# LANDSLIDES INCIDENCE IN THE PIEDMONT OF BAIA MARE URBAN AREA
## (CASE STUDIES)

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***ABSTRACT.*** **the landslides incidence in the piedmont of baia mare urbana area cae studies)**. The General Urban Plan (GUP) of Baia Mare municipality requires the study of expected susceptibility for landslides in order to build infrastructure within sustainable development conditions. The complexity and diversity of local geographic area factors, strongly affected by the human pressure, favours the triggering and extension of slope processes in the municipality's piedmont area. To prevent some major imbalances it is imperative to implement some adequate measures based on in-depth studies.

***Key words:*** landslides, terrain energy, slope, the digital model of the land.

### 1. Introduction

In the Protocol of the Accession Treaty of Romania to the European Union, Annexe VII – Section Environment (31st of March 2005, Brussels), there are included strict obligations, with precise deadlines, that apply to our country in respect to risk management.

In accordance with these, but also before accession, the Romanian legislation paid attention to this (Law 124/1995, Government Decision 124/1995, Law 575/2001, Government Decision 382/2003, Government Decision 447/2003, Ministry of Public Works and Territorial Arrangement Order 62/N/1998, etc. together with the specific urban planning, buildings' location, design and construction authorization, such as intervention measures in order to diminish the destructive effects, regulations).

Out of these, the Government Decision 447/2003 refers, in particular, to the *Methodological elaboration norms and to the content of natural risk maps for landslides and floods.* The law stipulates in chapter I, article 3 (2) that "*the natural risk map for landslides is the document upon which the county council can declare an area as landslide risk area*", and in article 4 it is mentioned that, based on these maps, *"the*

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*authorities of the public local administration .... declares, monitors and ensures the management of crisis situations in case landslides occur, thus establishing prevention measures and reducing the natural risk for landslides, as well as the authorization conditions for construction performance in the respective areas".*

## 2. Methodology

The elaboration of land's susceptibility map for urban area landslides was based on the two methodologies, one from the Government Decision 447/2003 concerning the *Methodological elaboration norms and to the content of natural risk maps for landslides and floods*, materialized in the *Writing guide of risk maps for slopes landslides to ensure construction durability – Indicative GT-019-98* and another, derived from the first and improved, tested and used at the Institute of Geography of the Romanian Academy. Both take into account the most significant natural and anthropic indicators that compete for triggering landslides.

In this paper, cartographic modelling techniques derived from the ESRI programs package (Map Algebra from ArcGIS Spatial Analyst) were used. To have the landslide susceptibility map, a susceptibility indicator was measured taking into account the factors which control the landslides generation: lithology, slope, terrain energy, land usage, precipitation and seismicity.

*The Probability Indicator of Landslides generation* (PL) was measured using ArcGIS and a series of functions from Spatial Analyst. It was hypothesised that landslides cannot occur on areas with the smallest slope (0–2°), neither on areas occupied by bodies of water, watercourses and swamps. For these areas, the PL value will be 0. The values were grouped in four susceptibility groups: without susceptibility (0-2), low (2-4), medium (4-6), medium-high (6-7) and high (7-10).

### 2. 1. The elaboration of thematic maps.

*Slopes map for Baia Mare urban area.* The largest part of the urban area has slopes between 0-1$^{o}$, corresponding to couloir Săsarul. Here it is included the cliff of 4-5 m from the right and left side of the river, the cliff of 20-25 m till the Cărbuneasa Valley; towards the Lăpuş grassland, with a distinct top with a slope of 10-20$^{o}$; these areas present a high durability but, are easily flooded in absence of regulation and channel maintenance. This is the case of Craica beck, angled, a little deepened and for the most part not dammed up; if in the superior and medium course, the minor channel, although angled, has shores of 1-3 m with slopes up to 30-50$^{o}$, in the inferior course, towards the confluence with Lăpuş, it is a little embedded, shores' slope not exceeding 10-15$^{o}$ (figure 1).

The piedmont strip between the Borcut and Usturoi valleys, gradually narrowed from west to east, is characterized through slopes of 15-25$^{o}$, the contact with the mountain area (slopes of 30-40$^{o}$) being trenchant. Besides, here, most landslides were identified. Among the conditions of favourability of their triggering we mention the abundance of clay fraction from the piedmont deposits, the contribution of surface and phreatic leakage from the neighbouring mountain area and the use, sometimes improperly, of the terrain, including construction. *This area is the most vulnerable to the risk of geomorphologic processes (landslides), requiring an attentive monitoring.*

*Terrain's energy map.* This geomorphologic indicator is extremely important for establishing the altimetric *"potential"* of a standard area. Actually, it represents the difference between the maximum and minimum altitude related to 1 $km^2$ ($m/km^2$).

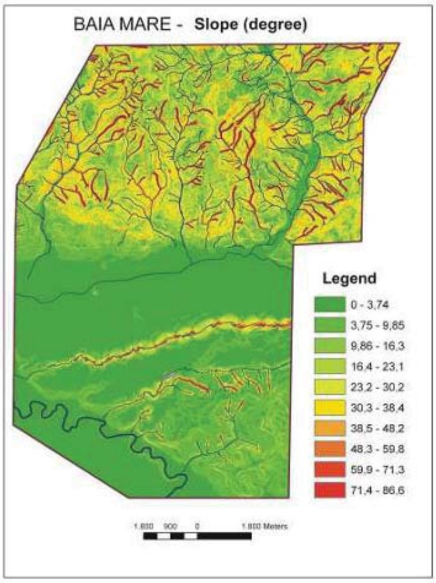


**Figure 1**. Slopes Map

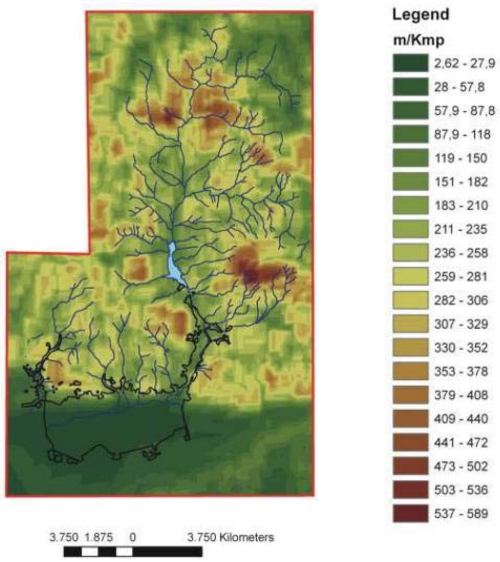


**Figure 2**. Terrain's energy map

On the similar cliff from the right side of Săsar, the terrain's energy gradually increases up to values of 260-280 $m/km^2$ close to Usturoi Valley and between Sf. Ioan – Vicleanul Mare valleys, at the north limit of the urban area. Precisely, in some isolated areas of the urban area from the left side of Borcut Valley, values of 450-470 $m/km^2$ (figure 2) are recorded. These high values create special difficulties both for building the constructions and for the infrastructure elements (access roads, sewerages, water supplies, gas and electricity networks etc.), but also increase the vulnerability coefficient for landslides.

The current expansion of the residential area of Baia Mare municipality is performed, just along the Săsar piedmont and the Baia Mare-Seini glacis, meaning it is built in contraindicated sectors from a geotechnical perspective, due to the semi-consolidated materials (gravel and boulders from the proximity volcanic area, with a rich clay content). In the given slope conditions (predominant 10-25$^o$), these have a high susceptibility towards the fluvial-denudational (ravines, streams) and landslides.

The north piedmont sector of the urban area can be differentiated in a few sectors (figure 3):

*Red - Usturoi Valley sector.* Although it has steep slopes, it has a lower morphodynamic potential, the substratum of sedimentary deposits being built from rigid andesitic rocks.

*Flowers Hill sector* has a medium morphodynamic potential, the expansion of sedimentary rocks from the substratum being relatively low.

*Cross Hill sector* constitutes an area with low morphodynamic potential, restrained by the presence on the surface of rigid andesitic pyroclastics.

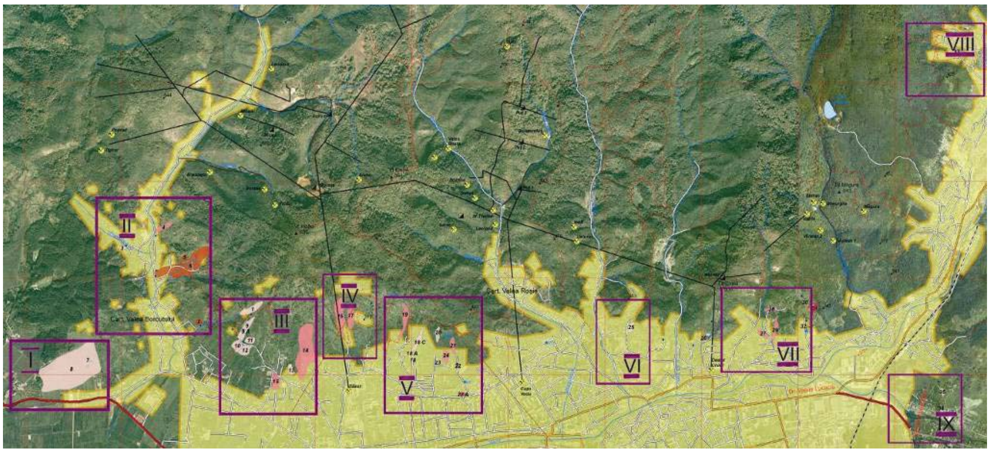


**Figure 3.** Landslides location.

*Amadei – Firizei Valley sector.* Here, the coluvio-proluvial deposits have a large development, and towards the east side, eruptive rocks fixed till the glacis' base appear. The here and there steep slope and the high expansion of the pannonien sedimentary rocks in the quaternary deposits' substratum determine a high morphodynamic potential.

*The Firizei Valley upstream sector* reveals an alternate development of the pannonien and quaternary deposits, with a genetic complexity of the glacis. The piedmont deposits were removed from erosion between the Săsar river and the volcanic formations, and at the base of the erosion glacis formed on the sedimentary formations, a coluvio-proluvial accumulative glacis was formed. The erosive sector is characterized by slopes of 8-15$^o$, and the accumulative one has lower dips of 8$^o$.

In the piedmont level of the Baia Mare urban area 9 perimeters with 37 landslides were analyzed (table 1).

**Tabel 1**. The genetic and morphometric characteristics of the landslides .

| No. | Code | Length (m) | Width (m) | Surface (ha) | A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 275 | 55 | 1,43 | A1d | B2 | C2 | D1 | E2 | F1 | G2 | H2 |
| 2 | 2 | 75 | 60 | 0,38 | A1c | B2 | C3 | D1 | E2 | F1 | G2 | H1 |
| 3 | 3 | 55 | 45 | 0,22 | A1d | B1 | C3 | D1 | E2 | F1 | G2 | H1 |
| 4 | 4 | 195 | 45 | 0,87 | A1a | B2,3 | C3 | D1 | E3 | F1 | G2 | H1 |
| 5 | 5 | 94 | 45 | 0,41 | A1c | B2,3 | C3 | D1 | E3 | F1 | G2 | H1 |
| 6 | 6 | 645 | 130 | 7,66 | A1c | B2 | C2 | D1 | E2 | F1 | G2 | H3 |
| 7 | 7 | 230 | 135 | 3,34 | A1a | B2 | C2 | D1 | E2 | F1 | G2 | H2 |
| 8 | 8 | 634 | 372 | 7,95 | A1d | B1,2 | C2 | D1 | E1,2 | F2 | G3 | H3 |
| 9 | 9 | 265 | 55 | 1,45 | A1d | B2 | C2 | D1 | E2 | F1 | G2 | H2 |
| 10 | 9A | 45 | 30 | 0,12 | A1b | B2,3 | C3 | D1 | E2 | F1 | G2 | H1 |
| 11 | 10 | 110 | 90 | 0,98 | A1d | B2 | C3 | D1 | E2,3 | F1 | G2 | H1 |
| 12 | 11 | 100 | 65 | 0,62 | A1d | B2 | C2 | D1 | E2 | F1 | G2 | H1 |
| 13 | 12 | 110 | 80 | 1,02 | A1d | B2 | C2 | D1 | E2 | F1 | G2 | H2 |
| 14 | 13 | 110 | 50 | 0,57 | A1a | B2 | C3 | D1 | E2 | F1 | G2 | H1 |
| 15 | 14 | 580 | 150 | 7,88 | A1a | B2 | C2 | D1 | E2 | F1 | G2 | H3 |
| 16 | 15 | 175 | 74 | 1,25 | A1d | B2 | C2 | D1 | E1,2 | F1 | G2 | H2 |
| 17 | 16 | 400 | 75 | 2,93 | A1a | B2 | C2 | D1 | E2 | F1 | G2 | H2 |
| 18 | 17 | 220 | 71 | 1,37 | A1a | B2 | C2 | D1 | E2 | F1 | G2 | H2 |
| 19 | 18 | 122 | 21 | 0,29 | A1d | B2 | C2 | D1 | E2 | F1 | G2 | H1 |
| 20 | 18A | 34 | 16 | 0,06 | A1a | B2 | C2 | D1 | E2 | F2 | G2 | H1 |
| 21 | 18C | 250 | 28 | 0,85 | A1d | B2 | C2 | D1 | E2 | F1 | G2 | H1 |
| 22 | 19 | 375 | 38 | 1,63 | A1a | B2 | C2 | D1 | E2 | F1 | G2 | H2 |
| 23 | 20 | 150 | 42 | 0,58 | A1d | B1,2 | C2 | D1 | E2 | F1 | G2 | H1 |
| 24 | 21 | 191 | 46 | 0,77 | A1a | B2 | C2 | D1 | E2,3 | F1 | G2 | H1 |
| 25 | 22 | 93 | 27 | 0,24 | A1a | B2 | C3 | D1 | E1 | F1 | G2 | H1 |
| 26 | 23 | 128 | 67 | 0,79 | A1d | B2 | C2 | D1 | E1,2 | F1 | G2 | H1 |
| 27 | 24 | 51 | 21 | 0,10 | A1c | B2 | C3 | D1 | E1 | F1 | G2 | H1 |
| 28 | 25 | 114 | 52 | 0,50 | A1d | B2 | C2 | D1 | E2 | F1 | G2 | H1 |
| 29 | 26 | 63 | 32 | 0,19 | A1a | B2 | C3 | D2 | E2,3 | F2 | G3 | H1 |
| 30 | 27 | 135 | 49 | 0,58 | A1a | B1 | C2 | D1 | E1 | F2 | G2 | H1 |
| 31 | 28 | 137 | 50 | 0,61 | A1a | B2 | C2 | D1 | E2 | F1 | G2 | H1 |
| 32 | 29 | 315 | 34 | 0,96 | A1a | B2,3 | C3 | D1 | E2,3 | F1 | G2 | H1 |
| 33 | 30 | 44 | 21 | 0,09 | A1a | B4 | C3 | D2 | E3 | F1 | G3,4 | H1 |
| 34 | 31 | 140 | 43 | 0,51 | A1b | B2,3 | C4 | D1 | E2,3 | F1 | G2 | H1 |
| 35 | 32 | 73 | 22 | 0,16 | A1d | B2,5 | C3 | D2 | E3 | F1 | G2 | H1 |
| 36 | 33 | 41 | 27 | 0,11 | A1a | B2 | C3 | D2 | E3 | F3 | G2 | H1 |
| 36 | 34 | 34 | 15 | 0,04 | A1a | B2,4 | C3 | D1 | E2 | F1 | G2 | H1 |
| 37 | 35 | 80 | 35 | 0,25 | A1d | B2,3 | C3 | D1 | E3 | F1 | G2 | H1 |

A1 – contemporary landslides (a – active, b – reactive, c – inactive, d - stabilized), A2 – historical landslides; B – landslide causes (1 – anthropogenic, 2 – excessive humidification, 3 – steep slope, 4 – land overloading, 5 – under-digging); C – Shape of landslide area (1 – circular-cylindrical; 2 – translational; 3- random; 4 - mixed); D – Relation with the geological structure (1 – consistently; 2 – by-levels); E – Flank slope (1 – under 10º; 2 – 10-30º; 3 – over 30º); F – Position of landslide level (1 – at the contact between the dome and the bedrock; 2 – in the bedrock; 3 – in the cover deposits); G – The depth of landslide level (1 – superficial, under 1 m; of low depth, 1-5 m; deep, 5-20 m; very deep, more than 20 m); H – The surface of landslide terrain (1 – low landslides, under 1 ha; 2 – medium landslides, 1-5 ha; 3 – large landslides, over 5 ha).

The main characteristics of the landslides from "The Guide concerning the landslides' identification and monitoring and establishing the intervention framework solutions over the land for preventing and reducing their effects, in order to satisfy the security requirements in construction exploitation, reconstruction and environmental protection” – Ind.GT 006-97, elaborated by ISPIF S.A in the year 1998, are:

***Case studies.***

**GRIVIȚA district AREA** (figure 4)

The area from the south of the Cross Hill is relatively stable, due to the reduced expansion of sedimentary rocks at the surface. In the median section of the street, in the performed digging for the grating of some new houses, a reduced thickness of the quaternary deposits (less than 1 m), the substratum being formed of volcanic pyroclastics. The fountains have a depth of 6-7 m, the water level being of 4 m.

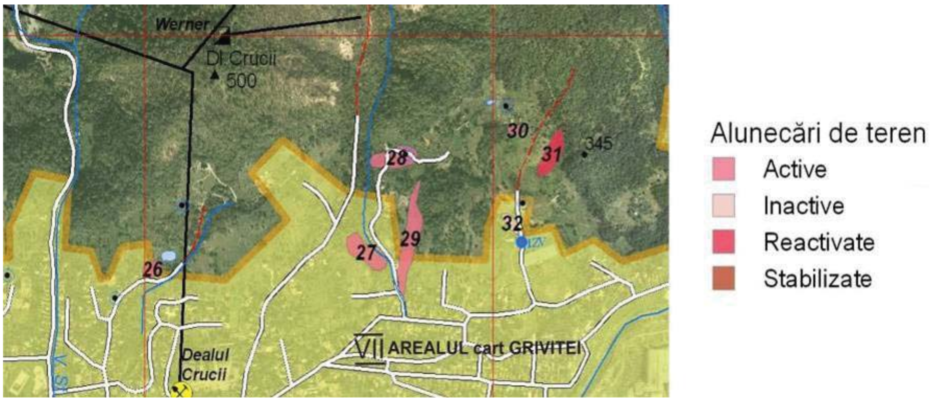


**Figure 4**.Grivița distric area

**Landslide 26 – from Plaiului street.** It is situated upstream of the stable area with a volcanic pyroclast in substratum. It is an active landslide, in a constructed area, determining chinks in the grating and the walls of a house, as well as land unevennesses determined by the landslide (figure 5).

**Figure 5**. Landslide from Plaiului street

At the superior side of the landslide, there is lowland, where the water is accumulated under the shape of bonds with bulrush. This suggests the presence of a deep landslide, a separation of a significant mass of ground, not just a superficial landslide.

The surface of the landslide is of 0,19 ha, maximum length of 63 m, medium width of 30 m. There are no data in respect to the rocks from the substratum of the quaternary rocks, but probably this is formed from clays and pannonien marls. The cover quaternary deposits, while digging, have a thickness larger than 1,5 m, being made from flysch deposits, formed from a brownish matrix, where fragments of grey, porphyria andesites are clamped. The permanent stagnation area of the infiltration water from the upstream, permanently moistens the rupture level, determining the active character of the landslide. In upstream of the landslide area, in the yard of the Greek-catholic monastery "Saint Mary", in a fountain of 5 m depth, the level of the water is at – 4 m. The landslide is **active**, deep, but of small dimensions with a risk coefficient $\mathbf{K_m=0,38}$ and occurrence potential from **medium to high.**

On Colinei street 3 landslides were outlined, arranged in both shores of the Amadei Valley.

**Landslide 27 from the right flank of the Amadei Valley.** In the year 2008, the land owner from the right flank of the valley opened ground and started its offset, fact which determined a landslide both in the area of digging, as well as down the river (figure 6). The land dislocation was produced at the end of the summer and determined the dislocation towards the east side of the watercourse from Amadei Valley. The landslide affected the air duct that ensures the gas supply. In the downstream of the landslide, swamps with hydrophilic flora, streams of water that come out from quaternary deposits, active trenches of dislocation of quaternary deposits. The land slope in the right flank of the Amadei Valley is of 30-40º, and above the landslide area, the slope decreases at 10-15º.

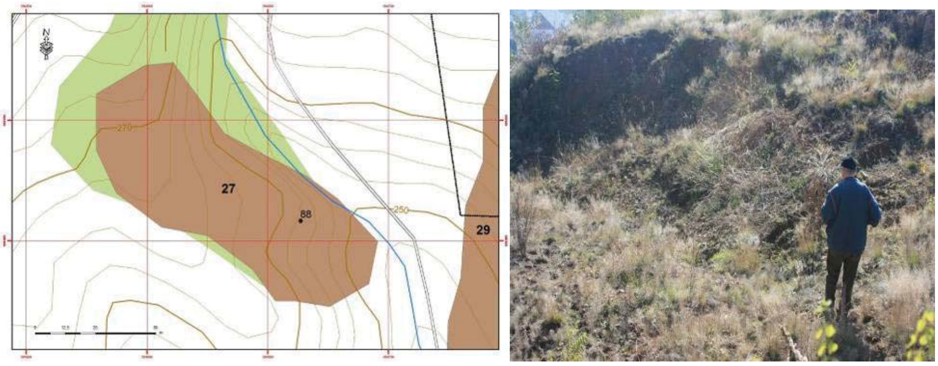


**Figure 6**.Landslide 27

The landslide surface has 0,58 ha, maximum length 135 m, medium width 45 m. It also affects the pannonian substratum, at surface being observed fragments marls and grey clays (with rare clayed feldspars). In the active area of the landslide, a consistent contribution of underground water is observed. The landslide is **active,** determined by anthropic digging works in a sector with a lot of underground water, having a risk coefficient **$K_m$=0,42** and an occurrence potential from **medium to high**, of low depth, affecting the superior section of the pannonian sedimentary subasment.

**Landslide 28 from the left flank of Amadei Valley.** The land is uneven, with hills and depression areas. The last house on the street, situated on the landslide, has chinks and even dislocations in grating and walls. The road that crosses the landslide (asphalted in the year 2007) is uneven in such a way that the downstream section is lowered and raised with asphalt. On the landslide's surface more humid areas with hydrophilic flora are observed.

In the superior part of the landslide a coomb with a height of 1,5 m is observed, in the flysch quaternary deposits, with andesitic fragments clamped in a grey-brownish detritic matrix. The land's slope in the coomb area (performed with the bulldozer for the land's grading) is of 35-40º, in the lower side of the landslide decreasing to 15-25º. The landslide's surface has 0,61 ha, maximum length 137 m, medium width 50 m. The landslide affects the flysch quaternary deposits, the substratum where the landslide occurs being represented probably by clays and pannonien marls. The water's level in the fountain from upstream of the house situated in the landslide area is at -1 m. In conclusion, the landslide is **active**, of low depth, having a risk coefficient **$K_m$=0,41** and occurrence potential from **medium to high.** The priming of the landslide was probably of gravitational nature, due to the rather steep slope, due to the accumulation of surface waters at the contact of the quaternary deposits with clay pannonien deposits from the substratum.

**Landslide 29 from the offset crest area.** In the year 2008 a crest made from pyroxene andesites was built to make a hotel's grating. On the west flank of this crest, at the contact between pyroxene andesites and pannonien sedimentary rocks, previously a landslide occurred. Currently, the landslide's surface includes many households, up until the superior section of the old landslide, with offsets that modified the land's morphology. At the superior section of the landslide there is a grassy landslide level, active at the base, with more landslide levels (figure 7). The land's slope is rather high (30-35º), the landslide being favoured also by the overloading with constructions from upstream. The landslide's surface has 0,96 ha, maximum length 315 m, medium width 34 m. The landslide substratum is made of clays and pannonien marls, at the contact with pyroxene andesites. The household from the superior section of the landslide has 2 fountains, with a depth of 5, respectively 7,5 m (the upstream fountain, only has infiltration water, and the one downstream of 5 m, has water all the time, underlining the discontinuous distribution of the groundwater in the landslide mass). In conclusion, the landslide is **active**, developing into an area with steep slope, having a risk coefficient **$K_m$=0,28** and a **medium** occurrence potential.

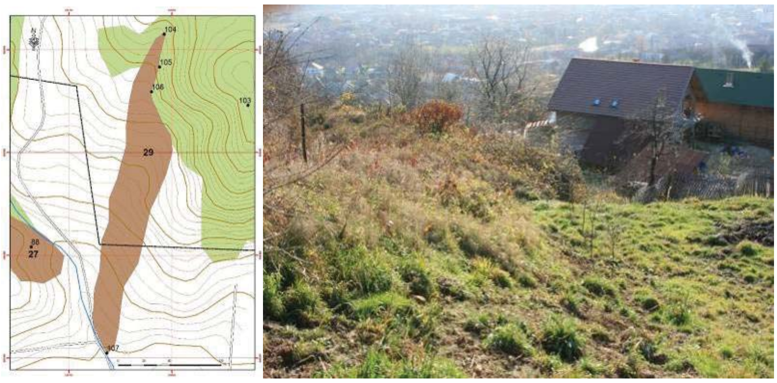


**Figure 7**. Landslide 29

The south part of the Viilor Hill (situated between Amadei and Vicleanul Mare Valley) has a characteristic terrain: a succession of cvasihorizontal *plateau* (at least three), separated by steeps, sometimes wooded. This sector is the most representative (on the Baia Mare municipality's urban area) for the deep landslides, with the gravitational separation and dislocation of some larger land surfaces. Curiously, this landslide type has almost no effect over the existing buildings, with the exception of those situated exactly at the base of the dislocation steeps. It is determined the existence of some areas with water and accumulation contribution for these at the base of the dislocation steeps (now stable), whose draining off allows the removal of one of the risk factors.

*The superior plateau.* It is developed next to the inferior limit of the pyroxene andesites, on the marls and pannonien clays substratum. It is an accumulation surface of the surface waters and precipitation. A former swamp area was transformed, here, into a pond. Probably, the stagnant waters determined, here, the downstream dislocation. Currently the surface is drained enough and it does not seem to be a risk factor anymore for the downstream area.

*The intermediary plateau.* It is easily angled and does not have swamps, although at the base of the dislocation comb there is a substantial water accumulation. It is present only in the east side of the area, towards the west it is spliced in medium slope at the inferior plateau.

*The inferior plateau.* It is limited by a declivitous area towards the north (probably dislocation declivitous), where swamp areas with bulrush appear.

*The water tanks ledge,* probably a fluvial ledge, not landslide, is spliced with a similar surface, situated towards the west, in the andesites area. It has a low steep in the north side, of almost 8 m, with groundwater contribution at the base.

For stabilizing the location where water tanks are built, at the base of the steep and on its tor, a concrete culvert was built along an access road. Between this and the water basin there is a sour land, with *Phragmites communis* and *Equisetum.*

**Landslide 30 – from the tor of the dislocation steep between the superior and the intermediary surface (Cerbului Street No. 29).** Here, the house built exactly on the margin of the dislocation steep presents more grating and walls chinks, even if the grating is deeply inserted. The dislocation steep has a height of almost 8 m, the terrain's slope being of 60º.

*Measures.* The surface 0,09 ha, maximum length 44 m, medium width 20 m.

*Ecological data.* The landslide's substratum is represented by pannonien marly-clay sedimentary deposits.

*Hydrological data.* The superior surface had swamp area (one transformed into a pond, others being drained off). There are two fountains, one (that from downstream) with paved walls, depth 2 m, the water (of good quality) being at the level of 0,2 m. The upstream fountain is made of concrete, has a depth of 3 m, the water being situated at the level of -1,0 m.

*Conclusions.* **Active** landslide, of medium depth, of gravitational nature, due to the overloading from the top of landslide's front, having a risk coefficient **$K_m$=0,38** and occurrence potential from **medium to high.**

***Conclusions***

- The area with the most active current processes (landslides) corresponds to the piedmont level from the right side of Săsar, parasitized at the contact with the ledge of debris cones of the feeders (Borcut, Rosie Valley, Usturoi, Sf. Ioan Valley). On the piedmont level of Baia Mare municipality there were identified, topographic lifted and mapped a number of 37 landslides, totaling 49,76 ha; they were classified as active, reactive, old/inactive and stabilized. In absence of stabilization works, the ratio between these categories is continuously changing.
- Most landslides develop on small gullies, concave, with a slope between 10-30º and which continuously accumulates precipitation on the surface of the clays and pannonien marls.
- The ground water is irregularly arranged, which gives it a character of secondary factor.
- The landslides are for the most part of low depth, affecting just the cover superficial deposits. They rarely affect the superior side of the pannonien sedimentary deposits (landslides: 7 Cemeteries-Dura, 8 8 orchard Dura, 18A Ciocârliei Est Street, 27 Colinei Street downstream); there was identified only one deep landslide, dislocating large masses of rocks and affecting a larger land surface (Colonia Topitorilor Street)
- Exactly in the piedmont areas where no landslides were made reference of, sometimes chinks in the buildings' foundation with built levels in the last 5-7

years are signalled, due to either chosen grating solutions, or to overloading the land with buildings; this phenomenon can occur, especially, in areas with a slope higher than 10º.

- Other cause of the landslide triggering can be: damaged drainage works, broken water pipelines, water accumulation (anthropogenic or natural) at the superior side of the area with landslide risk or in their inside, overloading with buildings on the location with increased steeps, under-digging or due to some heavy construction.
- Landslides in the piedmont zone are mostly old; in the past the piedmont surface was used just for orchard, vineyards or light construction.
- The correction works of the terrain and the water sewerage from piedmont, lead to the stabilization of many areas with landslides. Because an area where landslides occur will always present a reactive risk in relation to these, it is necessary to periodically verify the performed designs and their rehabilitation in case some damages are signalled.
- From field observations results that the superficial landslides and of low depth can be efficiently stabilized by performing quard ditches upstream from the built surface and through sewage of the temporary or permanent becks.

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