CRYO-NIVAL MODELING SYSTEM. CASE STUDY: BUCEGI MOUNTAINS AND FĂGĂRAŞ MOUNTAINS[1]

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Système de modèle cryo-nival. Étude de cas: les Monts Bucegi et les Monts Făgăraş. Les étages hauts des monts, situés généralement au-dessus de l'altitude de 1 800 m représentent une surface morpho-structurelle caractéristique. Cette-ci correspond au relief des cimes, plateaux et sommets hauts des massifs: le domaine d'extension appréciable de la surface d'érosion Borăscu (2 000–2 200 m), des cirques, vallées glaciaires et des cimes disposées autour des sommets principaux (Moldoveanu, Vânătoarea lui Buteanu, Omu, Bucşoiu etc.), tout comme sur les côtes des cimes hautes qui lient ces sommets. Le climat actuel des prairies alpines est plus doux que celui pléistocène, quand les glaciers aient occupé les origines des vallées de ces massifs, mais en comparaison avec cela des surfaces plus basses, il est pourtant rude et humide, défavorable au développement des forêts. Ceci est caractérisé par des températures moyennes multiannuelles basses (0^0 C), en atteignant même valeurs plus réduites (-2,5^0C au sommet Omu) sur la surface des sommets hauts. Les précipitations atteignent des valeurs multiannuelles plus de 1 200 mm, et environ 50% de celles-ci représente des précipitations solides. Le nombre des jours à gel varie en fonction de l'altitude (au sommet Omu il y a 260 jours/an). L'alternance du gel et dégel se produit intensément pendant les saisons de transition, tout comme les oscillations thermiques diurnes ont un rôle assez important sur la dégradation du relief, par des processus de gélifraction. Les gelifractes forment à la base des versants des cônes et des accumulations de débris. La durée prolongée de couche de neige (jusqu'à 217 jours par an au sommet Omu) contribue au modelé du relief, surtout sur les surfaces abritées contre la direction des vents dominants (ouest, nord-ouest et sud-ouest). Le compactage de la neige dans les bassins de réception de la base de l'abrupte, près avalanches, ont enfouisses des cirques nivaux suspendus tout comme ceux des origines des vallées: Moraru, Pripon, Mălin, Coştila, Alba. Le relief actuel formé de cimes et cirques glaciaires, de surfaces planes peu enclinées, et de pentes abruptes et découvertes représente une condition qui favorise l'activité des processus cryonivaux, gravitationnels et torrentiels. Les roches ont un caractère relativement prononcé de gélivité (gneiss, paragneiss, micaschistes, calcaires cristallins, calcaires, conglomérats) et elles sont fissurées, fait qui facilite l'action de la gélifraction. Dans le même temps, les surfaces rocailleuses, dénuées de sol, sur les crêtes (Moraru, Gălbinele, Picătura etc.) et les cimes les plus hauts, aux conditions peu favorables à l'installation de la végétation, assurent le développement des processus de dégradation du relief. En fonction des conditions mentionnées, il y a des processus de dénudation avec un caractère périodique. On distingue initialement l'action du couple gel-dégel et de la neige, auxquelles on ajoute des processus complémentaires, gravitationnels, l'érosion aréolaire et l'érosion torrentielle, qui s'assœient dans différents rapports d'interaction.

1. INTRODUCTION

During the Upper Pleistocene, both study areas stood below the snow line, where periglacial processes were extremely active. Supporting evidence in this respect is given by the presence of old periglacial deposits (scree, coluvium, eluvium, patterned ground and striated soils), most of them stabilized by soils and vegetation, which cover almost the entire high mountain area (Nedelea 2005).

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These deposits are accompanied by scarps present at all elevations, from the alpine and subalpine belts to the forest altitudinal belts. Postglacial evolution has given the Carpathian realm a new aspect.

Thus, in the investigated perimeters, the forest has advanced by more than 1,000 m upwards, irrespective of the various local conditions imposed by slope aspect, declivity and rock, the last one turning most often into a pedogenetic control factor. Above 1,750 – 1,800 m, in the realm of alpine meadows, subalpine meadows and barren rocks a cryo-nival zone has taken shape, where cryo-nival processes with seasonal manifestation have been stimulated by a cold climate, though milder than the Upper Pleistocene one (Niculescu 2005).

It is apparent that such processes are present at lower elevations as well, but without becoming prevalent. However, they cannot reach below the elevation of ± 1,500 m, roughly corresponding to the isotherm of 3ºC, which is considered to be the limit of active solifluction (Urdea 2000). At the same time, this elevation also overlaps the timberline of the mixed forests that develop on median mountain level, which roughly coincides with the timberline of beech forests (Oprea 2005).

2. GENERAL INFORMATION AND METHODOLOGICAL ISSUES

The high mountain steps, generally lying above 1,800 m altitude, represent a specific morphosculptural area of high summits, plateaus and peaks.

The most obvious landforms occurring here are the Borăscu erosion level (2,000 – 2,200 m), with a large extension, as well as the glacial cirques, troughs and arêtes situated around the main peaks (Moldoveanu, Vânătoarea lui Buteanu, Omu, Bucşoiu, etc.) and on the sides of the ridges that connect them.

The actual climate of the alpine meadows is milder than the Pleistocene one, when glaciers were occupying the upper stretches of the valleys. However, in comparison with the lowland climate it is harsh and wet, which makes it unfavourable for the growth of a wooden vegetation. Thus, yearly temperature averages are usually low, around 0ºC, or even less on the high peaks (-2.5ºC at Omu Peak), while precipitation exceeds 1,200 mm per year, half of this amount falling in the form of snow.

The number of frosty days varies with the altitude (for instance, the Omu Peak weather station records about 260 days/yr). The alternating freeze-thaw cycles, which are specific to the transitional seasons, and the daily thermal oscillations play an important part in rock decay by frost shattering. Consequently, gelifracts accumulate at the base of the slopes generating talus cones and fields. The lengthy snow cover (up to 217 days/yr at Omu Peak) contributes to modeling the relief especially in the areas sheltered from prevailing winds (blowing from the west, northwest and southwest).

Snow settling in the catchment areas dominated by scarps and avalanches have carved hanging nival cirques and semi-funnels, like those that are found at the headwaters of the Morarul, Priponul, Mălinul and Alba valleys.

The present relief, consisting of ridges and glacial cirques, gently inclined leveled areas and barren steep slopes, is a major control factor for cryo-nival, mass movements and erosional processes. The rocks (gneisses, paragneisses, micaschists, limestones, crystalline limestones and conglomerates) are prone to gelivation due to the presence of cracks and joints that encourage gelifraction. Likewise, the barren rocky areas on the highest peaks and ridges (the Morarul ridge, the Gălbinele ridge, the Picătura ridge, etc.), so unfavourable for the growth of vegetation, are highly exposed to weathering processes. Depending on the already-mentioned conditions, periodical denudation processes do influence the evolution of the landscape, primarily the freeze-thaw the cycles and action of snow, which are accompanied by mass movements, sheetwash, rill erosion and gully erosion.

This study has resorted to the topographic maps of the region on the scale of 1:25,000 and 1:50,000, aerial photographs, scale 1:50,000, the Negoiu, Cumpăna, Baiu, Comarnic and Braşov geological maps scale 1:50,000, as well as satellite imagery. At the same time, landforms have been mapped in the field and simple measurements of slope processes that develop above the timberline have been undertaken. The climate data have been provided by the nearest weather stations: Bâlea, Cumpăna, Curtea de Argeş, Sinaia Cota 1500, Lăcăuți and Omu Peak.

3. RESULTS

As previously mentioned, the ridges and slopes lying above 1,750 – 1,800 m altitude, beyond the timberline, are exposed most of the year to freeze-thaw processes, nivation and wind erosion. The analysis of Peguy climatogram shows that at Lăcăuți station (1,776 m), 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.

Thus, glacial-nival processes are specific to the last decade of November, the whole December, January and February and the first two decades of March, while a dry gelival regime is common to the remaining intervals. At the same time, the analysis of the mean number of days with freeze-thaw cycles reveals that above 1,750 – 1,800 m altitude such processes may occur all the year round.

1.1. Cryogenic relief

The actual frost-shattering, which continues on a smaller scale the Pleistocene processes, has been permanently polishing the relief, turning the summits into sharp ridges. In the Holocene, the process was considerably delayed, but on some escarpments it remained still active due to the frequent freeze-thaw cycles of the November-May interval.

Processes are more effective on the highly faulted, cleaved and diaclased dolomites and limestones, as well as on conglomerates (in the Bucegi Mts.) and on crystalline rocks (quartzitic micaschists, gneisses and paragneisses in the Făgăraş Mts.). Consequently, **castellated arêtes, glens and crags** were being formed (Fig. 1). Such landscape features can be seen in the Bucegi Mountains (the Morarului ridge with the Morarului crags, the Gălbinele ridge, and the Picătura ridge) and in the Făgăraş Mountains (the Buda saddle, the Podragu saddle, the Ucişoara saddle, the Râiosului crags, etc.). On the Bucegi plateau, wind together with weathering and rill erosion, is responsible for shaping pedestal rocks, which are scattered on the structural surfaces developing on the slopes of the Omu, Coştila, Babele, Caraiman, Piatra Arsă, Cocora and Lăptici peaks. Frost weathering widens the cracks and joints of escarpments generating new ones. **Gelifracts** accumulate at the base of the cliffs forming talus cones and fields. At the foot of the Bucegi Mountains, the biggest blocks are the result of the physical weathering of conglomerates and limestones. The present talus cones are underlain by older scree.

In the Făgăraş Mountains, screes 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 scarps with southern orientation (the side of the Arpăşelului ridge to the Fundul Caprei, where the scree is 980 m long), southeastern orientation (the side of the Râiosului ridge to the Râiosu Valley, where the scree is 1.3 km long) and eastern orientation (under the Lespezi Peak to the Călțun Valley). These screes are made up of big angular blocks of micaschists and limestones detached as faults and joints widened.

The screes are organized in various forms (Fig. 2): mobile screes, rock streams, specific to the sharp ridges that separate glacial cirques, as well as old and fossilized screes of periglacial origin. On steep slopes (25º – 45º) scree particles tumble, while on steep slopes (over 45º) they simply collapse; on slopes under 30º – 35º, screes begin to stabilise.

Fig. 1 – Castellated rocks on the eastern scarp of the Bucegi Mountains.

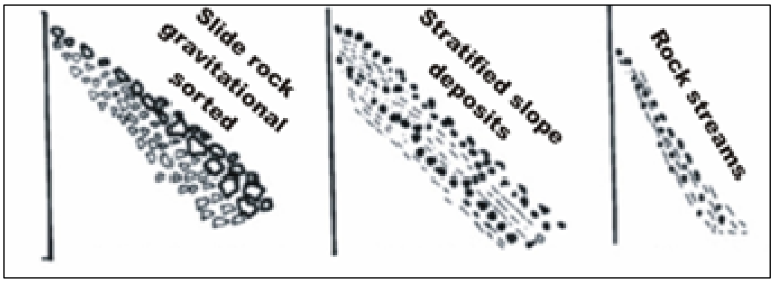

Fig. 2 – Types of mobile screes.

Solifluction occurs in the areas delimited by the annual isotherm of 3ºC (usually lying above 1,500 m altitude), on surfaces of 3º to more than 30º, which are underlain by thicker regolith and deeper soils. The maximum intensity of the process is recorded at elevations over 1,800 m, where frost penetrates more than 20 – 30 cm into the soil and lasts at least 3 – 4 months a year.

Solifluction lobes are visible in springtime on the surface of subalpine and alpine meadows, lending the topography a tumbling aspect. On the Bucegi plateau, solifluction develops frequently on the fine eluvium that covers the high ledges. In the Capra and the Buda catchments, such microforms are found above the timberline, generally on slopes with eastern, western and southern aspect. The process, which is encouraged by the traces left on slopes by animals and people, may affect the isolated trees that grow on the subalpine level.

Earth hummocks are circular mounds, 0.2 – 0.5 m high and 0.5 – 1 m in diameter. They are made up of materials generally having a sandy-loamy to loamy-sandy texture, with very few rock fragments. Their development is due to the vertical displacement of soil by frost heaving, under wet and cold conditions that seasonally favour ice formation. This seasonal ice that deeply penetrates the earth hummocks and the lateral pressure of the ice combined with the existing vegetation (usually tuffs of *Nardus stricta*), exacerbates or maintains these forms from one year to another. The hummock core is made up of earth material, as rock fragments are driven to the edges by frost heaving. Here and there, the formation of earth hummocks is stimulated by the mossy vegetation (*Polytricum juniperinum*), which develops properly under waterlogging conditions accumulating from one year to another (Beldie 1967).

Fig. 3 – Earth hummocks on the Lăptici Summit (the Bucegi Mountains).

In the field, such phenomena have been identified on the gently dipping surfaces (less than 18º) of the subalpine level, which experience waterlogging conditions due to snow stagnation, springs and poor drainage. For instance, in the Bucegi Massif, earth hummocks are found on the Lăptici – Plaiul lui Păcală (Fig. 3) and Blana summits. Likewise, in the Făgăraş Mountains they are spread on the Paltinu Plateau, the Năneasa and Râiosu – Muşeţeica summits, the western side of the Vistea Mare – Moldoveanu peaks, as well as on Mount Coastele and the eastern slopes of the Tarata, Corabia and Buda peaks.

The category of structured soils includes striated soils and patterned grounds. **Striated soils** are composed of parallel scores of rocks and earth materials that have a gentle dip (3º – 7º). Their genesis is linked either to the particles falling down along the slopes, or to the lateral migration of materials in the wake of freeze-thaw. Such soils have been identified inside the Orzaneaua Mare cirque in the Făgăraş Mountains (Fig. 4).

Fig. 4 – Striated soils on the cliffs of the Orzaneaua Mare cirque (the Făgăraş Mountains).

Patterned grounds are a sequence of more or less regular polygons with earth materials at the center and coarse fragments on the edges. They develop on almost flat surfaces and are ranging from 0.6 to 3 m in diameter. When the slope dips by about 5º, the polygons lengthen and sometimes turn into striated soils. Their sorting is accomplished vertically, due to frost heaving and gravitational sinking, or horizontally to lateral pressure. Out in the field patterned grounds have been mapped and investigated in the Făgăraş Mountains, more exactly in the Râiosul cirque, where they consist of rocks of various sizes, from several cm to 20 cm, and in the Orzaneaua Mare cirque, 2,000 m high, where they have a loamy-sandy core surrounded by particles less than one centimeter in size.

1.2. Nival relief

Nivation and nival processes represent the action of snow on the relief, which is accomplished by mechanical (settling, erosion, and accumulation) and chemical processes (dissolution and oxidation). The nival microrelief comprises a vast range of forms that vary depending on the rock affected by snow. Nivation is usually associated with gelivation (Ielenicz 1982). The process depends on snow accumulation in areas devoid of a wooden vegetation and becomes manifest at elevations above 1,500 m, where the snow layer can be more than one meter thick. The deflation caused by the wind piles up the snow in sheltered places, which in most cases overlap the areas where avalanches occur. The long stagnation of snow over platform or slope deposits leads to settling processes resulting in specific microforms (microdepressions, niches and nival cirques), the location of which is encouraged by the presence of pre-existent negative microforms.

The best nivation conditions are found on shaded slopes (with northern and northeastern aspect), where snow can persist from one year to another, as it happens in the Bucegi Mountains Valea Albă (the White Valley), whose name is so significant in this respect. Snow avalanches occur most often in the February–April interval, when the thickness of the snow layer is significant and the snow is quite loose because of temperatures above 0ºC. Their severest effects are recorded on the eastern scarp of the Bucegi and on the cliffs that surround the cirques in the Făgăraş Mountains, where high declivities generate an impressive modeling force. The avalanche chutes that scar all the cliffs shelter the snow until April and even longer on the northern slopes. In the rest of the year, the dominant process is gully erosion.

The materials detached from thalwegs and slopes are deposited downstream, in the valleys (Valea Seacă a Caraimanului, Valea Albă, Valea Coştilei, Valea Mălinului, Valea Urzicii, Valea Priponului, etc.) forming block agglomerations often mixed with fallen tree trunks. In the Bucegi Mountains, avalanches pose a threat to the forest only above 1,200 – 1,300 m altitude.

Nival microdepressions develop at the base of gently dipping slopes, in talus deposits, saddles and torrential catchment areas, or on interfluve surfaces with low declivities. Accumulated snow exerts a pressure that leads to the settling of weathered deposits (deluvial or eluvial), and consequently 1–2 m deep microdepressions emerge, either oval in shape or elongated down the slope. Such forms can be seen on the Bucegi plateau, as well as in the Făgăraş Mountains (on the Borăscu erosion level, under the Ciocanu, Piscul Negru and Podeanu peaks, or at the bottom of the glacial cirques and troughs, e.g. Capra, Călțun, Paltinu, Izvorul Moldoveanu, etc.).

Nival niches are placed both on slopes and within torrential catchment areas (which seasonally function as avalanche chutes) above 1,600 m. They are formed by the long stagnation of the snow pack in the respective areas. Nival niches have steep slopes and bottoms frequently capped with mobile scree, which indicates the presence of gelivation processes and suggest the intensity of their action. The deepening of the niches was accomplished especially during the Pleistocene, when the snow was covering the talus formed by mechanical weathering and caving-ins on the headwaters and in the catchment areas hanging above some knick points. However, their development was controlled by the presence of harder rocks, capped with thinner superficial deposits, which hindered settling due to snow pressure. The small size of nival cirques may be explained by the high gradient, over 25º – 35º, which unleashed especially avalanches and to a lesser extent nival processes, such as snow accumulation, stagnation and transformation. These cirques are hanging above the headwaters of the valleys in which they are situated and are separated by the thalweg through a break of slope. Such forms can be seen on the headwaters of some streams in the Făgăraş Mountains, e.g. as the Izvorul Moldoveanu, Orzaneaua Mare and Orzaneaua Mică, Buda, Izvorul Podul Giurgiului and Fundul Caprei. In the Bucegi Mountains, they are specific to the headwaters of the Morarului, Priponului, Mălinului, Coştilei and Alba valleys, a typical example of nival niche being Blidul Uriaşilor (The Gigants' Dish) (Fig. 5).

Fig. 5 – Blidul Uriaşilor – The Giants' Dish – (nival niche that supplies an avalanche chute) lying on the headwaters of the Valea Alba in the Bucegi Massif.

The forms of periglacial accumulation are represented by horseshoe-shaped **protalus ramparts**, with concavities facing uphill, which close inside small depressions. Protalus ramparts are in fact an accumulation of coarse angular rock debris, resembling a moraine, consisting of material that has slided from perennial banks of snow, and lying parallel to the slope that produced it. These forms are maintained by avalanches, but the present geomorphic processes contribute to their degradation. Protalus ramparts can be seen in the Făgăraş Mountains, both in the Izvorul Podu Giurgiului glacial cirque and in the Capra cirque, lying north of the homonymous lake (Fig. 6).

Fig. 6 – Protalus rampart in the Capra cirque (the Făgăraş Mountains).

4. CONCLUSIONS

Regarding the impact of cryo-nival modeling agents on the local relief:

- Slope instability largely depends on slope systems, rock nature, and anthropic impact and especially on climatic conditions.
- Gelifraction is extremely active above 1,800 m altitude where screes are very mobile.
- The frequency and intensity of freeze-thaw cycles increases with altitude.
- The most important part in slope dynamics is played by the wet snow avalanches, which begin in April on the sunny and semi-sunny slopes and in May on the shaded and semi-shaded ones.
- On sunny slopes avalanches correspond to alternating freeze-thaw cycles, while on shaded sides they occur simultaneously with the pluviometer maximum.
- The gradient controls frost effectiveness and consequently the higher the declivity the more intense the gelifracts transportation processes.
- The cliffs of rocky massifs are prone to gelifraction, which explains the formation of scree both on the subalpine and the alpine levels.
- In the cryo-nival zone, slope is a major control factor, its variations influencing the geomorphic processes as follows:
- With gradients higher than 45º, the only processes are the cryoclastic ones and rock falls. Occasionally, avalanches may sweep away the rocky walls, which explains why they are barren.

- Between 45º and 35º, apical cones and scree fields are formed, while the main modeling processes are rock falls, avalanches, mudflows and rill erosion.
- Between 35º and 25º accumulation prevails. The already mentioned processes lead to the formation of material deposits sorted out in different ways. Thus, when the role of gravity is essential, the granulometry of deposits shows a normal distribution, but when rheological transport is the main factor, deposit granulometry is reversed due to the progressive dissipation of energy. Sediment stratification is conditioned by the sequence of phenomena.
- Between 25º and 5º, the most active processes are reptation and gelifluction, which generate stratified sediments.
- Below 5º is the realm of cryoturbation processes whose intensity depends on lower temperatures, which are responsible for the occurrence of patterned grounds, rock accumulation and bulging areas.

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