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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; Kozlowska and Raczkowska, 2002; Palacios et al., 2003; Brancaleoni 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 occured 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 Negoiul 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 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).

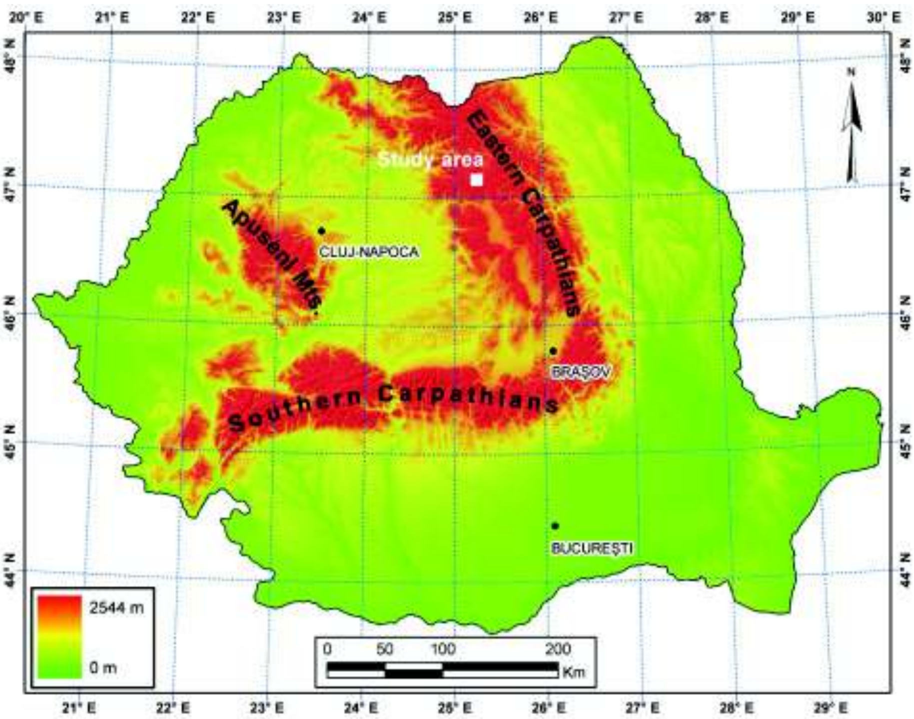

Figure 1. **Map location of the study area in Romania**

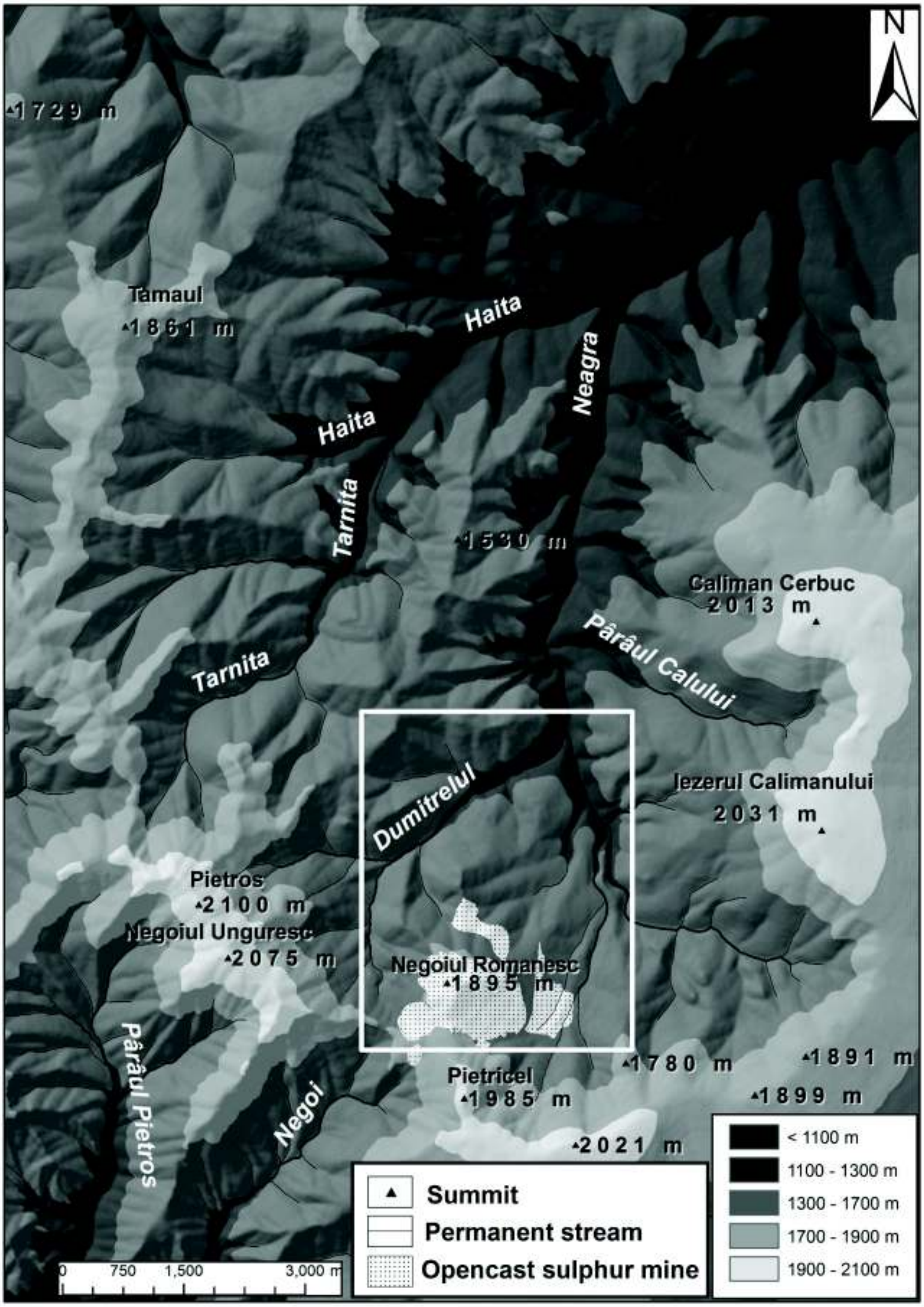

Figure 2. **Central part of Calimani Mountains: the white rectangle represents the sulphur mining affected area**

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 successin 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.

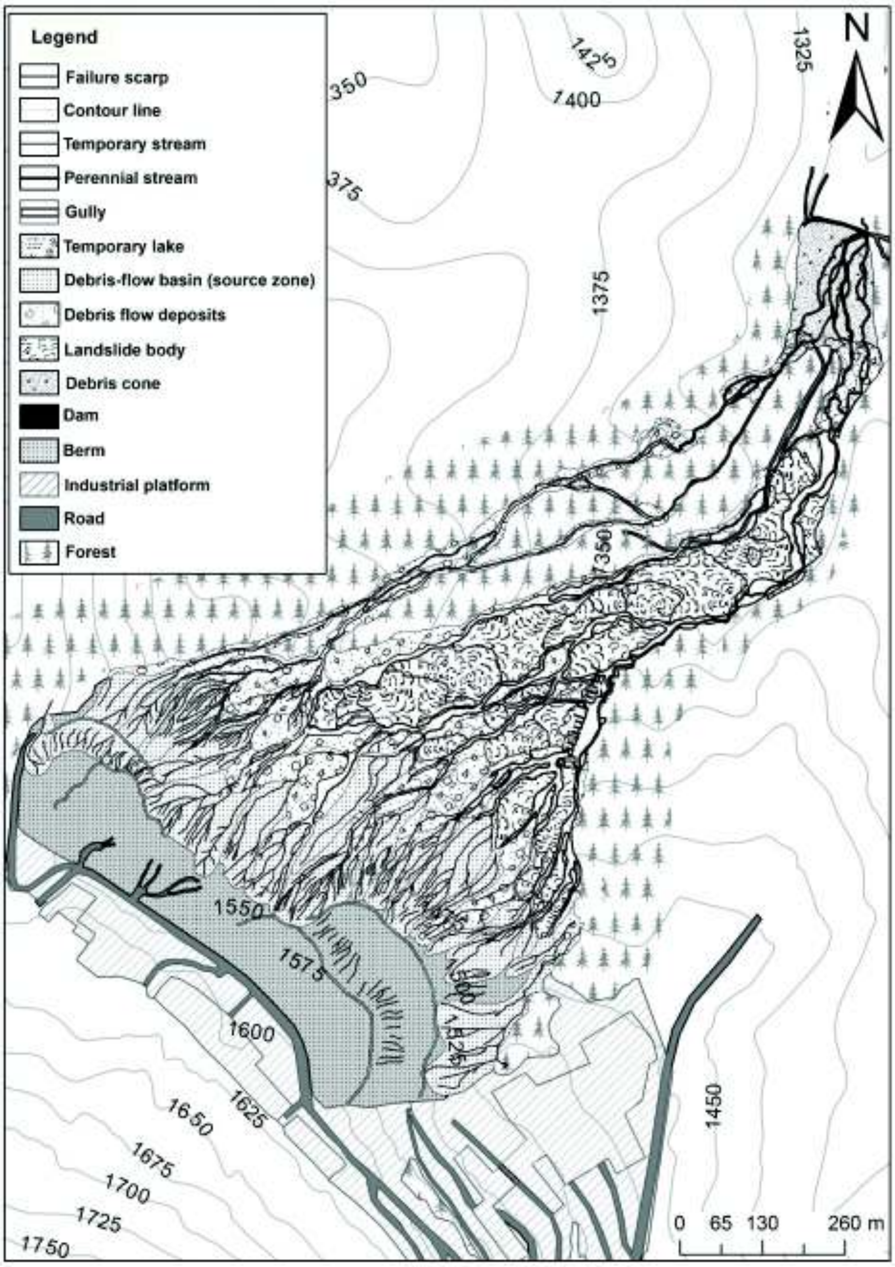

Figure 3. **Geomorphological map of Pinul waste dump area**

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**

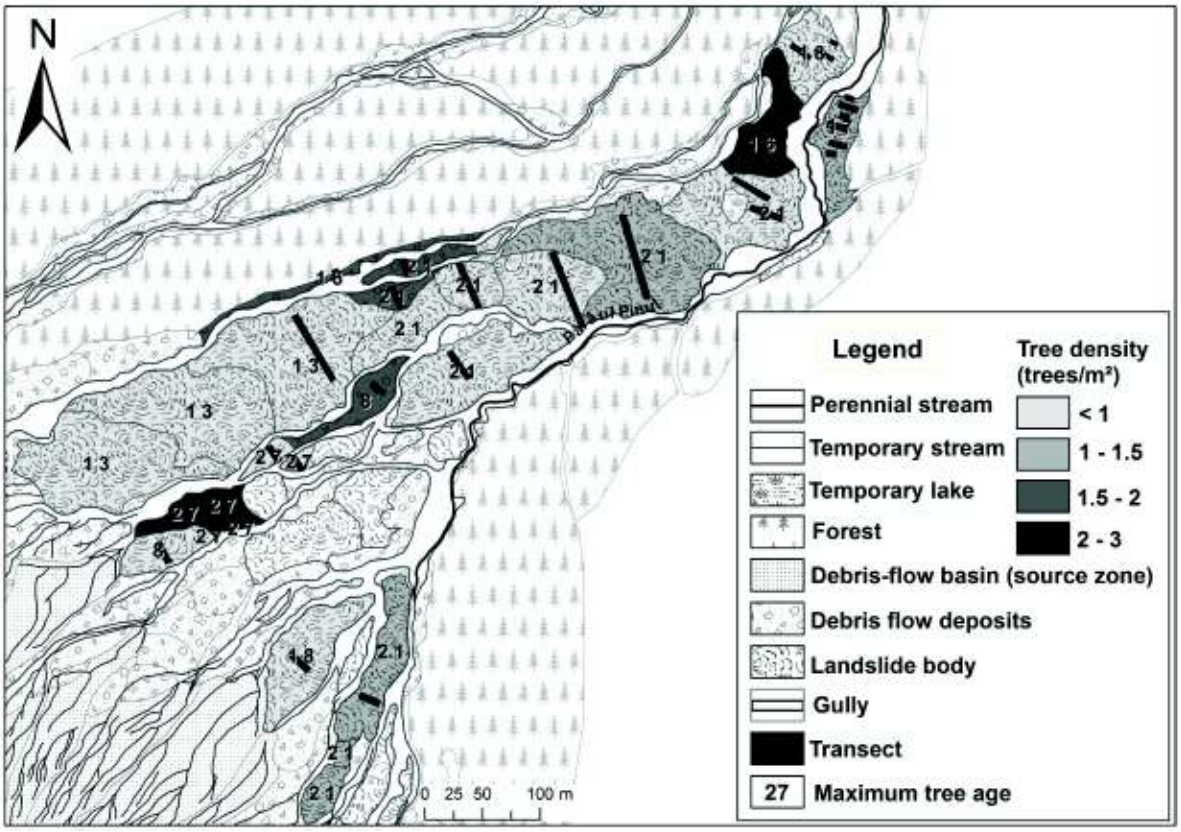

Figure 6. **Map of the density of the trees and maximum tree age**

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/m²)			
			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 lansliding 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 m^3 of material had be 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/m^2) 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 derivates 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 occured 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 bassin, 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.

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