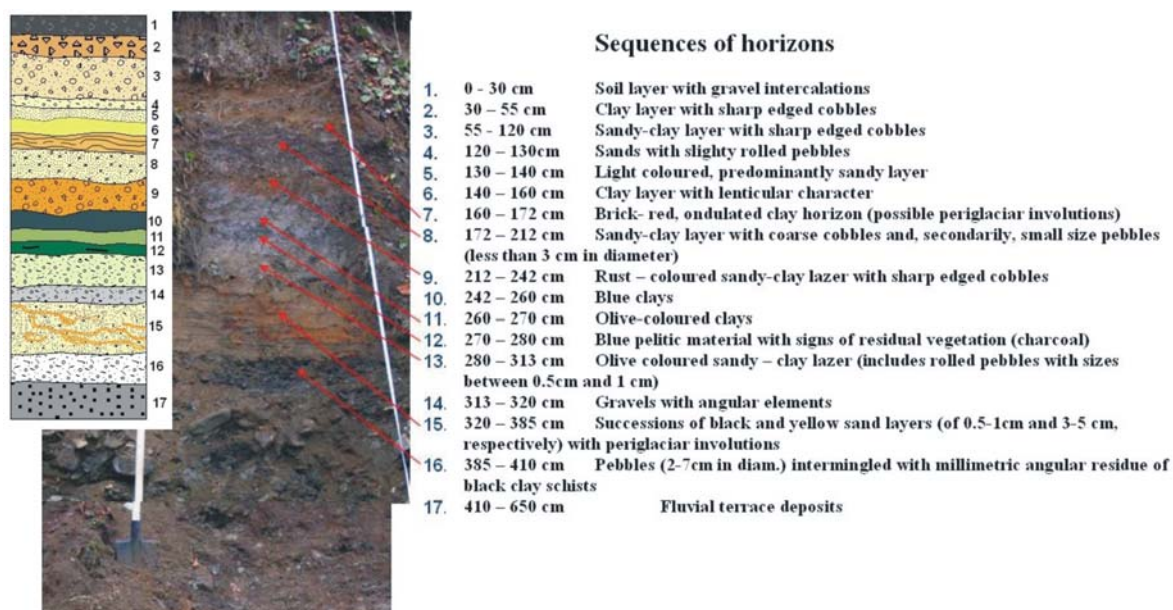


Photo 7. Display and petrographic characteristics of the periglacial structure



Photo 8, 9 Cryoturbations and lenticular structures

Their altitude is about 1343m and 1349 m respectively. From a structural point of view, the peaks are made of silicate sandstones and look like small cuestas, the scarp retraction occurring at the end of the rock bed. The length of the horizontal surfaces varies between 30 - 40 metres at the lower step and 80-100 m at the upper one. The height of the escarpments is of about 10-20 meters and it decreases towards the extremities.

Eolisation is a periglacial process during which the wind, charged with ice crystals, polishes rocks and isolated cliffs, creating erosion microforms named deflation hollows or eologlyptolites (term used by Ichim, 1972). Such microforms were identified on the western sides of some gelifraction affected residual peaks, situated at about 1300 m altitude.

Our identified deflation hollows are 20-25 cm in diameter and 4-8 cm deep (Photo 11, 12, 13), some of them being slightly asymmetrical possibly as a result of turbionary air movement. Asymmetry might also be explained by the different gradients of the surfaces subjected to wind erosion.

Their place of formation may be most likely the expression of the dominant winds during periglacial moulding and this confirms the general opinion

according to which winds had mainly a westward movement.

Conclusions

Placed during the Quaternary glaciations in the periglacial morphogenetic domain, the Obcinele Bucovinei Mountains preserve various forms of this morphology. The specificity of spatial distribution of periglacial processes is determined by structural and lithologic characteristics of the flysch deposits. The dominant processes such as gelifraction and solifluctions are distributed according to the rock characteristics. Gelifraction and its correspondent landforms such as debris covered slopes, residual ridges and peaks, terraces of altiplanation, occur mainly on sandstones, limestones and conglomerates. Solifluidal processes affected mostly areas with marls and clays, morphologically resulting in periglacial deposits. Nivation, eolisation and gelifluviation played a secondary part but the presence of their corresponding landforms confirms the diversity of the periglacial morphology in these mountains. We hereby consider that the Brodina River's hydrographic basin offers suggestive and conclusive examples.

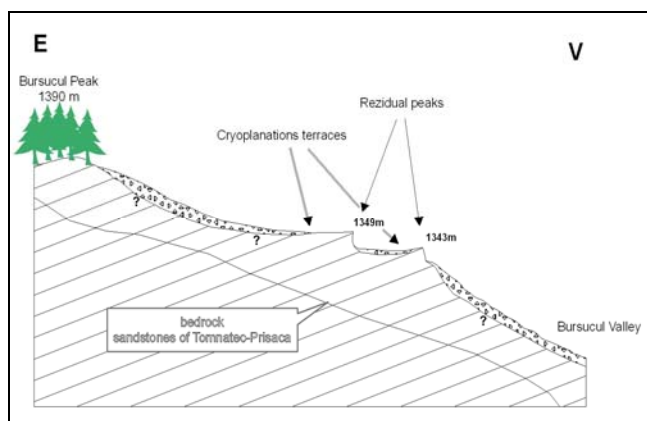


Fig. 3, Photo 10 Cryoplanation terraces



Foto 11,12,13 Eologlyptolite

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The Role of the Periglacial Processes in the Present Morphodynamics of the Doamnei River Basin (the Făgăraș Mountains)

Smaranda SIMONI

Rolul proceselor periglaciare în morfodinamica actuală în bazinul superior al Râului Doamnei (Munții Făgăraș).

Procesele periglaciare (sau crionivale, în funcție de accepțiunea diferită a acestor termeni) dețin rolul principal în dinamica actuală a reliefului situat deasupra limitei superioare a pădurii (1780 m). Dacă luăm în considerare izoterma de 3°C, ca limită inferioară de manifestare a fenomenelor periglaciare (French, 1996), relieful situat la peste 1800m altitudine în bazinul Râului Doamnei (adică 94 kmp) este modelat de procese periglaciare. Acestea se suprapun și continuă la scară mai mică procesele și formele periglaciare mai vechi, pleistocene și postglaciare, se îmbină sau alternează sezonier cu procesele fluviale, torențiale, gravitaționale, eoliene etc.

Procesele periglaciare sunt determinate de climatul rece, aspru și umed specific zonei înalte a Munților Făgăraș și influențate de o serie de alți factori (litologia, structura, panta și expoziția versanților, depozitele superficiale, solurile, vegetația), rezultând astfel un sistem complex de modelare actuală a reliefului situat la altitudini ce depășesc limita superioară a pădurii.

Formele periglaciare mai mari sunt, în general, relictate sau fosile, multe dintre acestea fiind distruse sau acoperite de pădure (grohotișuri fosile, ghețari de pietre). Alte forme își continuă evoluția din pleistocen, cu o intensitate mai redusă (creste, vârfuri, abrupturi), iar unele forme actuale le acoperă pe cele mai vechi, având dimensiuni mai reduse (grohotișurile actuale). Formele actuale diferă ca tip, mărime și extindere spațială și altitudinală, fiind în general mai mici (microforme) și mai puțin diversificate decât precedentele.

În arealul studiat nu întâlnim toată varietatea de forme periglaciare: undulațiile și terasetele de solifluxiune, mușuroaiele înierbate, conurile de grohotiș, torenții de pietre, culoarele de avalanșă, nișele nivale și potcoavele nivale sunt frecvent întâlnite; însă alte forme periglaciare distinctive, cum ar fi solurile poligonale, cercurile de pietre și ghețarii de pietre sunt rar întâlnite și doar în forme embrionare sau inactive.

Cuvinte cheie: procese periglaciare, forme de relief periglaciare, bazinul Râului Doamnei, Munții Făgăraș

Key words: periglacial processes, periglacial landforms, Doamnei River basin, Făgăraș Mountains

1. Introduction

The periglacial processes (or the cryonival processes, depending on the different acceptance of the terms) play a major role in the present dynamics of the landforms situated above the timberline (1780m). Considering the 3°C isotherm to be the lower limit of manifestation of the periglacial phenomena (French, 1996), the landforms situated above 1800m altitude in the Doamnei River basin (namely 94 sq.km) are shaped by the periglacial processes. They overlap and continue at a smaller scale the older Pleistocene and postglacial processes and landforms, combining and alternating seasonally with fluvial, torrential, gravitational and aeolian processes.

The mountain (upper) basin of Doamnei River (fig. 1) is located on the central-eastern part of the southern side of the Făgăraș Mountains (Meridional Carpathians). Geology is represented by the

crystalline rocks (crystalline schists, micaschists, gneisses and intercalated parallel east-west stripes of harder rocks, crystalline limestones and amphibolites) of the Argeș Nappe (Cumpăna Unit) and the Moldoveanu Nappe (Supragetae Unit) for the main ridge.

The mountain basin of Doamnei River is characterized by a typical alpine, subalpine and mountainous morphology. The main features of this subunit are: prevalence of high hypsometric steps that exceed 1600m altitude (including 4 peaks over 2500m and 18 peaks over 2400m), high values of landform energy (400-600m, and locally over 1000m for the area adjacent to the glacial valleys), very high and steep slopes (predominant slopes of and over 30°-50°), high massiveness. Because it spreads over one third of the southern slope of the Făgăraș Massif, the Doamnei River basin preserves a great variety and complexity of landforms, as a "genuine geomorphologic book": erosion leveled

landforms, relict glacial landforms, periglacial and nival landforms, fluvial landforms, structural and lithologic landforms.

2. The Periglacial Processes

The periglacial processes are generated by the severe, cold and wet climate specific to the high Făgăraș Mountains and are influenced by other factors, too (lithology, structure, declivity, aspect, surface deposits, soils, and vegetation), the result being a complex morphodynamic modelling system acting at present above the timberline.

The research for the Meridional Carpathians (Passoti, 1994; Urdea, 1992, 2000, 2001; Urdea et al., 2003; Voiculescu 2000, 2001, 2002; Kern et al., 2004) showed two permafrost sublevels: the **discontinuous (possible) permafrost sublevel above 2300m altitude**, and the **sporadic permafrost sublevel at 2050-2300m altitude** (with 200m difference depending on the slope aspect). According to the temperature limits (average yearly temperature), the vertical thermic gradient ($0.63^{\circ}\text{C}/100\text{m}$) and the references, two morphoclimatic levels were identified in the Făgăraș Mountains (Voiculescu, 2002; Urdea, 2000): the **periglacial**

level above the $2-3^{\circ}\text{C}$ isotherm (table 2) and the fluvio-denudation level below this isotherm (below the upper timberline). In the Doamnei River basin, the landforms situated above 1800m altitude represent 94 sq.km and 25 % of total mountain basin.

There are some favorable areas for permafrost formation and preservation (rock glaciers, protalus rampart, rock streams, talus cones) as the avalanches supply a mixture of snow and debris. There are many snow patches preserved from one year to another and they indicate the sporadic permafrost (fig. 1).

The processes that shape the landforms of alpine and subalpine Făgăraș Mountains are determined by the temperature variation and the freeze-thaw processes that alter the substratum (rock, mantlerock, debris, soil) differently (by frost weathering, frost shattering, frost heaving); the ice in the soil, the snow and the meltwater moisten this substratum and facilitate its movement. The characteristic alpine and subalpine vegetation reduces the material movement on lower slopes.

Frost weathering and **nivation** are the dominant periglacial processes and they combine and alternate seasonally with the fluvio-torrential processes.

Table 1. The periglacial morphoclimatic level in the Doamnei River basin

	Sublevels*	Temperature limits*	Altitude limits*	Area in the Doamnei River basin	Examples in the Doamnei River basin
THE PERIGLACIAL LEVEL	Intense weathering sublevel	-3°C , -6°C , -8°C	above 2500m	0.06 sq.km	the sharp ridge Viștea Mare-Moldoveanu, the high plateau Dara-Hârtoapele
	Complex periglacial process sublevel	0°C - -3°C	2050-2500m	49 sq.km	most glacial cirques, the leveled surface Borăscu I and II, the secondary ridges, the pyramidal peaks
	Solifluction sublevel	3°C (2°C) - 0°C	1800-2050m	44 sq.km	the walls of glacial valleys, the glacial thresholds, the lower steps of some glacial cirques, the leveled surface Borăscu II in the mountains: Preoteșele-Drăghina, Căpățâna, Grușoru-Lespezi, Otic, Păpău

* after Urdea, 2000; Voiculescu, 2002.



Fig. 1 Snow patches preserved from one year to another at the base of some avalanche tracks: the glacial threshold Buduri (left) and the glacial cirque Mutătoarea (right)

The **frost weathering** processes generate weathering landforms (sharp ridges and peaks, cliffs, needles, towers), debris (of many types depending on the gravitational processes and declivity) and detritus (that form soft deposits and than mantlerock). The freezing of water in rock, soil, debris or mantlerock also generates a series of processes: **frost shattering** (cracking), **frost heaving** and **frost thrusting**. The mechanism of frost heaving is responsible for polygonal and reticulate soils, stone circles, mud rings, earth hummocks and periglacial pavements. The frost weathering processes (also known as cryogen processes) are more active at higher altitudes and areas without vegetation, as the high ridges and peaks, or the walls of glacial cirques in the Făgăraș Mountains. The rock is directly exposed to freeze-thaw, insolation and wind erosion. The steep slopes recess through weathering and generate sizable quantities of debris. Thus the interstream area reduces and turns into intersection crests, peaks and outliers.

The **nivation** means the morphogenetic action of snow: sag, erosion, avalanche, and meltwater chemical weathering. The nivation associates and complements the frost weathering, frost creep, solifluction and meltwater action. Its intensity depends on the slope declivity and aspect, the snow layer duration and thickness, the existence of permafrost and the wind speed (that drifts and accumulates the snow in sheltered areas). For example, in the areas of gentle slope (the glacial floors, the fragments of the Borăscu leveled surface) or in the sheltered areas (the eastern, north-eastern, south-eastern slopes or the deep, narrow valleys) the snow accumulates in thicker layers and lasts longer, generates a slow erosion and nival sag, resulting snow niches and nivation hollows. The nivation may also turn the headwaters of torrents into snow niches and nival cirques. The steep walls of the glacial cirques and valleys are fragmented by a dense network of avalanche tracks ended with talus cones or protalus ramparts.

The **solifluction** affects the gentle slopes and the fragments of the levelled surfaces covered with mantlerock, soil and alpine or subalpine vegetation, while the rain-wash, the sheet erosion or the sheep paths increase this process. The solifluction is active especially in springtime, when the temperature oscillations of the moist soil (generated by the meltwater, the segregated ice or the rain) are around 0°C.

Other permanent, seasonal or periodical geomorphologic processes add to the periglacial ones: the fluvial, aeolian, gravitational and torrential processes.

3. The Periglacial Landforms

The classification of the periglacial (cryo-nival) landforms takes into account many criteria (age, dominant processes, climate and altitude, declivity, etc.), according to different authors (table 2).

The larger periglacial landforms are generally relict or fossil, and many of them were destroyed or covered by forest (fossil debris, rock glaciers). Other landforms have continued their evolution since the Pleistocene, but at a lower intensity (ridges, peaks, steep slopes), and some present landforms cover the elder ones, but they are smaller (the present debris). The present landforms are smaller in type, size, spatial and altitudinal extent (microforms) than the previous (Pleistocene) ones.

The studied area does not exhibit the entire range of periglacial landforms: solifluction waves and terraces, earth hummocks, talus cones and debris trains, avalanche tracks, snow niches, nivation hollows, and protalus ramparts are frequent; while other distinctive periglacial forms as the polygonal soils, the stone circles or the rock glaciers are rare, inactive or in the early stages.

3.1. Weathering landforms (residual landforms)

The alpine ridges (karling, arrête) and peaks (pyramidal peaks or horns, also representing outliers) in the Doamnei River basin resulted from the recession of the slope situated above the Pleistocene glaciers under the conditions of the supraglacial cryogen level. Their erosion under periglacial (cryo-nival) conditions continued more slowly during the Holocene, resulting smaller forms: towers, needles, sharp cliffs (fig. 2).

These are barren ridges and peaks situated at the highest altitudes in the studied basin. The frost cracking is facilitated by the rock type, geological structure, high declivity (even vertical) rock layers, and fissured crystalline rocks (gneisses, paragneisses, micaschists and intercalations of amphibolite, quartzite and crystalline limestone). Therefore the size and form of these residual landforms are very diverse: **isolated sharp cliffs, towers and needles; serrate ridges with microforms; deep and narrow passes; residual peaks of tor type.**

Table 2. Classification criteria of the periglacial (cryo-nival) landforms

Classification criterion	Landform classification	Periglacial (cryo-nival) landforms	The studied region	Author/ authors																										
Dominant processes	Cryogen micro-landforms	Weathering landforms (residual landforms): sharp serrate ridges, pyramidal peaks, towers, needles, sharp cliffs, gorges	Meridional Carpathians (especially the Făgăraș-Iezer Mountains, Godeanu Mountains)	Niculescu, Nedelcu, 1961; Nedelcu, 1965																										
		Accumulation landforms: debris (mobile, steady, semi-steady, reactivated), rock streams, rock torrents, talus cones, eluvium deposits (mantlerock), stone polygons and garlands, earth hummocks																												
		Solifluction landforms: solifluction terraces, earth hummocks, block slides																												
	Nival micro-landforms	Snow sag and snow erosion landforms: plateau nivation hollows, ridge nivation hollows, slope nivation hollows, nivation hollows in glacial cirques and valleys, snow niches																												
		Snow erosion landforms: avalanches																												
		Snow accumulation landforms: protalus ramparts																												
		Landforms generated by the chemical action of snow and meltwater: drains, furrows, karrens																												
Dominant processes (cryo-nival landforms)	Frost weathering landforms	sharp ridges, towers, needles, mushroom-rocks, steep slopes that generates debris, altiplanation benches and steps, block fields	all high mountains of Romania	Posea, Popescu, Ielenicz, 1974																										
	Nival micro-landforms	nivation hollows			Dominant processes, declivity	Patterned ground	circles, polygons, nets, steps, stripes	in general	Summerfield, 1994	Ground-ice phenomena	ice-wedges, pingos, palsas, thermokarst	Depositional forms related to mass movement	gelifluction sheets, gelifluction benches, gelifluction lobes, gelifluction streams, block slopes, block streams, block fields, rock glaciers	Asymmetric valleys		Cryoplanation terraces and cryopediments		Declivity	Periglacial ridges and peaks	pyramidal or conic peaks, rounded peaks, karling interfluves or ridges, towers, needles, sharp cliffs, tors	Retezat Mountains	Urdea, 2000	Slope periglacial landforms	block slopes, rock streams, rock torrents, talus cones, debris trains, ploughing blocks, slope deposits with rhythmic stratification, avalanche tracks, nival semi-funnels, cryoplanation terraces and surfaces, solifluction terraces, lobes and waves, nivation protalus, fluvio-nival torrents	Flat surface periglacial landforms	rock glaciers, periglacial pavements, block fields, stone circles, frost heaving stones, nivation hollows, earth hummocks	Dominant processes	Forms related to frost action	sorted circles, polygons, stone stripes, thufurs, structural soils	Tatra Mountains
Dominant processes, declivity	Patterned ground	circles, polygons, nets, steps, stripes	in general	Summerfield, 1994																										
	Ground-ice phenomena	ice-wedges, pingos, palsas, thermokarst																												
	Depositional forms related to mass movement	gelifluction sheets, gelifluction benches, gelifluction lobes, gelifluction streams, block slopes, block streams, block fields, rock glaciers																												
	Asymmetric valleys																													
	Cryoplanation terraces and cryopediments																													
Declivity	Periglacial ridges and peaks	pyramidal or conic peaks, rounded peaks, karling interfluves or ridges, towers, needles, sharp cliffs, tors	Retezat Mountains	Urdea, 2000																										
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	Flat surface periglacial landforms	rock glaciers, periglacial pavements, block fields, stone circles, frost heaving stones, nivation hollows, earth hummocks																												
Dominant processes	Forms related to frost action	sorted circles, polygons, stone stripes, thufurs, structural soils	Tatra Mountains	Baranowski et.al, 2004																										
	Forms related to mass movement	solifluction lobes, solifluction terracettes, nival niches, protalus ramparts, block fields, rock glaciers																												

3.2. Slope periglacial landforms

Many periglacial (frost weathering, frost heaving, nivation, solifluction, frost creep) and fluvio-torrential processes action on the walls of the glacial cirques and valleys or on the glacial thresholds (fig. 3). These processes generate a variety of landforms, depending on the rock type, declivity, aspect, vegetation cover and type.

The **snow niches** are usually situated above 1800-2000m altitude on the upper slope sector. They are the result of combined and alternant

(seasonal) action of snow, frost weathering, torrential and sheet erosion. Their shape is semicircular, ellipsoidal, elongated or funnel-like, while their size reaches a few tens of meters. In many cases, the snow niches continue with avalanche tracks. Their bottom is barren and filled with debris, which are evacuated partially or totally by avalanches or torrents. Though the snow niches have a double and seasonal function (avalanche supply basin and torrential headwaters), their genesis is mainly due to nivation (fig. 8).



Fig. 2 Weathering landforms (residual landforms) in the Doamnei River basin (Făgăraș Mountains)

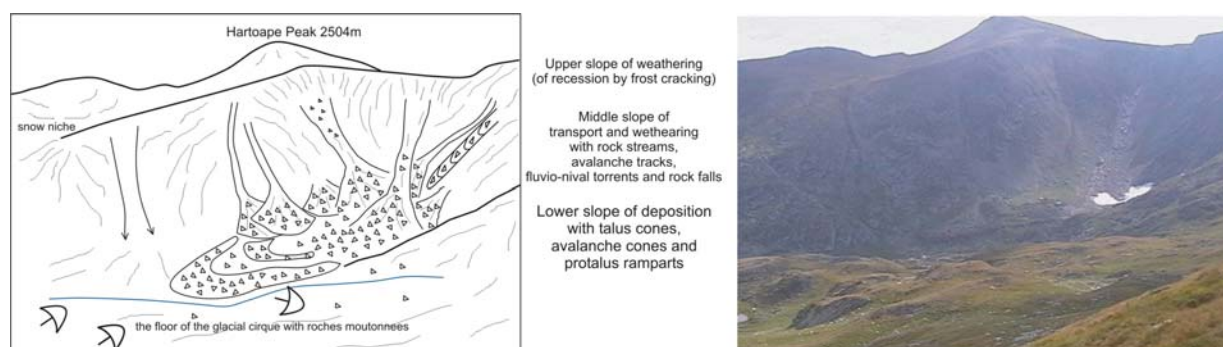


Fig. 3 Slope sectors and periglacial (cryo-nival) landforms in the glacial cirque Hârtoapele Leoatei (altitude 2250-2504m)

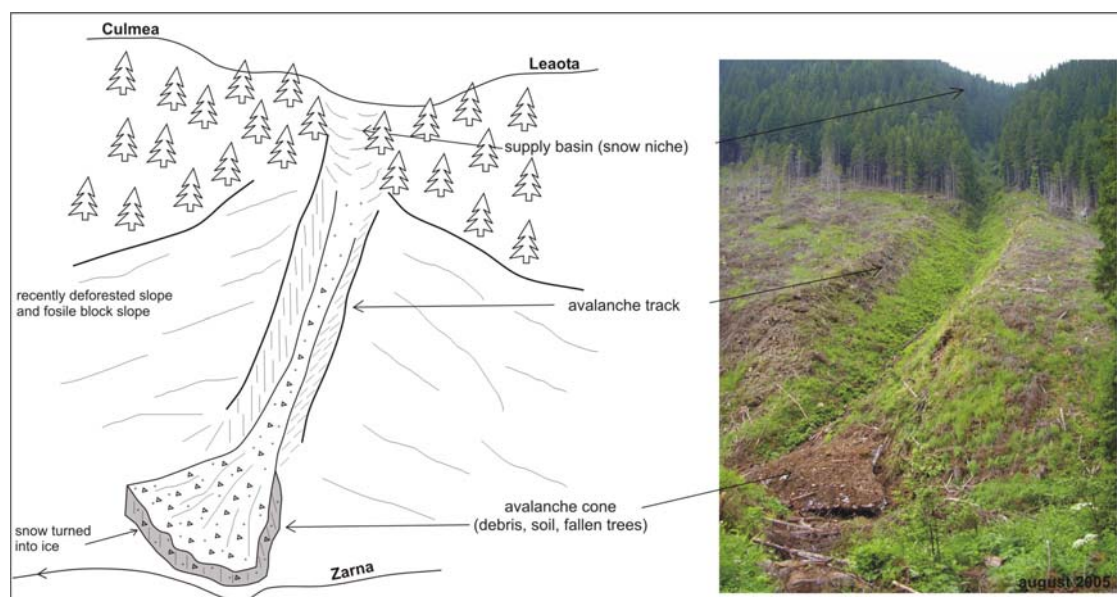


Fig. 4 Avalanche track and cone on Zârna valley (1350 m altitude) – main parts

The **avalanche tracks** are forms of snow erosion that mark the steep slopes (over 35° – 40°) of all glacial cirques and valleys in the Doamnei River basin. They form a dense and parallel network that crosses the entire slope along the line of highest declivity (fig. 5). The avalanche tracks reach a few hundred meters long, even 500-750m long and 8-10m deep in case of the slopes of some large former glacial valleys. The avalanche tracks are supplied by a basin which is usually a snow niche or a torrential basin. They deposit **avalanche cones** and **protalus ramparts** made up of snow, debris of different sizes, soil and vegetation (fig. 4, 6, 8). The avalanche tracks function seasonally and alternatively as follows: as a snow evacuation organism (avalanche) and as a torrential organism (during the warm season).

The form of the **protalus ramparts** (névé moraines) – semicircular, arched, asymmetric, convex outward) – suggests the push action of snow and moulds the snow tongue. This is also demonstrated by the nivation hollow situated between the slope and the rampart, which preserves snow patches or bogs (for example the protalus

rampart in the glacial cirque Malița). These landforms are more frequent at the base of the shorter, gentler and linear avalanche tracks. Also they develop only in higher altitude glacial cirques, where the climate is more severe and the rocky walls supply a sizable amount of frost-cracked blocks.

The two larger forms (5-6m in height, 20-30m in width) with double rampart situated in the glacial cirques Hârtoapele Leaoței and Malița are inactive (fig. 6), because they are separated from the slope and covered with grass. The two ramparts (waves) demonstrate two stages of formation, the first one being stronger (the outward rampart is larger and includes the second one). Their activity ceased not so long ago, because the soil is thin and discontinuous, and talus cones form behind them at present. Compared to the smaller, active forms, it is possible that these protalus ramparts functioned as incipient rock glaciers (as P. Urdea, 2000 demonstrates for similar forms in the Retezat Mountains). In addition, the nivation hollows on the Malița protalus rampart demonstrates that this could be a fossil rock glacier.

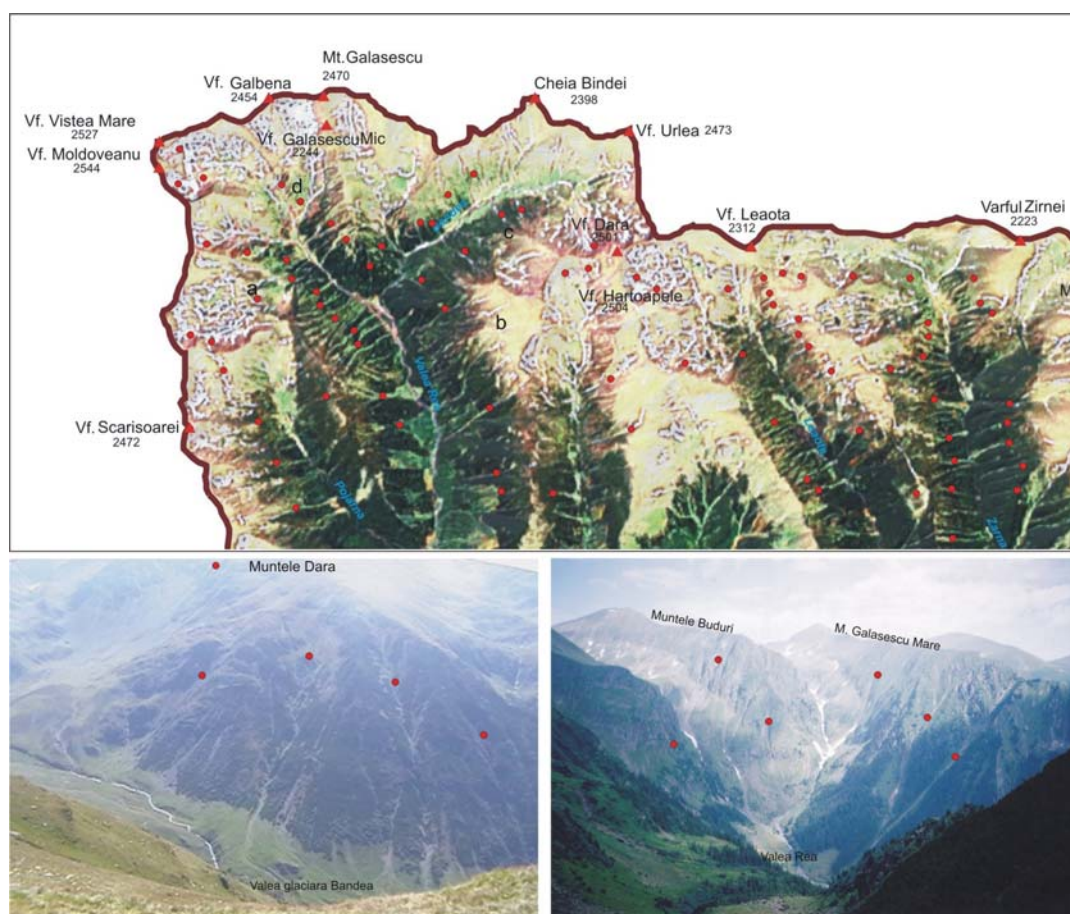


Fig. 5 Locating large avalanche tracks in the Doamnei River basin on a satellite image and on field (● marks the avalanche tracks)

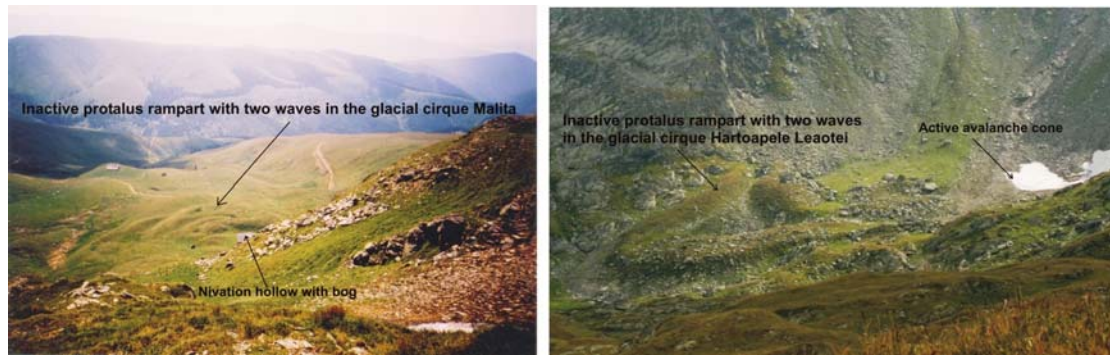


Fig. 6 Large inactive protalus ramparts in the Doamnei River basin (Făgăraș Mountains)



Fig. 7 Active protalus ramparts in the glacial cirques Valea Rea and Galbena

The active protalus ramparts are smaller and their arched form is less evident (fig. 7, 8). They contain only debris and are situated only at the base of northern or north-western walls of the high altitude glacial cirques (above 2100 m).

The talus or debris deposits are the most representative forms associated with frost weathering and characterize the landscape of many glacial cirques and thresholds in the Doamnei River basin. Some of these forms are frequent: **rock streams, stone torrents, talus cones, debris trains** (fig. 8). Others debris forms are rare, situated at a higher altitude, and most of them are fossil and

inactive: stone fields, rock glaciers, protalus ramparts.

The **rock streams** are debris strips situated above 1800 m altitude on the steep walls of the glacial cirques and valleys. The frost-cracked rocks are autochthonous and move down slowly due to the rock creep (Urdea, 2000). The rock streams and vegetation associate in parallel strips resulting “ribbon-like forms” and “striped slopes” (French, 2000), as the northern wall of the cirque Hârtoapele, the southern wall of the cirque Roșu, the northern cirque Bâdea, the northern wall of the cirque Valea Rea, etc.



Fig. 8 Talus cones, debris trains, avalanche tracks, snow niches in the glacial complex Valea Rea (the Doamnei River basin - Făgăraș Mountains)

The **stone torrents** generally exceed 100 m in length and 10 m in width, while their talus cones extend on 10-20 m width. The stone torrents occupy the deep fractures in the crystalline rock strata and inherit the deep channels of the former subglacial torrents, the avalanche tracks or the torrential channels (fig. 9).

The **talus cones** are debris depositional forms at the base of stone torrents, avalanche tracks, periglacial recession slopes, walls of the glacial cirques and valleys. The present talus cones are active and in motion, but they overlap older talus cones or other debris accumulation forms that belong to an earlier, larger generation. Therefore the present active talus cones develop at high altitudes, where the frost-weathering processes prevail: the glacial complexes Valea Rea (fig. 8), Bândeă, Dara, Leaota, Zârna, Pojarna. The other smaller glacial cirques situated at lower altitudes or with sunny aspects (Fața Unsă, Ludișor, Bourețu, Brătila, Tăiat, Lineaț, Mocanul, Malița) and most glacial valleys contain only old and fossil talus cones, covered with vegetation (fig. 10).

Sometimes neighboring talus cones merge, resulting **debris trains**, as those located in the glacial cirques Valea Rea (fig. 9), Galbena (fig. 9), Scărișoara Mică, Mutătoarea, Dara, Hârtoapele Leaotei, Lacul Roșu, Zârna, Jgheburoasa.

As other researchers noticed (Urdea et al., 2003), the talus cones, the stone torrents and the fossil rock glaciers tend to be covered with vegetation (alpine grassland, juniper and even coniferous trees) in many glacial cirques and valleys, especially the sunny ones or those located at lower altitudes (fig. 10): the cirque and valley Pojarna, the cirques Mocanul, Lineaț, Tăiat, Malița, the cirque and valley Brătila, the lower steps of the glacial cirque and the valley Zârna, the cirques Ludișor.

The **solifluction terraces** are small steps along the contour lines that develop on moderate slopes (10^0 - 30^0) above 1800 m altitude. The **solifluction waves** develop on mantlerock slopes (20^0 - 30^0) covered with soil and alpine vegetation, usually facing east, west and south. There are also **solifluction slopes**, entirely shaped by different solifluction forms (fig. 11).



Fig. 9 Stone torrents on the glacial thresholds Valea Rea and Buduri
(frost cracking actions on the slope and the resulted debris is transported by torrents and meltwater)



Fig. 10 Fossil periglacial talus cones covered with forest on Zârna valley
(left) and partially fixed talus cones on Valea Rea (right)



Fig. 11 Solifluction terraces in the Doamnei River basin (Făgăraș Mountains)

3.3. Flat Surface Periglacial Landforms

This category includes those periglacial (or cryonival) landforms situated on the flat interfluvies of the Borăscu leveled surface or on the flat or gentle slope floors of the glacial cirques and valleys. **Periglacial pavements** (fig. 12), **nival (nivation) hollows** (fig. 14, 15) and **earth hummocks** (fig. 16) are frequent in the studied basin, while block fields,

rock fields, stone circles and polygonal soils (fig. 13) are rare, incipient or inactive.

At present, the **periglacial pavements** form only on the high altitude plateaus (above 2400m), as the plateau Dara-Hârtoape (2450-2500m). The freeze-thaw and frost cracking generate the stones, and the frost heaving and sorting thrust them out from the thin mantle rock. The crystalline schists give small slabs that combine with sand, gravel, and small patches of grassy soil (fig. 12).



Fig 12. Periglacial pavement on the plateau Dara – Hârtoape (2450-2500 m altitude)



Fig. 13 Incipient polygone on the plateau Malița (2150 m)

Fig. 14 Nival hollows on moraine deposits on Pojarna Saddle (2040 m)



Fig.15 Plateau nival hollows with or without lake on the saddles Zârna (1923 m) and Brătîla (2125 m)



Fig. 16 Earth hummocks (thufurs) on the Fața Unsă Mountain (2200 m)

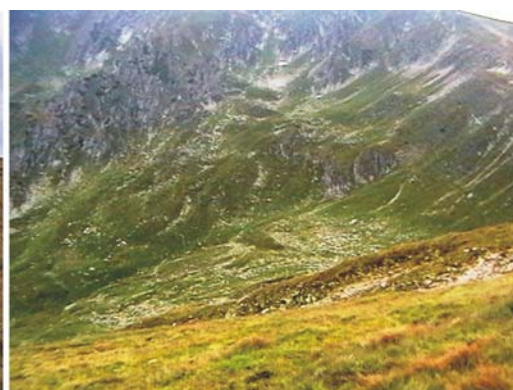


Fig. 17 Fossil rock glacier in the glacial cirque Brătîla

There are only fossil, inactive **rock glaciers** in the Doamnei River basin. Considering its appearance (a range of transversal waves, small mounds and hollows), the moraine in the glacial cirque Brătîla situated at 1900 m altitude may have functioned as a rock glacier after the glacier disappeared (fig. 17).

4. Conclusions

The periglacial processes (or the cryonival processes, depending on the different acceptance of the terms) play a major role in the present dynamics of the landforms situated above the timberline (1780 m).

Considering the 3°C isotherm to be the lower limit of manifestation of the periglacial phenomena (French, 1996), the landforms situated above 1800m altitude in the Doamnei River basin (namely 94 sq.km) are shaped by the periglacial processes. They overlap and continue at a smaller scale the older Pleistocene and postglacial processes and landforms, combining and alternating seasonally with fluvial, torrential, gravitational and aeolian processes.

The periglacial processes are generated by the severe, cold and wet climate specific to the high Făgăraș Mountains and are influenced by other factors, too (lithology, structure, declivity, aspect, surface deposits, soils, and vegetation), the result being a complex morphodynamic modelling system acting at present above the timberline.

The larger periglacial landforms are generally relict or fossil, and many of them were destroyed or covered by forest (fossil debris, rock glaciers). Other landforms have continued their evolution since the Pleistocene, but with a lower intensity (ridges, peaks, steep slopes), and some present landforms cover the elder ones, but they are smaller (the present debris). The present landforms are smaller in type, size, spatial and altitudinal extent (microforms) than the previous (Pleistocene) ones.

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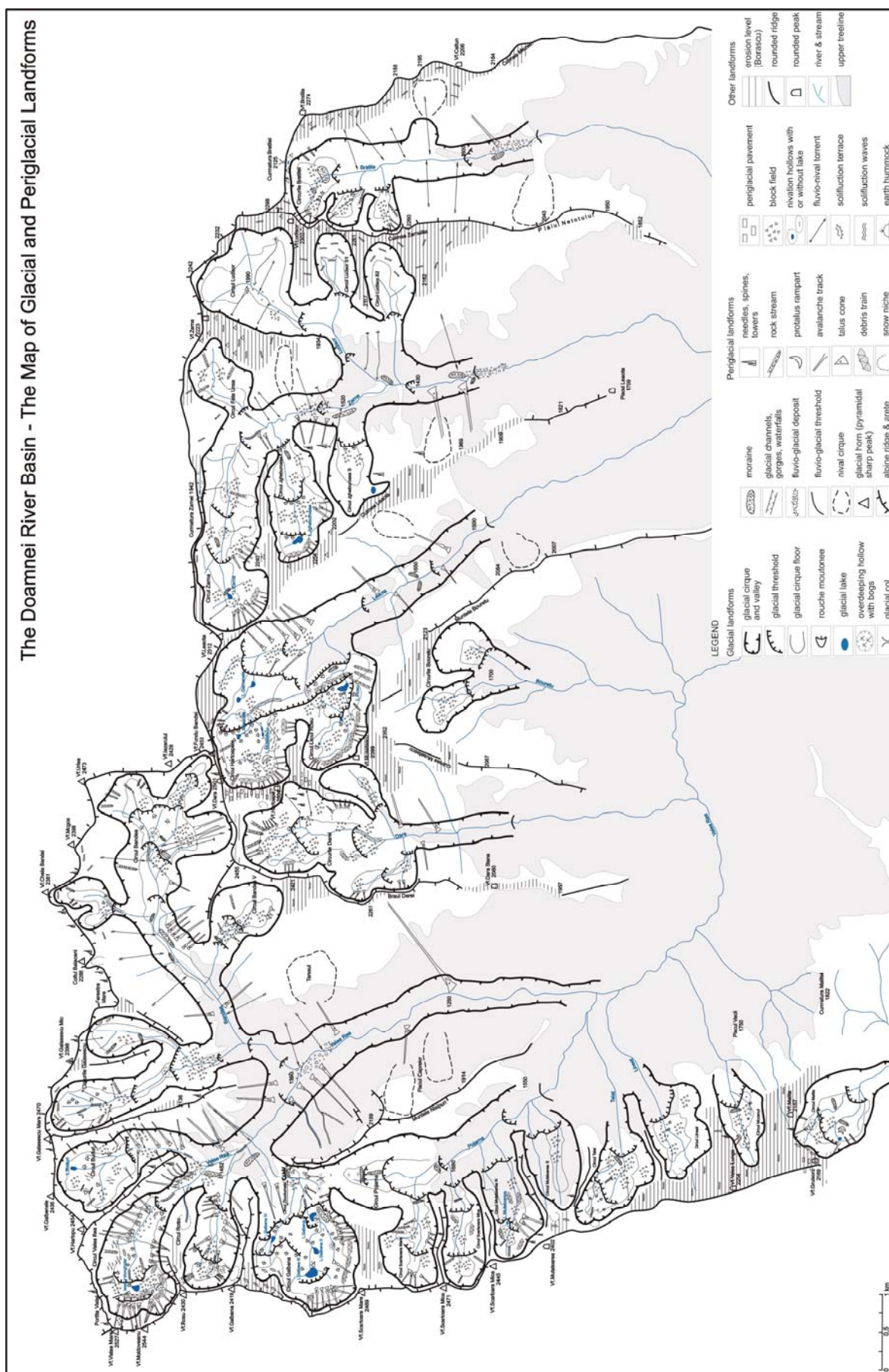


Fig.18 The glacial and periglacial map of the Doamnei River basin

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Călmățui (Teleorman) Hydrographic Basin – Morphometric Analysis Elements –

Maria ALBU DINU

Abstract. Teleorman Călmățui Basin is an important local basin located in Olt - Argeș Sector of the Romanian Plain. It springs from an altitude of only 160 m and pours into Suhaia lake, an old oxbow of Danube river, about 20 m altitude.

From the analysis of morphometry features of the basin we can draw a series of particularities of the relief evolution of this region. Although it started its evolution relatively recently, after the finalization of Boianu Plain, in the inferior Pleistocene, this river has already reached the maturity stage. Its fast evolution was favored especially by the accentuated descent of the basic level, the friability of the rocks in which it is carved but also the climatic variations. The acute depth of Călmățui and Urlui in the middle and inferior sectors led to the intersection of ground-water table and to the apparition of numerous springs and spring lines, preventing the total drainage of rivers during summer.

Key words: hydrographic basin, morphometry, paleogeomorphologic evolution, balance profile.

1. Introduction

Teleorman Călmățui Basin is a hydrographic basin autochthonous to the Romanian Plain, completely situated in Boianu Plain (fig 1). It springs from an altitude of only 160 m and pours into Suhaia lake, an old oxbow of Danube river. Regarding the major genetic type of relief, Boianului Plain is situated in the fluvial-lacustrine plain type, characteristic for the entire Romanian Plains, and as sub-types, within this basin, we can distinguish: a) *Iminog Plain* (Nord of Boianu Plain), occupying the northern part of the basin – a *Getic piedmont plain*, representing an extension of Getic Piedmont, and b) *Urlui Plain* – a *pre-Balkan piedmont plain* (piedmont plain with *Frătești Strata*), coming from an old pre-Balkan piedmont, that was covered with lacustrine and loess deposits and spreading to the south of the towns Radomirești-Mihăești, occupying the middle and inferior sectors of the basin (Gr. Posea, 1987).

Călmățui River is carved in loess deposits of Pleistocene age, having as basis the “Frătești Strata” of St. Prestian age (P. Enciu, 2007). The discordance between Romania deposits and Frătești Strata is based on the erosion bed of Paleo-Danube in front of the delta-cons, after exiting the defile (E.Liteanu, 1961). Due to the fast descent of the basic level, as well as the positive neotectonic movements, the river deepened in the inferior sector, in the loess deposits as well as in Frătești Strata.



Fig.1 Localization of Călmățui hydrographic basin within Teleorman Plain

2. Morphometric aspects

The fluvial geomorphology must highlight the way the climatic changes and tectonic activity influence the aspect of the valley on long term and of the longitudinal profile of the river (V. R. Thorndycraft, G. Benito, K. J. Gregory, 2008).

The morphometric researches are especially useful for the unstudied regions, in which the geomorphologic proofs miss for explaining the evolution of the relief. Through the faithful and

correct play of the current aspect of Earth's surface, the morphometric analysis leads us to paleoevolutive or genetic intuitions (F. Grecu, 1986).

2.1. Watershed

Watershed of Călmățui morphohydrographic basin has a length of 184.93 km, being symmetrically distributed on the two banks, the right bank 94.19 km (50.93%), and the left bank 90.74 km (49.07%). The watershed is almost rectilinear, the sinuosity coefficient of the watershed calculated using the formula (Zăvoianu, 1978, quoted by F. Grecu, 1992):

$$Ks = Lc/Lp, \text{ being of only } 1.08.$$

In this formula:

- Lc – length of the watershed,
- Lp – the distance on the watershed between the spring and the flow.

The difference between the two parts of the insignificant basin:

$$(Ks \text{ left} = 1.07 \text{ } Ks \text{ right} = 1.09)$$

The average height of the watershed is of 116.05 m, presenting higher altitudes on the right side of the basin (120.4 m) regarding the left one (111.7 m).

2.2. The shape of the basin

We can consider that the shape of the basin is a result of the action of drainage network under the conditions given by lithology, tectonics, climate and vegetation and it is modified during time. The geomorphologists came to the conclusion that hydrographic basins developing under homogenous morphotectonic conditions, tend to come to a balance of the watersheds and have a shape close to a pear, in the same time being discussed the shape of circle (A. Posea, 1977, quoted by Comănescu, 2004). Călmățui Basin broadens step by step from the springs to the flow area, reaching the maximum width of in the middle sector 32.6 km, and then there is a contraction in the inferior sector. We can say that the mechanic action of Clărmățui river tends to performing a balance shape not only regarding the longitudinal profile, but also regarding the contour of the watershed.

For Călmățui basin, the **shape index**, set by Gravelius as a report between the perimeter of the ($P=184.9$ km) and the perimeter of a circle with the same surface ($S=1375$ km²)

$$K = P/2\pi r \text{ is of } 1.4.$$

This value gives the ovoid aspect of Călmățui basin of Teleorman. The current aspect of the basin is determined by repeated modifications of the basic

level represented by the Danube, who generated several stages in the forming of the basin.

We must observe the flowing direction of the 4th order segments, who are mostly parallel to Călmățui. Due to this fact, within 4th order basins, we register values further from the unit of shape index it is of: 1.6 for the superior basin of Călmățui, 1.89 for Călmățuiul Sec, 1.43 for Totița basin and 1.92 for Urlui basin, which proves their high degree of elongation.

In order to have a real image of the basin's shape, we calculated **the shape report**, having as reference figure the square (Zăvoianu, 1978).

$$Rf = S/(P/4)^2 = 0.6.$$

We can observe that using as reference shapes the circle as well as the square, the difference between the shape and unity indexes remained the same (0.4).

The elongation report, calculated as report between the diameter of the equal area circle and the length of the basin

$$RA = \Phi CS/L = 0.53$$

(Schumm, 1956, Zăvoianu, 1978).

This shows that the basin is elongated, but the elongation degree is medium.

The roundness report can be calculated as report between the basin's surface S ($S=1375.07$ km²) and Scp – surface of a circle of equal perimeter ($P = 184.93$ km) using the formula (Miller, 1953, quoted by Comănescu 2004).

$$Rc = S / Scp$$

For Călmățui basin we obtain the value of 0.50 which indicates an elongated basin.

Analyzing the obtained results we notice that Călmățui basin is an elongated environment while the 4th order sub-basins have a much higher elongation degree.

Basin's asymmetry reported to the main course offer information regarding its evolution in time. The surface of Călmățui hydrographic basin of 1375 km², is asymmetrically distributed on one side and the other of the valley ax (fig. 2a). The surface of the right bank is of 623.84 km² (45.37%), and of the left side of 751.23 km² (54.63%). The asymmetry coefficient, calculated using the formula (Pișota, Zaharia, Diaconu, 2005):

$$kas = 2(Fdr - Fst)/F = 0.18$$

show that the basin is an asymmetric environment. This situation is due to the two important confluent Călmățui receives on the left side: Călmățuiul Sec and Urluiul.

If we consider the main ax of the basin (fig. 2b), then the situation is reversed. The surface on the right side of the main ax is of 949.14 km² (69.02%),

and on the left side of the main ax is only of 425.93 km² (30.98%), the asymmetry degree in this case being much greater. This asymmetry is due to the change of flowing direction of Călmățui river. In the superior course, the flowing direction is NNW – SSE, in the middle course the flowing direction is NW-SE, while in the inferior sector the flowing direction modifies again, becoming almost N-S.

2.3 Length dimensions

The shape of reception surface influences a series of important parameters: surface, perimeter, length and width. For the morphohydrographic basin of Călmățui and for the main sub-basins we calculated *the maximum length* – considered as the distance in straight line between the furthest points of the basin, *the maximum width* – is the longest segment, perpendicular on the length of the river and *the medium width* – determined as report between the surface of the basins and their length (Grecu, 1980).

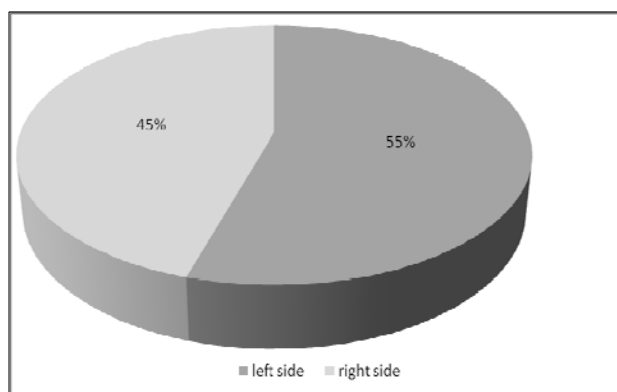
The length of Călmățui basin is of 78.32 km, and the ones of 4th order basins vary between 19.42 km (Totița) and 41.23 km (Urlui).

Analyzing the dimensions of length of Călmățui basin (table nr.1), we note that its shape tends to balance, while the 4th order sub-basins have more elongated shapes.

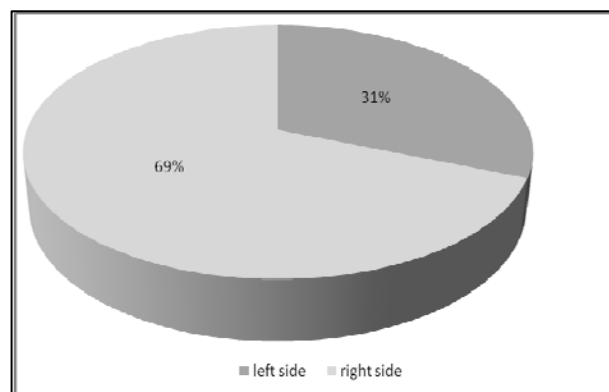
The length of the basins is variable on their different sectors. Thus, the basin of Călmățui river is very well developed in the central part (over 25 km), while in the north part of the basin the width decreases to less than 5 km. The average width of Călmățui basin is of 17.56 km, but we note values close to the average widths in the case of 4th order basins, varying between 2.33 km (Totița) and 2.76 km (Urluiul).

2.4. Hypsometry

The hypsometric specificities of Călmățui hydrographic basin of Teleorman are determined by its development on homogenous lithologic formations with tabular structure, by the positive neotectonic movements that affected especially the south side of the basin, by the oscillations of the basic level as well as the action of external agents. Within Călmățui basin we notice the concentric layout of hypsometric stages from north to south, their decrease performing along the Călmățui valley from the spring to the flow. The altitudes decrease step by step from NNW to SSE, the highest altitudes being situated on the watershed, in the north of the basin: Măgura Greci 163.5 m, Măgura Vâlcele 156.23 m, Măgura Greceanca 161.3 m, and the lowest, under 20 m, situated in the south of the basin, where the Călmățui flows into Suhaia Lake.



a)



b)

Fig. 2. The share of surfaces in Calmatui basin of Teleorman
a) regarding the ax of the valley; b) regarding the main ax of the basin

Table nr.1 Morphometric data for Călmățui basin and main sub-basins

Basin	Maximum length (km)	Maximum width (km)	Average width (km)
Călmățuiul	78,32	28,62	17,56
Călmățuiul superior	38,95	12,14	2,50
Călmățuiul Sec	36,71	7,34	2,46
Totița	19,42	6,75	2,33
Urluiul	41,23	12,25	2,76

The histogram performed for this basin presents a powerful symmetry, as the surfaces with values under 90 m as well as the ones with values over 90 m represent 19% of the basin's surface, while the hypsometric stage of 90–120 m extends on a surface of 852.3 km², occupies about 62% of the basin's surface, including the largest part of the interfluvies (F. Grecu, L. Comănescu, 1998).

Analyzing the cumulated diagram of the hypsometric stages (fig. 3) we can easily observe the convex shape of the curve in the inferior part, which indicates a process of powerful and fast deepening of the valleys. Comparing the shape of the hypsometric integral curve, reduced in the unit (Rădoane M., Dumitru D., Rădoane N., 2001), with Strahler's stages of relief evolution (fig. 4), we observe that Călmățui hydrographic basin is close to the maturity stage of its evolution.

2.6. The deepening of fragmentation shows the depth reached by the linear erosion. The largest part of the surface of Călmățui basin, respectively 53%, present values of fragmentation deepening under 10 m. The surfaces with value of fragmentation depth between 10 and 20 m occupy 22% of the surface of the basin and are situated especially along the valleys in the superior Călmățui basin. The surfaces with values of fragmentation depth between 20 and 30 m represent about 6% of the basin's surface and are especially disposed long the Călmățui valley in the middle sector and in the superior sector of Urlui valley.

A specificity of the relief's fragmentation depth is represented by the surfaces with values of fragmentation depth between 40 and 50 m as well as the one with values larger than 50 m, situated in

the inferior sector of Călmățui valley, values large enough for a plain area and which together occupy about 7% of the basin's surface. This fact is due to:

- the presence of loess deposits highly friable;
- the positive neotectonic movements of about +2 mm/year (D. Zugrăvescu et al., 1998);
- the accentuated descend of the basic level represented by the Danube.

2.7. The fragmentation density in Călmățui hydrographic basin of Teleorman is characterized by reduced values, specific to the plains area (Grecu, Comănescu, 1998). The values of relief fragmentation density vary between 0 and 5 km/km², the average density being of 1.25 km/km², also considering the valleys with torrential character.

The surfaces with very small values of fragmentation densities, under 1 km/km², are characteristic to the interfluvies between the main rivers and occupy 40% of the basin surface. The surfaces with values of fragmentation density between 1 and 2 km/km² represent about 23% of the basin's surface, and the ones with values between 2 and 3 km/km² hold about 23% of the surface.

We must note the fact that the surfaces with values of fragmentation density greater than 3 km/km², represent an important share of 17% of the basin's surface. These high values of the fragmentation density are due to the friability of rocks in which the basin is carved, as well as to the presence in the studied region of numerous springs and spring lines that appeared as a result of the intersecting of the phreatic aquifer layer quartered in "Frătești Strata" by the powerfully deepened valleys.

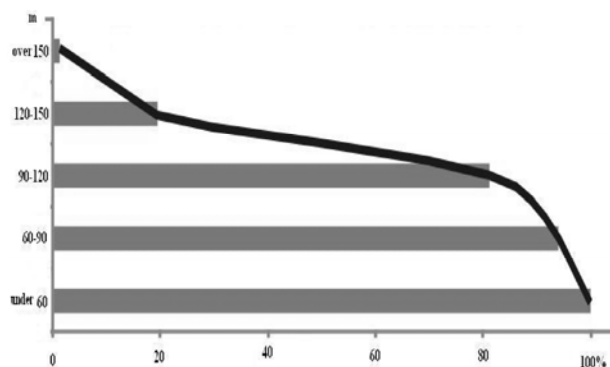


Fig. 3. The cumulated diagram of hypsometric stages in Călmățui basin of Teleorman

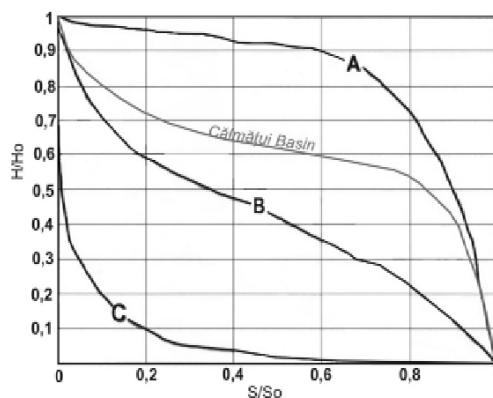


Fig. 4. The hypsometric integral of Călmățui hydrographic basin compared with Strahler's stages of relief evolution (A – youth, B – maturity, C – old age)

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2.8. Geodeclivity of morphologic surfaces in Călmățui basin is strongly correlated to the geological support, paleogeographic evolution and current modeling (Grecu F., Palmentola G. 2003).

The values of morphologic surfaces inclination were divided into 5 categories. The greatest share is of the quasi-horizontal surfaces in whose case the value of the slope does not exceed 2%, being represented by most interfluves and representing 77% of the basin surface.

The very weakly inclined slopes with values between 2 and 5% represent 12.29% and are characteristic to young valleys, with torrential character, whose profile is transversal as a widely opened „V”. While the size order of the river segments increases, the valleys deepen and the slopes become weakly inclined with values between 5 and 10% occupying 6.94%, of the basin surface.

The slopes moderately inclined, with values between 10 and 15%, represent 2.55% of the basin surface and are characteristic for the sides in the middle and inferior sectors of Călmățui and Urlui, and the moderated ones with values over 15% represent only 1.16% of the basin surface and occupy especially the right side of Călmățui valley in the inferior sector.

3. Geomorphologic regionalization

Analyzing the morphometric parameters such as: altitude, slope character, valley system, fragmentation degree, we can distinguish within the hydrographic basin Călmățui of Teleorman three sectors that present different characteristics (fig. 5), thus:

a) *Superior sector*, superposes in most part to Iminog Plain and spreads to the south up to the confluence of Călmățui with Călmățuiul Sec. The absolute altitude descends from 163.5 m in then north to about 108 m in the south, and the value of the slope reaches 1.42 m/km, due to the existence at the south end of the alluvial cone Olt-Argeș. This sector is crossed on the direction NNW-SSE by three important valleys: the superior course of Călmățui valley and its confluent: the valley of Călmățuiul Sec confluent on the left side and the valley of Sohodol confluent on the right side. The valleys are partially dried during summer, they have a transversal profile as a widely opened “V” in the superior sectors, and then begin to slightly deepen and widen on the base.

This sector is characterized by the absence of springs, and the ground-water table on the level of interfluves is found at great depth (20-25 m). Therefore, the human settlements are few, small and

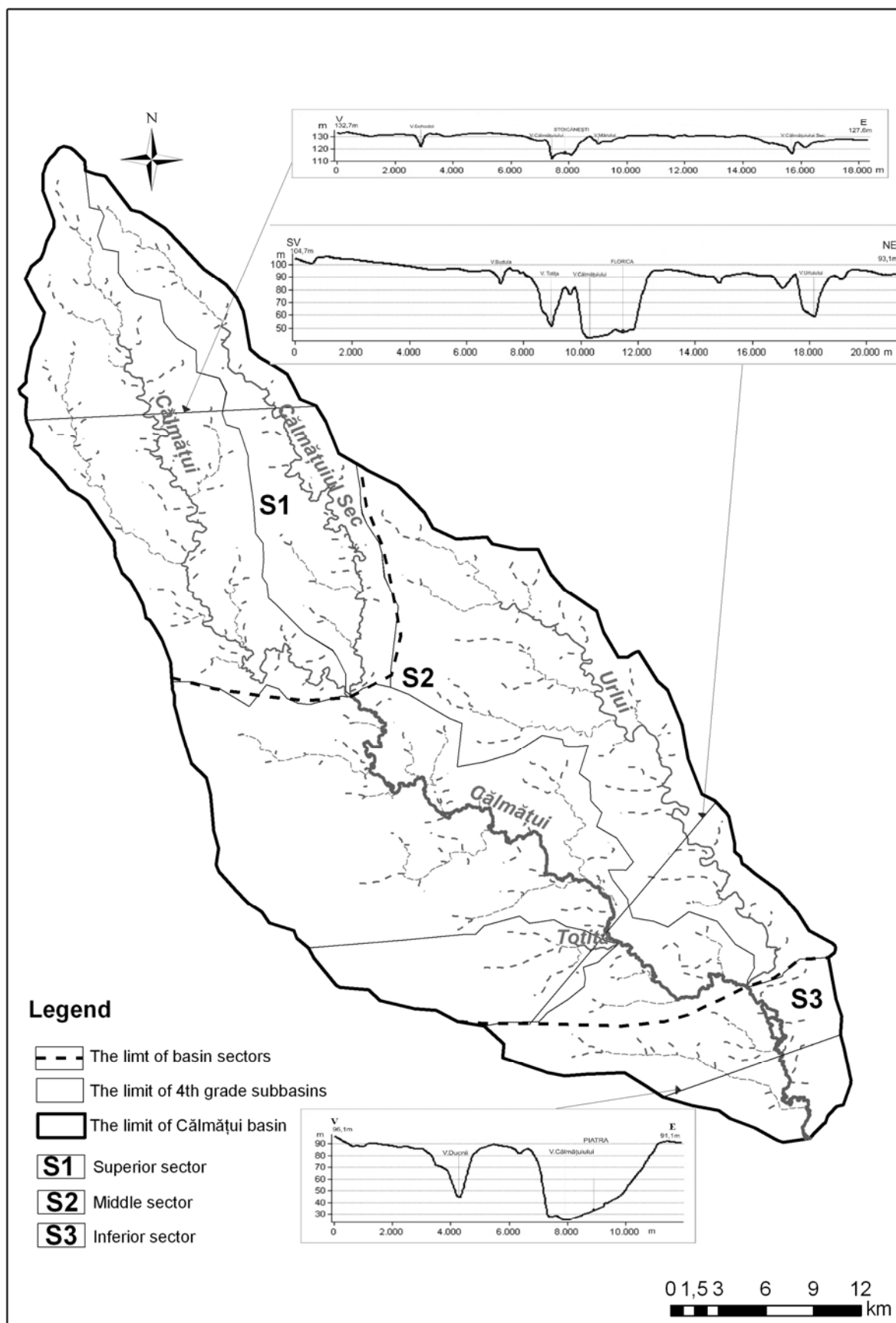


Fig. 5 Călmățui basin – Geomorphologic regionalization map

situated on valleys, where the depth of the ground-water table is smaller. The depth of fragmentation registers values of 10 and even 20 m in the south side, the density of fragmentation of the relief is the highest from the entire basin, being of over 1.5 km/km² (if we consider all valleys, including the ones with torrential character), the meadow is relatively narrow and the sides have values of the slopes of 5-10%.

b) *Middle sector* situated between the confluence of Călmățui with Călmățuiul Sec and the confluence of Călmățui with Urlui is the largest and it is drained by the middle sector of Călmățui and its left confluent, Urlui. The main valleys have water all year long, presenting wide and complex meadows, with numerous tied up meanders, hills as well as one-two terrace levels as patches. Numerous meanders determine the change of main direction of flow of the rivers that become NW-SE. The sides become more abrupt, the slopes generally have values between 10-15% and even exceeding 15%. The general slope of the relief's surface is very reduced, reaching 0.25 – 0.3 m/km, this due to the extension towards west of the depression groove of Călniștea. An important characteristic of this geomorphologic sector is its richness of springs, some of them with pretty important debit, appearing in great numbers on the base of the sides of main valleys, marking the end of the alluvial cone (I. Rădulescu, 1956), fact that determined the apparition of numerous settlements. The fragmentation density is of only 1.1 km/km², but the valleys deepen pretty much, the fragmentation depth reaching values of 30-40, 40-50 and even over 50 m.

c) *Inferior sector* situated on the south of Călmățui's confluence with Urlui, has a reduced surface. It is drained on the north-south direction by a deep valley of Călmățui, with "micro-canyon" aspect formed of loess. The fragmentation depth exceeds in this sector 50 m. On the sides with slopes of 10-15 % and even over 15% most of the current geomorphologic processes take place. The two levels of terrace are present only on the left side of the river and have so bevel surfaces that it is difficult to set their altitude only by one value. It

appears that during the forming of the terraces, the river used to descend pretty fast towards the current basic level (G.Vălsan, 1915).

The surface of this sector is almost horizontal, a like Burnas Plain. But what distinguishes it is the lack of inverse slope, from south to north and of the rivers with this flowing direction. The altitude difference is about 5-10 m, registered between the northern and southern extremities of this sector is determined by the presence of the 4th terrace of Danube in the south of the basin. Under these conditions the density of the hydrographic network is similar to the central sector, being of 1.2 km/km².

Conclusions

Călmățui Basin of Teleorman is an important autochthonous basin in the Central Sector of Romanian Plains. Although it started its evolution relatively recently, after the finalization of Boianului Plains, in the inferior Pleistocene, this river has already reached the maturity stage. Its fast evolution was favored especially by the accentuated descent of the basic level, the friability of the rocks in which it is carved but also the climatic variations.

Currently, some confluent of Călmățui, with torrential character, increase their length by draining certain microdepressions, as in Călmățui basin of Teleorman the theory of N. Florea (1970) is very well illustrated, theory according to which "the plains with microdepressions represent a stage in the evolution of loess plains".

The acute depth of Călmățui and Urlui in the middle and inferior sectors led to the intersection of ground-water table and to the apparition of numerous springs and spring lines, preventing the total drainage of rivers during summer.

Acknowledgments. This work was supported by project: POSDRU/88/1.5/S/61150 "Doctoral Studies in the field of life and earth sciences", project co-financed through Sectorial Operational Program for the Development of Human Resources 2007-2013 from European Social Fund.

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Use of GIS techniques to identify areas to consider when designing the Posada – Sinaia motorway sector so as to meet sustainable development requirements

Robert DOBRE

Abstract. In the present geo-political context, Romania plays an important role at the level of passengers and goods transport, as a basis between Central and Western Europe on the one hand, and Asia Minor and the Middle East on the other hand. At the end of the 20th century, the mountainous axis Bucharest – Ploiesti – Brasov was one of the most circulated axes from the entire Carpathian bow. Railway traffic, but especially road traffic had already exceeded the infrastructure's limits, even if it was extended and modernized in different stages.

The mountainous highway would cross several sectors which are difficult from the point of view of the relief (narrowing, abrupt slopes with intense geo-morphological processes) but also from the point of view of lands' use (the axis of mountainous resorts Sinaia – Busteni – Predeal). Thus, the identification of areas which are suitable for the construction of the first mountainous highway from Romania in the context of sustainable development proves to be an extremely important challenge.

With the help of GIS techniques, by interposing several types of spatial data, it was identified a straightway of mountainous highway which would cross the clough, having a reduced impact upon environment, and in accordance with European norms. The project was done at the scale 1:3000, by interposing several ground mappings, morphographic maps (lands' use, tectonic maps, lithological maps, geomorphological maps) and morphometric maps (declivities, fragmentation density, relief energy). The precise representation of the crossed area was done by juxtaposing orto-photo-plans over the numerical model of the land. The radiuses of curves, the buckets and declivities were done according to European norms, so that they could allow a circulation with the speed of 120 km/hour in safety conditions

Keywords: motorway, Prahova, GIS, geomorphotechnical map

The transport connection, over the Carpathians, along the Prahova and Râșnoavelor Valleys, is of a more recent date compared to the other available options (Rucăr-Bran Couloir and Telejenului Valley) which served this purpose as early as the Antique Era or the Middle Ages. The route along Prahova Valley was first mentioned in a document dated back to 1358 by which the Hungarian King, Ludovic, grants free passage to Brasov merchandisers *between Buzau and Prahova, meaning from Ialomita's discharge into the Danube up to Siret's* (Nistorescu, 2004).

In the current context, with Romania part of the European Union, its responsibilities in terms of improving the transport flow are greater. As such, in order to create the basis of a healthy economic development, Romania started investing in the development of a strong, well planned, homogenous transport infrastructure, a suitable extension to the transport links crossing the old continent.

Planned to link Constanța to Central and Western Europe (from Brașov onwards by the Transylvanian Motorway to Cluj Napoca – Oradea

or through Fagaras Depression on to Sibiu, connection with the 4th Pan-European Corridor), the future A3 motorway is the first infrastructure of the kind crossing the Carpathians. To implement this project, the Prahova Valley – Râșnoavei Valley route was chosen over Cozia – Turnul Roșu (Olt Valley) based on traffic value surveys despite the restrictions imposed by the relief or the many urban areas crossed through. An average of 22.413 cars / day use the Bucharest – Ploiești – Brașov route whereas the Bucharest – Pitești – Rm. Vâlcea route is merely used by 12.492 cars / day (*according to the Ministry of Transport*).

In view of the above, considering the need to build a motorway along Prahova's Couloir, the current study aims, among other things, to identify the best alignment for the construction of a fast transport connection. The large number of cars taking this route (figure 1 A) and the need to provide an efficient transport link, not only for strategic reasons but also to prevent disruptive events (figure 1 B), recommend this project as a priority.



Fig. 1 – Busy traffic along DN. 1 quite common during weekends – A; bizarre situation considering the rank of this transport route – European Connection, transhumance Vadul Cerbului – Sinaia – B
(foto: Dobre, 2008)

Most of the times, for financial reasons consultancy companies developing motorway projects neglect certain environment aspects (whether it is the local geology, geomorphology or flora and fauna). Although temporarily advantageous financially, this kind of approach may turn out to be several times more costly, when calculated against the entire operation period, as a result of environment related costs, maintenance or other hidden costs. Still, building at the lowest price proves sometimes more tempting than landscape integrated solutions.

These considered the current study aims to provide a methodology, a model, to help design such infrastructure in mountain areas, applicable further for the analysis of similar areas in the Carpathians. To this purpose, several field trips were taken so as to collect data and GIS techniques were used in lab analyses.

In terms of design, the chosen study area (The Posada Defile) is actually the most challenging section of the Bucharest – Braşov Motorway.

The first step in this endeavour was to identify, with the help of GIS techniques, surfaces suitable for the construction of such infrastructure that is, areas within the following parameters:

- over 26m wide;
- of low gradient;
- that do not overlap the existing road or railway infrastructure;
- with stable lithology.

At this stage, the previously prepared geomorphotechnical map was, as expected, a very useful tool (Dobre et al., 2011) (fig. 2).

The access point in the defile area, located at an absolute altitude of 622.5 m with Posada train

station as landmark, shall be considered kilometer 0+000 of this Section which stretches up to the junction with DN1, near Sinaia's Izvor Suburb (located at an absolute altitude of 770m) over a distance of 6.8 km (km 6+800) (figure 3).

Further, the motorway alignment was established by drawing the axis of the future infrastructure keeping in mind the above mentioned parameters. Along the axis, two parallel lines were drawn, 13m apart on either side of the axis, thus establishing the usable width of the motorway.

Based on the elevation contour lines extracted from 1:5000 scale topographic maps, through interpolation, a numeric terrain model was generated where each pixel equals 1 square m. At a later stage, based on the DEM, absolute elevation points were generated (over 121000 points), 3 m apart from each other, intersecting the previously established axis of the motorway (figure 4)

The longitudinal profile of this motorway section was determined by intersecting the road axis to the absolute elevation points established thus demonstrating that the low gradient requirement is met (fig 5). The difference in elevation for this motorway section, roughly calculated against the elevation of its starting point (kilometer 0+000) and that of its end point (kilometer 6+800), is 148 m. When analyzing the longitudinal profile of the motorway the following parameters are of interest: the ideal motorway profile (as per the mean gradient – represented in red), the actual motorway showing slight upward / downward variations (the yellow line), and the contour line of the existing landforms (the red line).

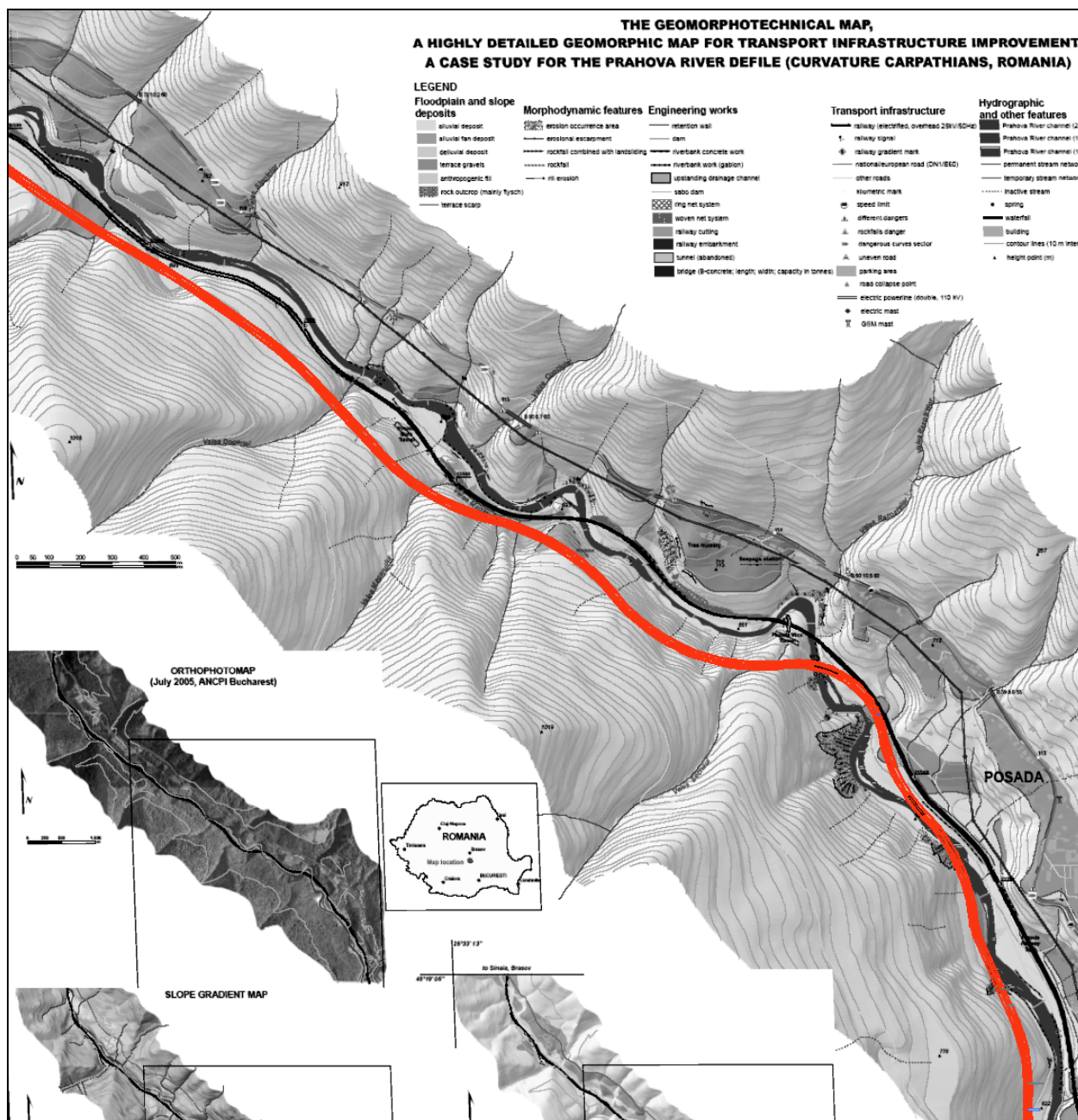
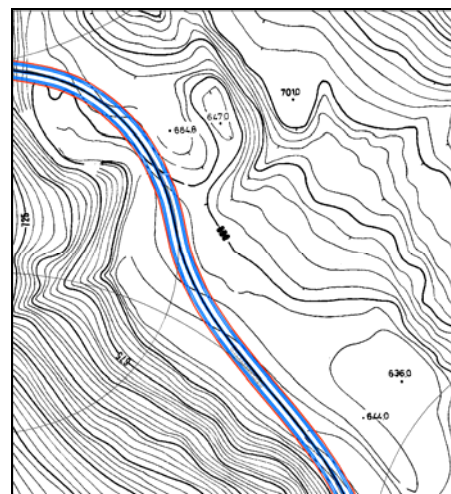


Fig. 3 – Motorway alignment, solution proposed for the Florești Basin



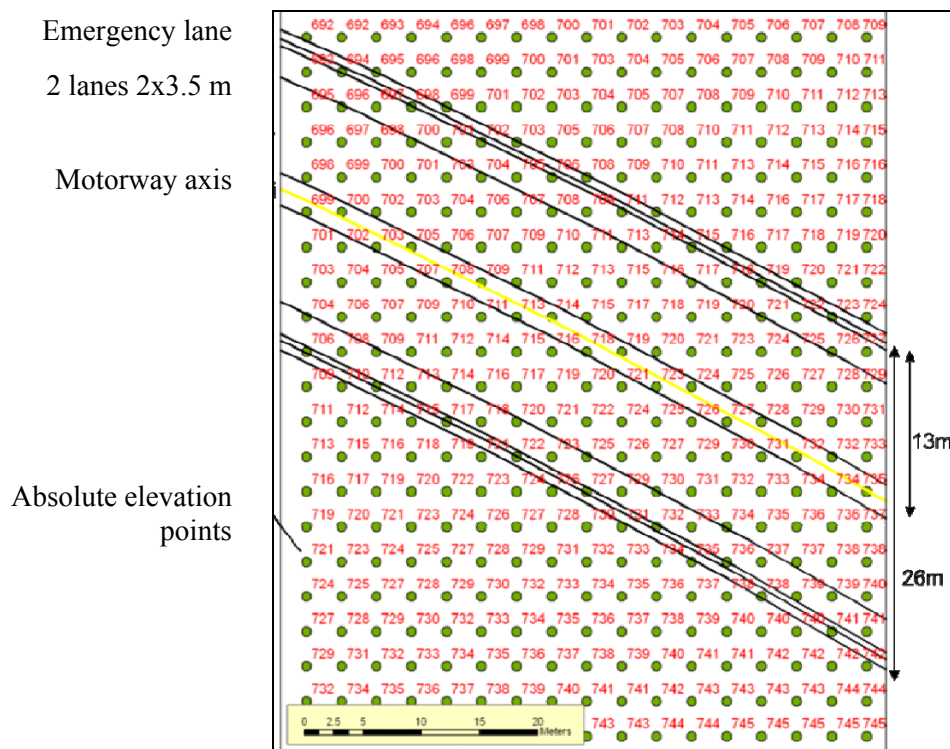


Fig. 4 – Configuration of the Posada Motorway Section against the absolute elevation points determined for this Defile area

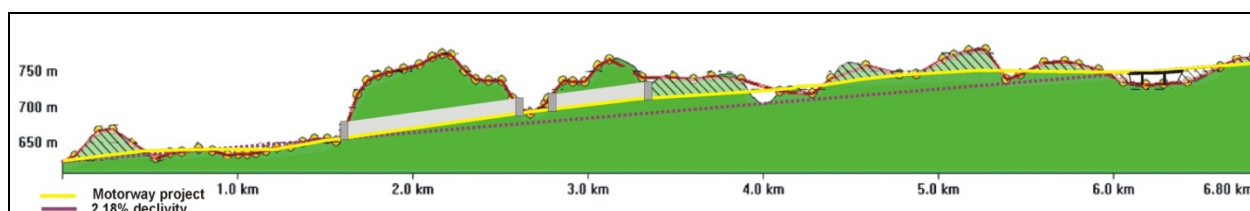


Fig. 5 – Posada Defile Section, longitudinal profile

The mean gradient of the Posada Defile motorway section, calculated as ratio between the difference in elevation and the length of the section, is 2.18%, an average value if calculated against gradient values of similar European road infrastructures crossing the Alps. By further analyzing the particularities of the motorway alignment, 3% gradient sectors were identified in the case of which specific regulations related to length and alternation with lower gradient sectors are to be observed. As per the European Normative an additional climbing lane is to be included in the design of long uphill sectors of 3% to 4% gradient and over whereas in the case of downhill steep sectors the design of an additional lane is necessary to prevent overuse of brakes which may overheat causing runaway vehicles. The length of the high gradient sectors identified along this motorway alignment does not require such technical solutions.

In order to properly analyze the motorway design, the 6.8 km long section was divided into 68 sectors, 100 m long, which were further included in

a database and analyzed against several parameters such as: absolute elevations at the beginning and the end of the sector, sector difference in elevation, elevation variation, and extreme absolute elevations within the sector (fig. 6).

The data obtained up to this point was included in a database with the help of which new data was generated through spatial analyses. Thus, by analyzing the motorway profile against the relief profile the technical solutions necessary along each of the 100 m long sectors could be identified: tunnels, cut and fill earthworks, floor, viaducts, etc (figures 7 and 8).

For instance, the tunnel shall be the best technical solution for instances where the difference in elevation is 20 and over for the same point as identified on the motorway's profile against the relief's profile. Also, should the difference in elevation be negative, take the case of a 7m difference, the best technical solution is fill earthworks (figure 9).

Attributes of fragment										
FID	Shape *	Id	km	mabsolut	masl	diferenta	tip	minim	maxim	variatie
0	Polyline	0	0.1	638.5	626	-12.5		622	638.5	+
1	Polyline	0	0.2	667	630	-37		638.5	667	+
2	Polyline	0	0.3	671	634	-37		667	671	palier
3	Polyline	0	0.4	647	637	-10		647	671	-
4	Polyline	0	0.5	624	640	16		624	647	-
5	Polyline	0	0.6	636	642	6		624	636	+
6	Polyline	0	1.6	654.5	656	2.5		650	658.5	- +
7	Polyline	0	0.7	637.5	642	4.5		636	638	palier
8	Polyline	0	0.8	642	644	2		637.5	642	+
9	Polyline	0	0.9	631	643	10		631	642	-
10	Polyline	0	1.1	635	644	10		633	635	palier
11	Polyline	0	1.2	642	645	2		635	642	+
12	Polyline	0	1.3	643	647	2		642	643	palier
13	Polyline	0	1.4	652.5	649	-4.5		643	652.5	+
14	Polyline	0	1.5	658.5	653	-6.5		652.5	658.5	+
15	Polyline	0	1	633	642	9		630	634	- + -
16	Polyline	0	1.7	723	0	0		654.5	723	+
17	Polyline	0	1.8	739.5	0	0		723	739.5	+
18	Polyline	0	1.9	766	0	0		739.5	768	- +
19	Polyline	0	2	758	0	0		742	766	- +
20	Polyline	0	2.1	769	0	0		758	769	+
21	Polyline	0	2.2	787.5	0	0		769	788	- +
22	Polyline	0	2.3	757	0	0		757	788	-
23	Polyline	0	2.4	740.5	0	0		740.5	757	-
24	Polyline	0	2.5	743	0	0		740.5	746	- +
25	Polyline	0	2.6	695.5	0	0		695.5	743	-
26	Polyline	0	2.7	692.5	0	0		689	695.5	- +
27	Polyline	0	2.8	710	0	0		692	710	- +
28	Polyline	0	2.9	741	0	0		710	741	+
29	Polyline	0	3	744	0	0		719	744	- +
30	Polyline	0	3.1	761.5	0	0		744	761.5	+
31	Polyline	0	3.2	766.5	0	0		761.5	769.5	- +

Fig. 6 – Parameters analyzed for each of the 68 motorway sectors identified

Technical solutions	Values
Floor	-5 la +5
Cut earthworks	+5 la +15
Tunnel	> +15
Fill earthworks	- 5 la -15
Viaducts	< -15

Fig. 7 – Technical solutions as per the established difference in elevation

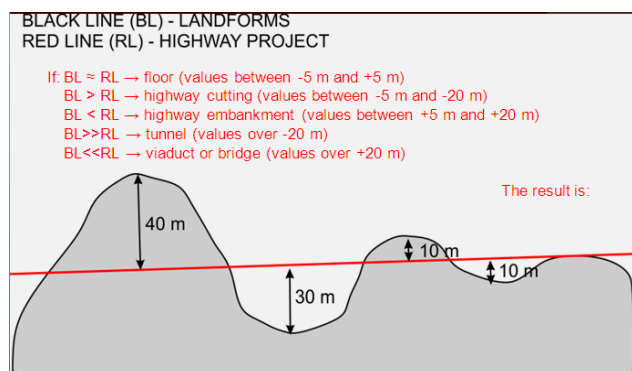


Fig. 8 – Interrelation between the two profiles

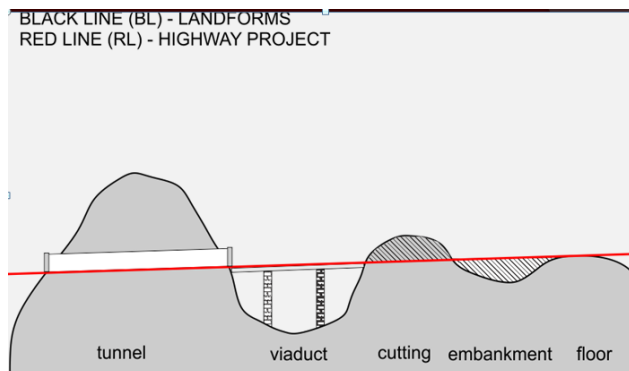


Fig. 9 – Technical solutions as per the difference in elevation between the two profiles

By reclassifying the 68 motorway sectors theme we could generate, for each of these, the best technical solution in line with the configuration of the relief (figure 10). The results thus achieved could be analyzed (figure 11). The identified

technical solutions could further be represented in a linear graphic of the motorway section indicating also their location on either side of the motorway (figure 12).

FID	Shape *	Id	km	masl	mabsolut	diferenta	tip	minim	maxim	variatie
48	Polyline	0	4.5	736	764	-28		0	0	
52	Polyline	0	5	745	767	-22		0	0	
67	Polyline	0	6.7	743	764	-21		0	0	
49	Polyline	0	4.6	738	757	-19		0	0	
39	Polyline	0	3.4	728	746	-18		0	0	
42	Polyline	0	3.8	733	749	-16		0	0	
59	Polyline	0	5.8	748	761	-13		0	0	
0	Polyline	0	0.1	626	638	-12		622	638.5	+
58	Polyline	0	5.7	752	764	-12		0	0	
66	Polyline	0	6.6	743	755	-12		0	0	
50	Polyline	0	4.7	740	751	-11		0	0	
3	Polyline	0	0.4	637	647	-10		647	671	-
33	Polyline	0	6.8	760	770	-10		0	0	
43	Polyline	0	3.9	730	740	-10		0	0	
60	Polyline	0	5.9	744	754	-10		0	0	
40	Polyline	0	3.5	732	740	-8		0	0	
57	Polyline	0	5.6	755	763	-8		0	0	
47	Polyline	0	4.4	734	741	-7		0	0	
61	Polyline	0	6	740	747	-7		0	0	
14	Polyline	0	1.5	653	659	-6		652.5	658.5	+
27	Polyline	0	2.8	704	710	-6		692	710	- +
41	Polyline	0	3.7	736	742	-6		0	0	
51	Polyline	0	4.8	743	748	-5		0	0	
13	Polyline	0	1.4	649	653	-4		643	652.5	+
35	Polyline	0	4.9	744	748	-4		0	0	
38	Polyline	0	3.6	735	738	-3		0	0	
45	Polyline	0	4.2	728	730	-2		0	0	
25	Polyline	0	2.6	696	696	0		695.5	743	-
6	Polyline	0	1.6	656	655	1		650	658.5	- +
8	Polyline	0	0.8	644	642	2		637.5	642	+
37	Polyline	0	6.5	742	740	2		0	0	
7	Polyline	0	0.7	642	639	3		636	638	palier
11	Polyline	0	1.2	645	642	3		635	642	+
12	Polyline	0	1.3	647	643	4		642	643	palier
34	Polyline	0	4.1	724	720	4		0	0	
62	Polyline	0	6.1	736	732	4		0	0	
64	Polyline	0	6.3	737	733	4		0	0	
56	Polyline	0	5.5	751	746	5		0	0	
63	Polyline	0	6.2	734	729	5		0	0	
65	Polyline	0	6.4	740	735	5		0	0	
5	Polyline	0	0.6	642	636	6		624	636	+
26	Polyline	0	2.7	700	693	7		689	695.5	- +
10	Polyline	0	1.1	644	635	9		633	635	palier
15	Polyline	0	1	642	633	9		630	634	- +

Fig. 10 – Technical solutions generated automatically through the classification of the database

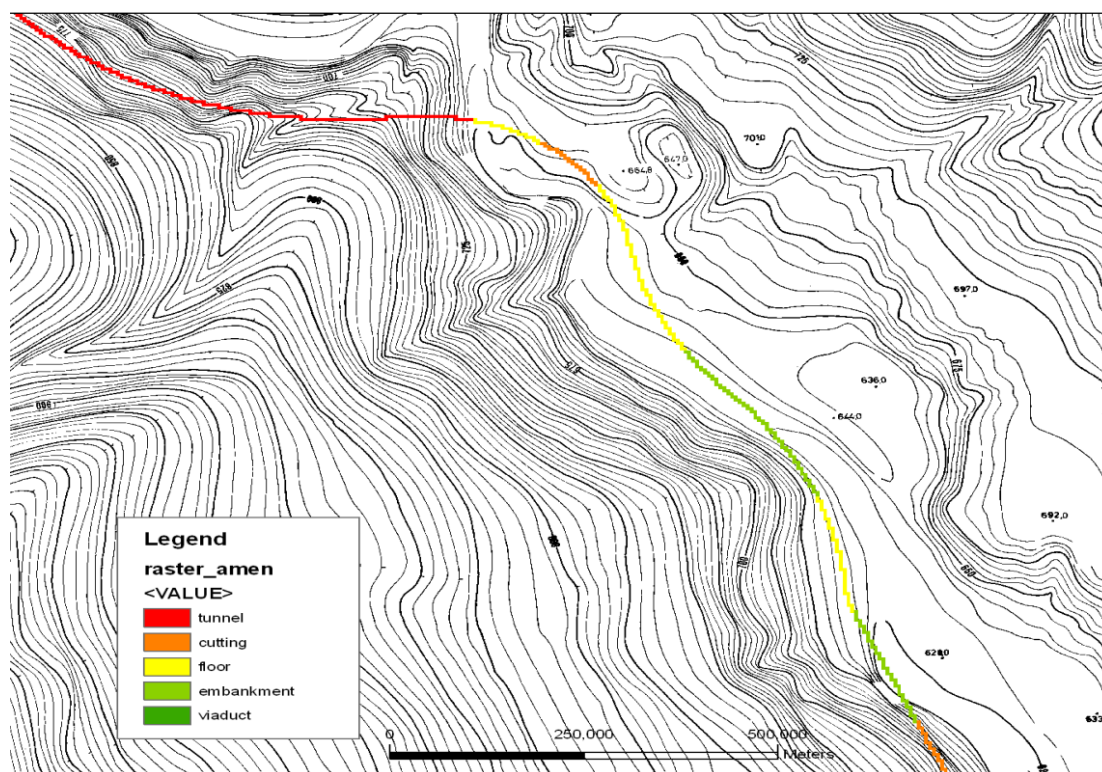


Fig. 11 – Graphic representation of the technical solutions identified as necessary after re-classification

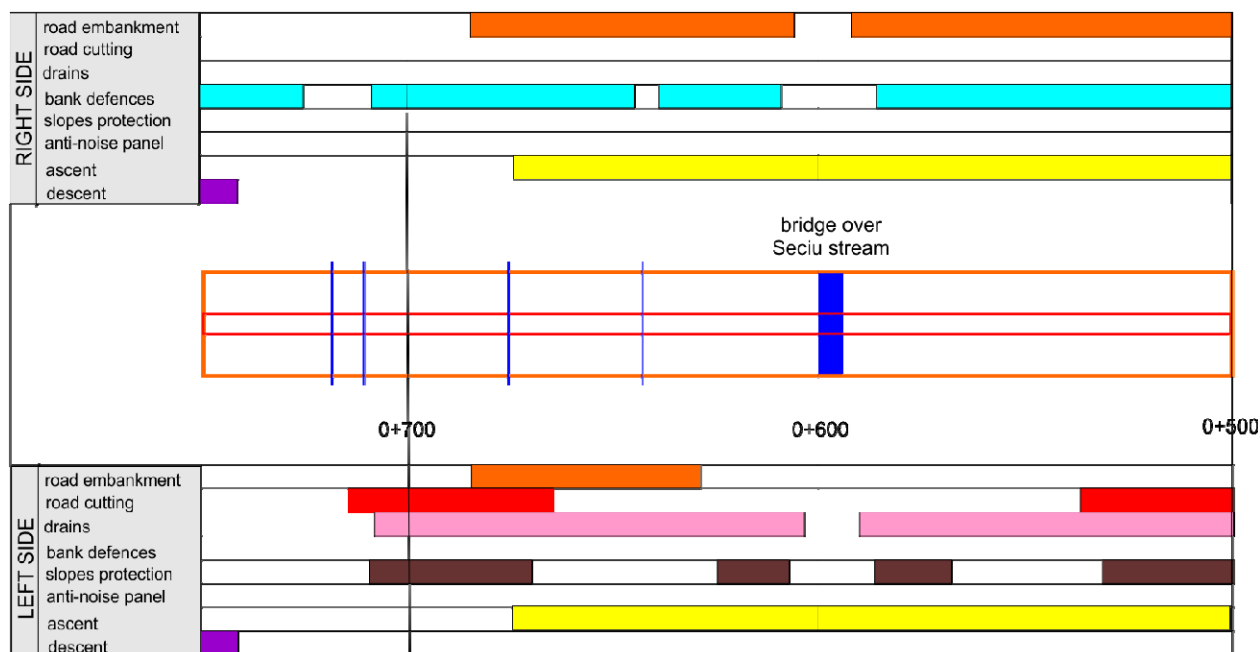


Fig. 12 – Location of the works necessary on either side of the motorway

The current study also takes on evaluating the feasibility of the presented design in terms of radius of the curves and horizontal curvature, extremely important parameters in determining the safest maximum speed. This analysis was carried out as per the European standards in force as presented in *TEM Standards and Recommended Practice*.

Each curved motorway sector was perfectly overlapped onto circles, as shown in figures 13 A and B, so as to calculate their radius.

As per the table presented under section 3.1.4 of the European Highways Design Standard based on the radius of curves four categories of safe speeds were identified (figure 14).

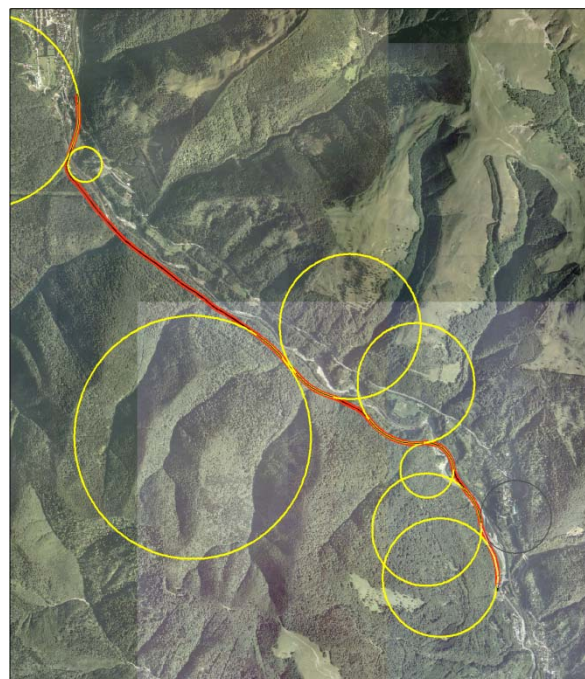
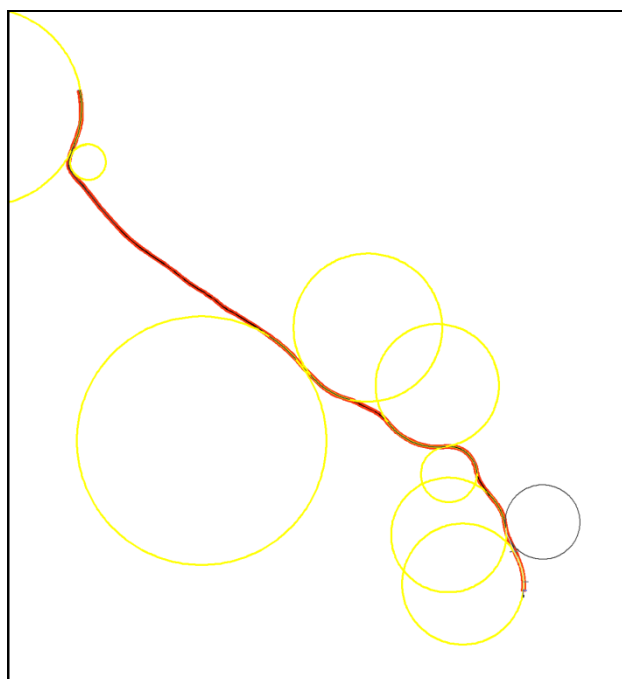


Fig. 13 – The sectors of the Posada Motorway Section that curve were overlapped onto circles

Safest maximum speed (km/h)	140	120	100	80
Minimum curve radius (m)	1000	650	450	240

Fig. 14 – Interrelation curve radius - safest maximum speed

Selected Attributes of AxAutoPoVL							
	FID	Shape ^	Id	1	raza	viteza_bru	viteza
▶	12	Polyline	8	7384.75	1175.35413	140	140
	13	Polyline	8	4401.2202	700.496612	122.886	120
	14	Polyline	8	3653.1001	581.426086	112.517	100
	15	Polyline	8	1657.91	263.872359	82	80
	30	Polyline	8	3611.6799	574.833667	111.889	100
	31	Polyline	8	2282.8201	363.332814	91.746002	80
	32	Polyline	8	2761.4199	439.506593	99.000603	80
	33	Polyline	8	4401.2202	700.496612	122.886	120
	34	Polyline	8	7044.7202	1121.235113	140	140
	35	Polyline	8	3402.3899	541.523141	108.716	100

Fig. 15 – Attribute table indicating the interrelation between ‘the perimeter of the circle’, radius’, ‘gross speed’ and ‘safest maximum speed’

The curve radius of ten of the curves occurring along the 6.8 km section was determined with the help of the GIS tool and the data was then introduced into the attribute table as new field. These values were calculated by measuring the lengths of the circles based on the following formula:

$$L=2\pi R$$

Based on the resulting values and considering the data in the table above, the recommended gross speed was determined for each of the analyzed curves, further the safest maximum speed (which may be lower or equal to the gross speeds determined) could also be established (figure 15).

By this exercise was determined that three of the curved sectors part of this Motorway Section require a speed limit of 80 km/h (sectors located near the entrance point in the defile area), another three curved sectors are to observe a speed limit of 100 km/h (also located in the first few kilometers) whereas the curved sectors forming the central body of this design allow speeds as high as 120km/h (two of them) and even 140km/hour (another two) (figure 16).

The motorway project vector was exported under .kmz format and then imported into Google Earth for a better visualization (figure 17).

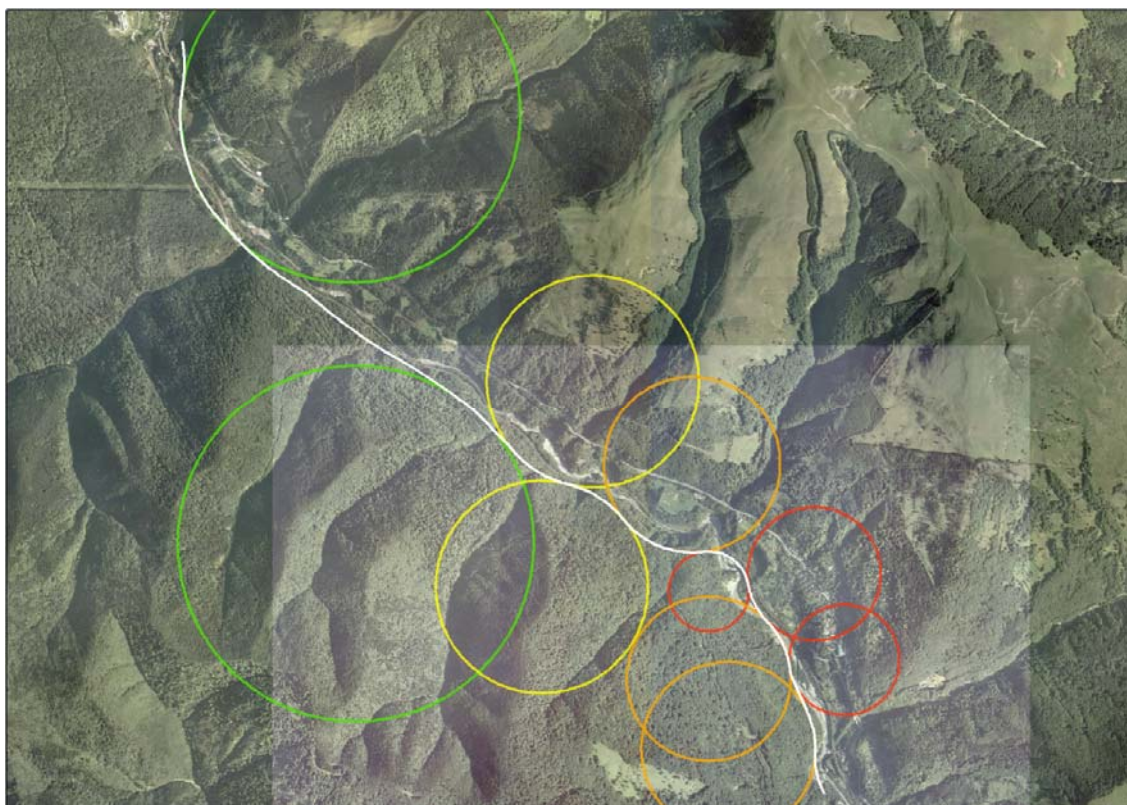


Fig. 16 – Graphic representation of the safest maximum speeds along the Posada Defile Motorway Section (red = max 80km/h, orange=max 100km.h, yellow=max 120km/h, green=maximum 140km/h)



Fig. 17 – The motorway project as imported under .kmz format into Google Earth

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