The 3D analysis of Valea Viei mudflow morphodynamics, Buzău Subcarpathians

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Abstract. The study presents the preliminary results of the field investigations carried out on the morphology and dynamics of Valea Viei mudflow within April 2005 - March 2006 interval. Detailed topographical surveys and the monitoring of the mobile landmarks position spread over the whole mudflow area have been undertaken during each fieldwork campaign. Based on the surveys, four DTMs were obtained at a seasonal scale and used to extract level and volume changes for each morphological unit of the mudflow. Transversal and longitudinal profiles, derived from DTMs, were used to obtain an accurate view of the detailed morphology (cracks, landslide waves, lateral pressure ridges etc.) as well as to quantify their dynamics. The monitoring of the mobile landmarks position trajectories allowed us to get the morphodynamic zonation of the mudflow body as follows: i) the most dynamic sector (10.5-17 m/month) develops in the central part, overlapping both on the lower limit of the main source area and on the upper third of the flow channel; ii) the moderate active sector (1-9.5 m/month) occupies the up-slope area of the mudflow, respectively the part of the main-source area between the escarpments and the narrowing sector; its main feature is the co-existence of rock falls which affect the scarps, of the steplike landslides on the lateral flanks and of the mudflows in the axial part of the main source area; iii) the less dynamic sector stretches over the median and lower parts of the flow channel; here, the intra-seasonal displacement velocities are very uniform but varies inter-seasonal between 5-6 m/month in spring-early summer interval and 0.5-2 m/month during winter.

The one-year seasonal pattern of the mudflow dynamics, for the entire study area, reveals great discrepancies between the most active spring - summer interval (9.2 m/month), the moderate-active late summer - autumn (6.1 m/month) and the less dynamic winter season (4.8 m/month).

1. Introduction

Former studies conducted in the Subcarpathian Curvature area (Bălteanu 1974, 1976, 1983) defined as being typical for Buzău Subcarpathians several mudflow morphodynamic types: i) mudflow with fixed source areas – dynamic equilibrium state, with small reactivations across the main scarp and lateral slopes, ii) mudflows partially reactivated – with periodically reactivations due to high rainfalls and different kinematics, texture and depth of the deposits, iii) completely reactivated mudflows – material moving rapidly and simultaneously from the scarp, lateral slopes or tributaries. The mudflows characterize the steeper slopes, consisting of a succession of marls, clays and sands, while the displaced material is very heterogeneous, with a dense presence of illit and montmorillonit, meaning that superior Atterberg limit is overrun in the presence of more than 10 % of water (Bălteanu, 1983). The transition between slope modeling imposed by fluvial erosion / mass movements is made by mudflows depending on the water quantity, the morphological configuration and the geotechnical properties of the sedimentary deposits.

In the Romanian literature, many landslide studies may be found, due to the natural favorability of the mountainous and hilly areas. The regional studies are focused on general aspects concerning the morphology and the morphodynamics of the landslides, based on large scale geomorphological mapping or topographical survey (Badea and Posea, 1953, Surdeanu, 1975a-c, 1990, 1994; Bălteanu, 1976, 1983; Mac, 1997; Ielenicz, 1977/a, 1977/b;

Grecu 1985, 1997; Popescu, 1990; Grecu and Josan, 1995; Cioacă, 1996; Dinu and Cioacă, 1997; Mac and Irimuş, 1998; Sandu, 1999; Ene, 2002;), earthquake-induced landslides (Bălteanu 1979, 1999), land-use changes and landslide dynamics (Dinu and Cioacă 1996; Muică and Bălteanu, 1995), frequency, cyclicity and the correlation between rainfalls and landslide occurrence (Surdeanu and Zemianschi, 1991; Dinu and Cioacă, 1997, 1999), distribution, inventory and classifications (Ielenicz 1970; Bălteanu, 1983; Grecu, 1985; Surdeanu, 1998; Rosenbaum and Popescu, 1996; Constantin and Chendes, 1997; Ielenicz et al. 1999), landslide vulnerability and risk analysis (Cioacă et al. 1993; Surdeanu, 1994; Bălteanu et al., 1996; Grecu 1996, 1997; Dinu and Cioacă, 1999; Constantin, 2002).

Concerning mudflows *stricto-senso*, there are just a few studies based on the observations related to dimensions and speed changes, correlated with favorability and triggering factors, helping in the reconstruction of the former pulsations (recorded data concerning different parameters of lateral pressure ridges or the terminal, accumulative sector), as well as in the possibility of determining the future dynamic behavior (Badea and Posea, 1953, Tufescu, 1959; Josan, 1979; Bălteanu, 1974, 1976; Constantin, 2002).

Synthesis studies, in which slope mass movements, regarded as functional relief units, are well fundamented, were realized by Tufescu (1966), Donisă (1968), Brânduş (1981), Mac (1997), and Surdeanu (1998). Based on experimental case-studies Bălteanu (1983) outlined the way in which the transfer of material between river channels and slopes is realized. In his study, M. Ielenicz (1984) deals with the correlation between slope and structural units, relief steps, valley generations, and the way in which is reflected in the intensity of morphodynamic potential. Ichim and Rădoane (1986), are studying landslides as extreme phenomena related to river dams, Popescu (1990) studies the meander-landslide relation and the evolution of cuesta surfaces through landslides in the southern part of Transylvania. Sandu (1998), based on the assessment of denudation ratio, outlines slope typology and evolution, while Armas et al. (2003) introduces in landslide assessment the use of probability theories, pointing also the importance of human perception related to the event.

At international level, the studies concerning mudflows are based on several surveys related to seasonal variability of the daily speed movement, the groundwater level changes correlated with different ways in which surface water is infiltrating (depending if the surface is frozen or not), correlation between soil temperature and pore water content, seasonal and yearly dynamics (Jackson et al., 1996; Parise and Guzzi, 1992; Varnes and Savage, 1996). The knowledge of different physical, chemical and mechanical parameters proved also to be vital (Angeli et al., 1996, Herrmann 1997, Klotz 1999).

Along with the development of remote sensing, digital photogrametry, modern topographical surveys and GPS, their support in the study of mudflow spatial distribution and dynamics increased considerably (Gilli et al., 2000; Kimura and Yamaguchi, 2000; Malet et al., 2000, 2002). Combined all together, the methods mentioned above are leading to an easier understanding and 3D representation of the mudflows, and also to a more accurate behavior analysis (Genet and Malet, 1997; Pasutto and Silvano, 1999, Flageollet et al., 2000).

The main objectives of this study are: i) to get insight into the detailed morphology, i) to assess the morphometric changes in relation with the controlling factors, and iii) to propose a morphodynamic zonation based on the spatial and temporal patterns of the mudflow dynamics (displacement velocities).

2. Study area

The study area is situated in Manta-Muscel Hill, more precisely within Valea Viei catchment (a right tributary of Buzău River), on its right slope, along a small tributary called Valea Vladii sculptured on a north-east oriented cuesta front (Fig. 1). The mudflow has about 600 m length covering a 140 m relief energy but the lowest part is covered by a young dense forest (15-20 years) and almost stable, so that the monitoring is carried out just on the dynamic and relatively bare surface. The monitored bare mudflow develops between

390m and 302m. The layers dip into SSW direction while Valea Vladii is south - north aligned imprinting an obsequent development of the monitored mudflow (Fig. 2A).

Buzău Subcarpathians represent a relief unit characterized by a wide petrographical and structural complexity, a young relief, formed of hills and depressions, a fragile environment, affected by land degradations through accelerated erosion and mass movements, which, due to the youth of the relief, impose an accentuated dynamic. Neotectonic movements (anticline bendings, local subsidence areas) have amplitude values up to 3-4 mm/year (Zugrăvescu, 1998) making the slopes even more unstable. The entire area is also very seismically-active, the sub-crustal earthquakes causing fault line reactivations and triggering landslides and rock-falls.

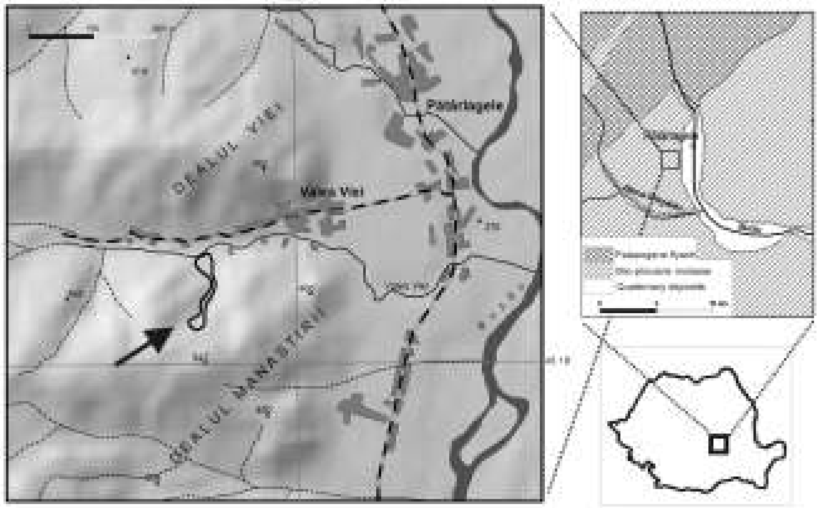

Fig. 1 **Study area position**

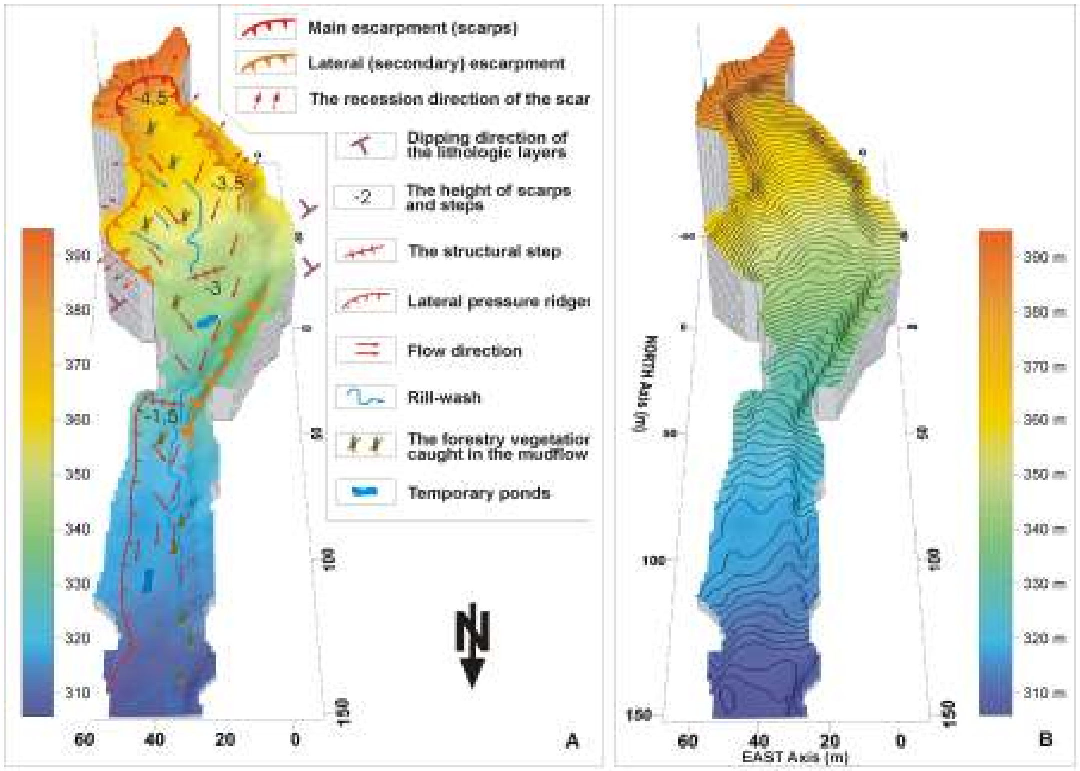

Fig. 2 **The geomorphological map of the Valea Viei mudflow (A) and the Digital Terrain Model (B)**

Manta-Muscel Hill (988 m maximum altitude) follows a north-south direction, between Buzău and Bâsca Chiojdului rivers, along 15 km, and has 8.5 km maximum width. It has a serrated profile, marked by peaks corresponding to hard rocks (limestone, sandstone, gravels) and saddles developed on soft rocks (marls, clays). An important feature is the presence of structural relief, formed by south oriented structural surfaces and north oriented cuesta fronts. The petrographic relief is also present, characterized by large landslides developed along valleys sculptured in loose materials (“*landslide valleys*”), cliffs and karst micro-formes.

Characteristic for the region is the interference of Palaeogene Carpathian flysch (Văleni spur, built on sandstones with clay-marly intercalation, gypsum and conglomerate lens) with inferior molasses deposits (Miocene sedimentary cycle, realized in sweet and brackish water conditions, marked by thick layers of sandstone, sands, marls, tuffs, salt-breccia, gipsum). The Quaternary evolution is underlined by the accumulation of Cândeşti gravels (on the northern edge of Calvini-Şoimari basin, in the southern part of Manta Muscel Hill), the lowering of the base level imposing the rhythmical deepening of the river network and the construction of the terraces (Badea şi Bălteanu, 1977, Bălteanu, 1983).

The climate of the studied area is characterized by low nebulosity, high values of solar radiation, high temperatures and mild winter phenomena, due to orographic barrier of the Carpathians, shelter effect imposed by depression configuration and foehn canalized on Buzău valley. June is considered the most rainy month, while February is the driest (the precipitation annual mean sum at Pătârlagele is 637m, in the 1960-1990 interval). The relief of the slopes and river channels is shaped mainly by heavy rainfalls (up to 80-100 l/m^2), with a higher frequency of 40-50 l/m^2 interval (Bogdan et al., 1974). During October-April period, an important role in the landslide processes is played by the freeze-thaw processes which have a multiannual mean of 94.5 cycles at Pătârlagele, which includes the studied region in the specific gelival regime of valleys, basins and gorges regime with 75-100 freeze-thaw cycles (Vespremeanu-Stroe et al., 2004).

Manta-Muscel Hill has a rich river network, drainage density reaching values of more than 4 km/km^2 (Micu, 2005). The loose petrographic setting, modeled by a torrential pluvial regime, together with the land use (large deforested areas), represents conducive factors for rapid erosion processes (with monthly and season changes), the highest rates of alluvial transport characterizing May-July interval, due to heavy rainfalls, frequently having a torrential character, intensifying slope erosion processes. The lowest alluvial transport characterizes the December-January interval, due to lack of precipitation and negative temperatures (Sandu and Bălteanu, 2005). The area is covered by deciduous forests (*Quercus petraea*), which due to intense human pressure, were severely affected by mass movements and erosion, determining the appearance of specific vegetal formations (degraded, salty areas are covered by *Hippophaea sp*. bushes). The typical soils are represented by cambisoils, eutricambisoils, districambisoils, associated with meadows, pastures and orchards, and luvisols under the deciduous forests, with a moderate humus content and a neutral-weak acid reaction.

Favorable conditions – accessible relief, shelter climate, the presence of salt deposits, intense trade exchanges between mountains and plain, allowed the appearance and development of human activities, the increased number of inhabitants, having as direct effect the slope overloading with buildings, changes in drainage and further large areas affected by land degradation.

3. Methodology

Valea Viei mudflow morphodynamics was investigated primarily through accurate topographical surveys (± 0.3 cm elevation) with a Total Station (Sokkia 610) both on individual cross-flow profiles (2D) and on global surface surveys (3D). All the measurements were reported to a benchmark established and geo-positioned in April 2005. The fieldwork campaigns were planed on a seasonally basis: April, August and November 2005 and March

2006; in November, due to bad weather conditions, were made just the ordinary topographical surveys and two-weeks later, in December 2005, the correspondent landmarks monitoring. Because of the permanent and temporary visual obstacles (vegetation) the overlapped survey area (S = 8480 m^2) covers the most part of the active mudflow but not entirely. In order to find the movement trajectories and to assess the displacement velocities of different mudflow sectors 43 mobile landmarks were planted successively during the first three campaigns and their position was monitorised through direct measurements.

Based on topographical data (between 780 and 1014 points) a digital terrain model (DTM) was obtained for each survey period. We used Kriging interpolation method (Golden Software's Surfer) and chose the grid cell size based on the results of the comparative analysis of the residuals error (Andrews et al., 2002). A 1-m grid cell size was found to be the optimum size for our data point density. The comparison of successive DTMs was used to derive the morphological and morphometrical changes, expressed in surface, heights and volume changes. The 2D and 3D morphological changes were correlated with the precipitation distribution at Pătârlagele meteorological station computed from daily values.

4. Results

4.1. Geomorphological features

The mudflow is divided into three sectors, well outlined in the general aspect. The first sector, representing the main source area (Photo 1, 2), has a 100 m length, is edged by the main scarp (cut in sandy formation), having a semi-circular shape, stabilized from time to time by trees. The main scarp has 30 m length, heights between 1.2-4.5 m, and a 50-90° slope (Fig. 5). The widely opened area of the scarp is affected by sheet wash and by frequent small size rock falls due to wetting-drying and freeze-thaw processes. Uphill from the scarp (2-5 m), there are long, parallel cracks, with a maximum width of 40 cm. Within the main source area, the median part of the right flank placed in between the scarps and the axial part of the mudflow, is composed by an association of steep slopes (30-50°), partly affected by rill erosion, which functions as a friction lens for the step-like landslides. Along with the main scarp, several lateral secondary scarps are showing a rapid regressive evolution. Within the main source area, two erosion sectors could be observed, separated by two structural steps that allow accumulation.

Immediately under the scarp, there is an erosion sector (0-1.5 m of moved material), followed by a sector of temporary accumulation (0-2 m). Under this sector, one secondary scarp shows strong regression, underlined by an erosion of up to 4 m, material transported with 30-40 m down-slope, forming a second major accumulation sector (1-2 m).

The next part is represented by the flowing channel (Foto 3), having 130 m length that starts from one narrowing sector, immediately after the second structural step (Foto 2). Along this sector, the flow reaches 12-20 m in width, being edged by lateral pressure ridges up to 1.2-1.5 m in height. The displaced material, 1-3 m deep, is represented by a sandy-marly matrix, with a menilite and sandstone skeleton (10-15%), with 5-15 mm diameters. The third sector, the most extended one (about 300 m length) follows Valea Vladii until its confluence with Valea Viei, being undercut by it during floods. This is stabilized by acacia and fruit trees.

The microforms differ spatially, the upper part of flowing channel displaying the richest micromorphology as a consequence of high morphodynamics. There are small landslide waves, lateral pressure ridges, cracks, friction lens and temporary ponds. Towards its terminal part, the morphology shows a change of the movement, from flow to plastic, favoring its fixation with grass and bushes. During the summer the cracks are denser and deeper with a width of 2-10 cm and a depth of 20-50 cm. These microforms are completely replaced by new ones, at each pulsation of the flow, with the notable exception of friction lens which appear more frequently along the inner slopes of the lateral pressure ridges, reaching up to15 meters in length (Photo 4).

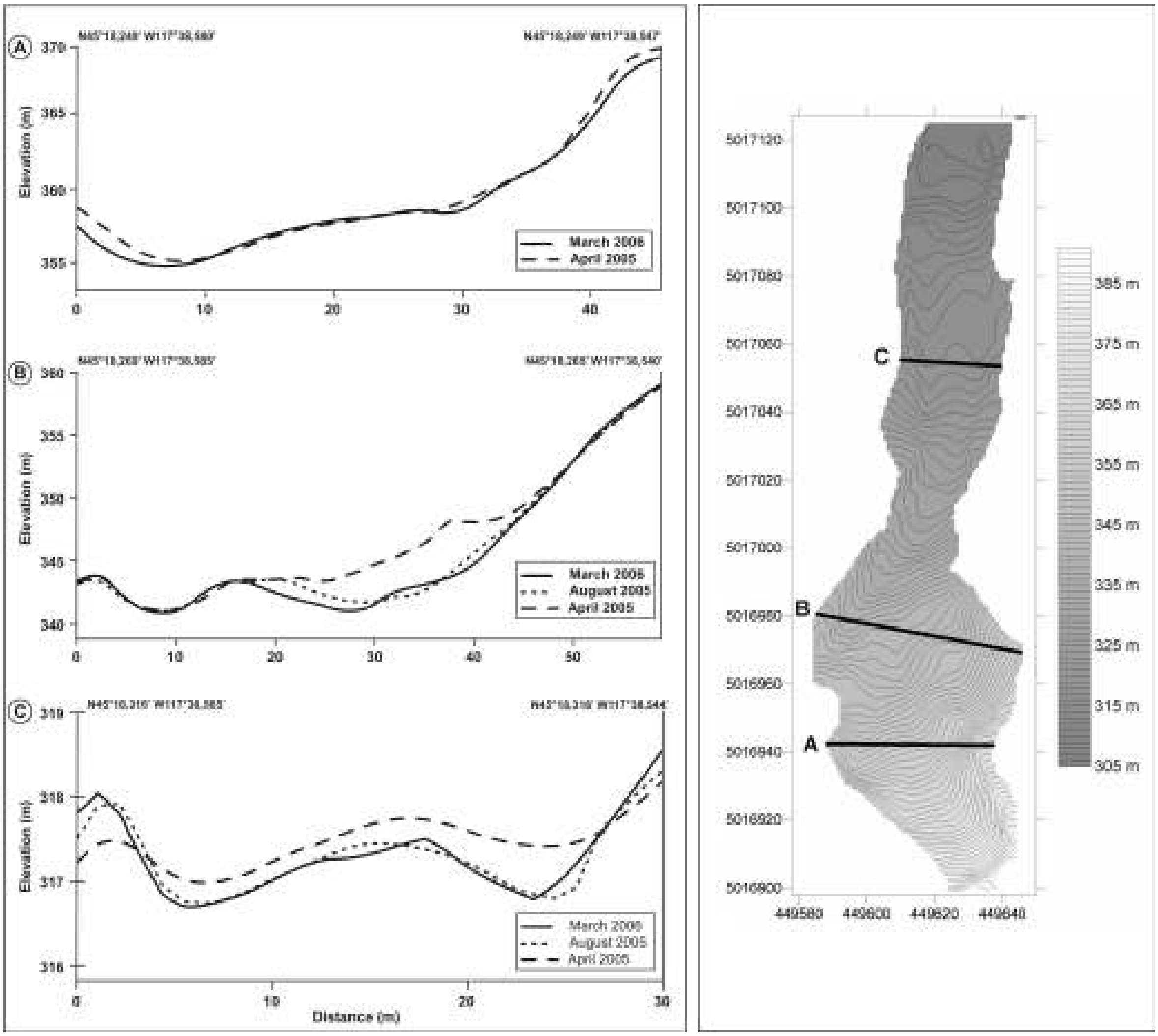

Fig. 3 **Transversal cross-flow profiles illustrating the scarp retreat** (A), **the formation and migration of landslide steps** (B), **and the raising of the lateral pressure ridges** (C)

4.2. Morphometric changes

The overall estimation of volume changes in the mudflow body for one-year interval points out an important volume loss of 2727 m^3, but this cumulated value hides major differences in temporal evolution. During the late spring and summer (17 April-11 August 2005) the climate forcing factors (469 mm precipitation, representing 78% of the multiannual mean) induced the most dramatic changes expressed in a 94.5% (2576 m^3) of the net volume changes (loss). In accordance with these negative volume changes, the surface affected by erosion was 2.4 times more extended than the accretionary surface (Tabel 1). The surface level changes reached their maximum at the end of the spring on the right (eastern) slope of the main source area. An entire landslide step, developed on about 400 m^2 with a length of 25 m, was swept downslope producing a vertical erosion of 3-4.5 m (Fig. 3B); significant negative level changes occurred also in the frame of main escarpment (1-2.5 m) in relation with the retreat of the right flank with 0.8-3 m (Fig. 3A).

During the late summer and autumn (11 August-28 November 2005) the erosive processed remained prevalent but became less intense (802 m^3 eroded and 735 m^3 accumulated resulting a net volume loss of 67 m^3; a ratio of 1.42 between the erosive and accretionary surfaces). During this interval the major processes were reflected in the lateral overflowing occurred pre-eminently on the flowing channel, in the lower sector of the mudflow, and morphological expressed in the local aggradation of the lateral pressure ridges (Fig. 3C, Fig. 4). Additionally, it is noticeable the high accumulation from the central sector, between +25 and +45 m on the North Axis of DTM, as a temporary effect of mud piling.

During the winter and early spring (28 November 2005 – 26 March 2006) the ratio of erosive/accretionary surfaces becomes 1.04 while the negligible net volume changes (-18 m^3) points to a temporary equilibrium between the erosion and accumulation superimposed on a seasonal diminishing of the geomorphologic processes intensity. The most important level changes occurred in the central part of main source area where small (0.2-0.5 m) but well-grouped accumulations composed from a mud and debris mixture are coming from the scarps.

4.3. The mudflow dynamics (obtained from landmarks monitoring)

The whole mudflow body records significant displacements but with spatial differences as rhythm and intensities depending on the local slope and water content, detailed morphology and geological settings (especially the hydro-geological and geotechnical properties). Thus, the highest displacement speeds occur in the central part, between 0 m and +70 m on the North Axis of DTMs (Fig. 4), where the slope has moderate values reported to the overall slope distribution in the frame of the study area. Independent of the analyzed season the landmarks dynamics indicate this sector as being the most active with migration rates varying between 10.5 m/month and 17 m/month. The upper sector which corresponds to the main source area, in spite of its steeper slopes (Fig. 5), occupies the second position in the hierarchy of the sector dynamics. The landmark distribution covers the most part of the escarpments rim and stretches between -60m and 0m on the North Axis of DTMs displaying migration rates which vary between 0.8-9.5 m/month. In this sector the main characteristics of displacements processes are the combination between rock falls which affect the main escarpment, step-like landslides and ordinary mudflow processes. Due to the overall geomorphologic context, especially to the adjacent lateral slopes which are steeper on the right side of the valley, the central (southern) and right (eastern) flanks of the main source area are more dynamics and sensitive to rock falls and step-like landslides (which can move up to 25m distance) than the left (western) flank.

The lower part of the mudflow, stretched between 70-150m on the North Axis of DTMs, displays both the lowest and the most uniform intra-seasonal displacement speeds in comparison with those specific to the upper and central sector (Fig. 6). Thus, during the most active interval (April-August 2005) the displacement velocities were 5-6 m/month, then slowly diminished to 3.5-5m/month (August-December 2005) in order to reach the lowest values, 0.5-2 m/month, during the most stable period (December 2005 – March 2006). The same time evolution of mudflow dynamics, assessed from the landmarks monitoring, was found in all three sectors, but the intra-seasonal variability was high in the frame of the main source area and moderate in the most active central part.

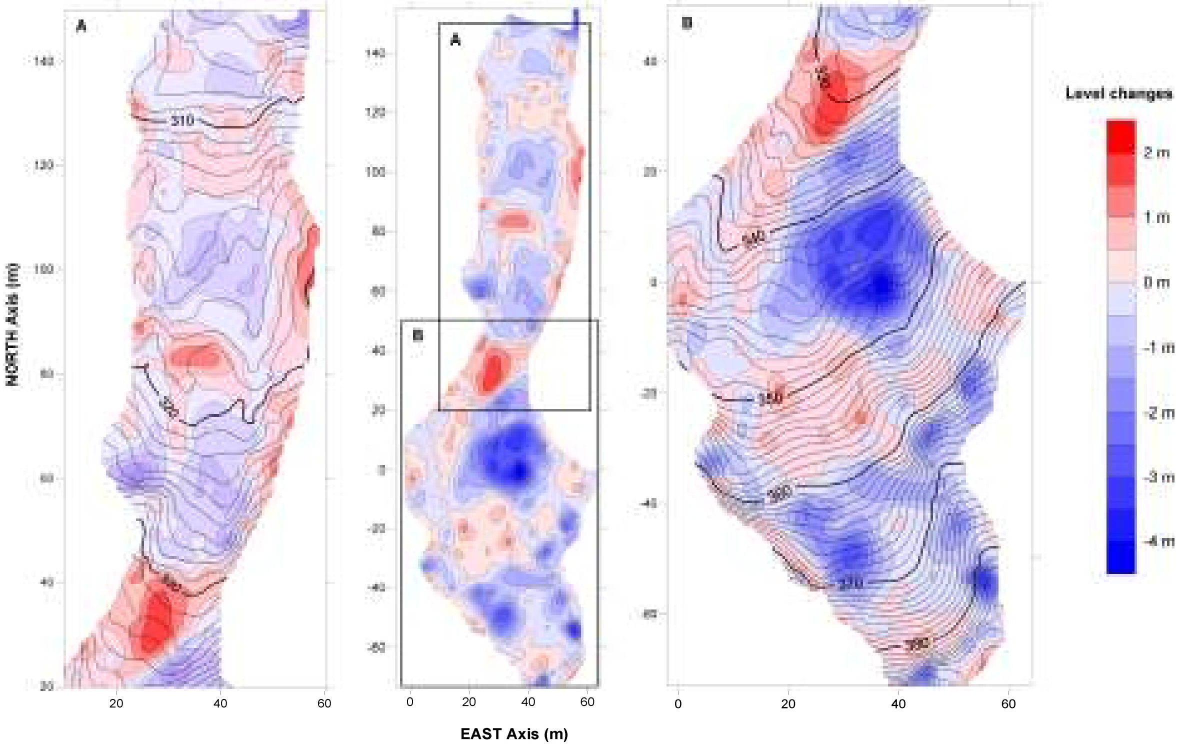

Fig. 4 **Level changes resulted from the subtraction of the DTMs surveyed in April 2005 and March 2006. A detailed view of changes within the flowing channel** (A) **and the main source area** (B)

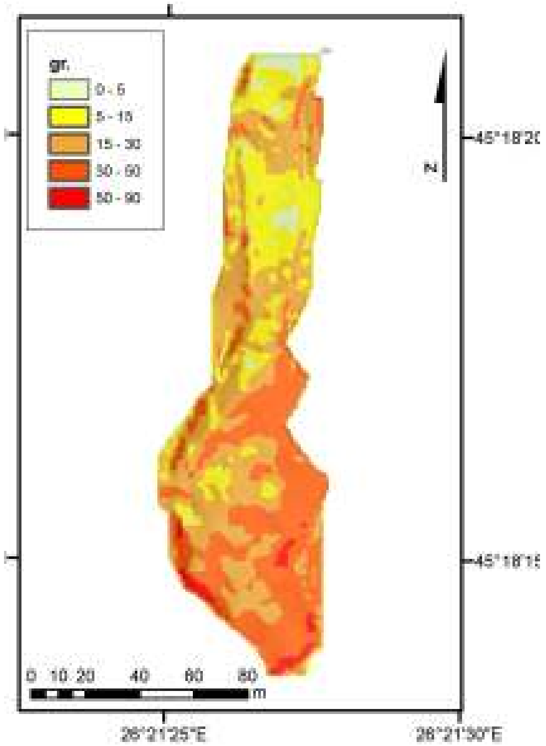

Fig. 5 **The slope map**

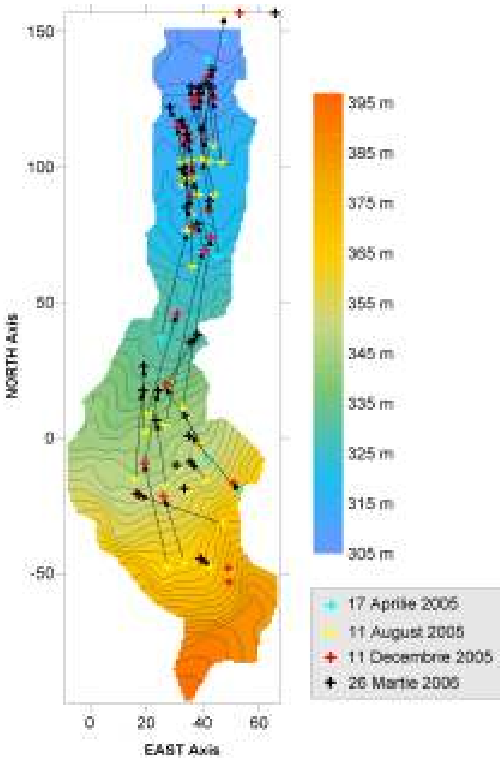

Fig. 6 **Superficial mudflow dynamics obtained from landmarks trajectories**

Photo 1 - The main source area (lateral view); **Photo 2** - The main source area, structural and landslide steps (down-view); **Photo 3** - The flowing channel and dyed mobilised trees (used as landmarks); **Photo 4** - Lateral pressure ridge on the right flank functioning as friction lens; **Photo 5** - A landmark dyed, planted and positioned

A general view of the entire mudflow dynamics obtained from the mean values of displacement velocities reveals great differences between the first analyzed interval (April-August 2005), very active, with a mean total landmarks migration of 35 m (9.2 m/month), the second (August-December 2005) with 24.5 m (6.1 m/month) and the last (December-March) with 16.8 m (4.8 m/month).

Table no. 1

DTMs comparative analysis and the changes of the main morphometrical parameters (volume, surface, landmarks migration) **beside the precipitation regime**

Time Interval	*Volume m^3 (-)*	*Volume m^3 (+)*	*Net Volume (m^3)*	*S m^2 (-)*	*S m^2 (+)*	*Ratio S - / S +*	*Precipitations (mm)*	*Landmarks migration (m)*
Apr 05 – Aug 05	3183	607	- 2576	5126	2137	2,39	469.3	35
Aug 05 – Nov 05	802	735	- 67	4272	2991	1,42	313.1	24.5
Nov 05 – Mar 06	528	510	- 18	4210	4051	1,04	148	18.4
Apr 05 – Mar 06	3982	1255	- 2727	5187	3074	1,68	930.4	77.9

5. Discussion and Conclusions

From a morphological point of view, three different sectors are distinguished along the flow: i) the main source area, (down-slope extended on 100 m[1], between -75 m and 25 m on the North Axis of DTM), having an oval, amphitheatre-like shape, surrounded by main and secondary scarps; the main source area has the highest erosion rates, ii) the flowing channel with 130 m length (between 25 m and 155 m on the North Axis) which function as a transit-zone for the sediments and iii) the toe (spreading cone) of the mudflow, which is partly covered by an acacias plantation and which is not part of our monitoring polygon.

Within the main source area, the co-existence of several permanent erosive sub-sectors with those characterized by a bi-phase accumulative/ transit activity is imposed by the lithologic layers succession in the frame of the cuesta front; the complementary accumulation/transit processes occur on the harder layers (loose sandstone, menilites), that forms structural steps, highlighted by a decrease in slope values, while the removal of material characterizes the soft layers, especially marls, with higher slope values of the profile. Thus, the displaced material, coming from underneath the main scarp, has a first accumulation sector on top of the first structural step, which is episodically overrun. Further down-slope the removed sediments coming from the main scarps, including those detached from the secondary escarpments, have an accumulation area at the first narrowing sector of the flowing channel. The flow direction is generally imposed by slope and the spatial distribution of deposits which can exceed the liquefaction threshold as quick clays and quicksands while the landslide-type movements additionally to the slope follow directions imposed by the structure (layer disposition) and detailed morphology.

The mudflow channel is characterized by uniformly decreasing slopes (from 30° to 2°), affected by intense transport processes which are expressed by the episodic alternation of accumulation and erosion. As a consequence, the level changes are reversible, with a moderate intensity ($\Delta Z < 1.5$ m) and developed at a seasonal timescale. The analysis of landmarks movement trajectories reveals the co-existence of two patterns on the mudflow dynamics in the frame of the flow channel.

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[1] This value (100 m) is measured on the horizontal projection of the main source area; its real length is 116 m

Thus, the upper sector of the channel (20-70 m on the North Axis) alongside the lower extremity of the main source area (-20…0 m on the North Axis) have a similar behavior displaying the most active dynamics both horizontally with displacement velocities varying between 10.5-17 m/month during the year and vertically with the most extreme level changes of the mudflow body: -4.5…+2.5 m (Fig. 4, 6). Noteworthy is that the extreme morphodynamics overlap neither the steepest slopes nor the gentle ones. Their main causes are supposed to be the position in the frame of the mudflow, linking the main source area with the flow channel, and perhaps more importantly, the overall configuration of this sector. It's noticeable that the most active sector benefits from a "funnel effect" which accelerate the flow when happens, general imposed by a sudden change in pressure or a shock acting on water saturated or supersaturated sediments. This is the area where frequently forms enormous mud pilings due to the narrowing of the active flow channel section. Conversely, the central and lower parts of the mudflow channel have a completely different dynamics, generally slower, with the lowest migration rates from the entire study area (< 5.5 m/month) and with a relatively homogeneous distribution of displacements velocities for every season. Owing to the lower position and clay accumulations, this sector records the highest water contents which give a more uniform distribution of the morphodynamic processes, and an outer-longitudinal arrangement of accumulation sectors. This area represents the terminal segment of the active mudflow.

Based on the analysis of movement features, seasonal differences were noticed. The spring - summer interval generally records the most intense dynamics and is characterized by big amounts of precipitation (Fig. 7); the displacement velocities vary between 5-17 m/month with a mean value of 9.2 m/month. The heavy rainfall, imposes a pulsatory character to the dynamic behavior of the mudflow, with rapid flows on short and medium distances (1-20 m), occurring until short time (hours, rarely days) after the rain stops. The monitoring of landmarks movement from spring - summer interval clearly indicates the presence of short and strong signals (fast displacements), during and after heavy rainfalls, overlapped on longer periods (weeks) with a very weak but generally prolonged signal. Every significant water input in the mudflow body is quickly expressed in fast displacements of the superficial deposits while the deep-delluvium mass has a more prolonged and uniform movement. During the second half of the summer, generally, the precipitation regime changes (the total precipitation quantities decrease and are expressed by rare and heavy rainfalls) and, implicitly, the dynamics becomes less intense and discontinuous. Besides the precipitation regime another main cause is the quick water evaporation due to high temperatures / low humidity conditions and to a dense network of cracks and fissures at the surface of the flow.

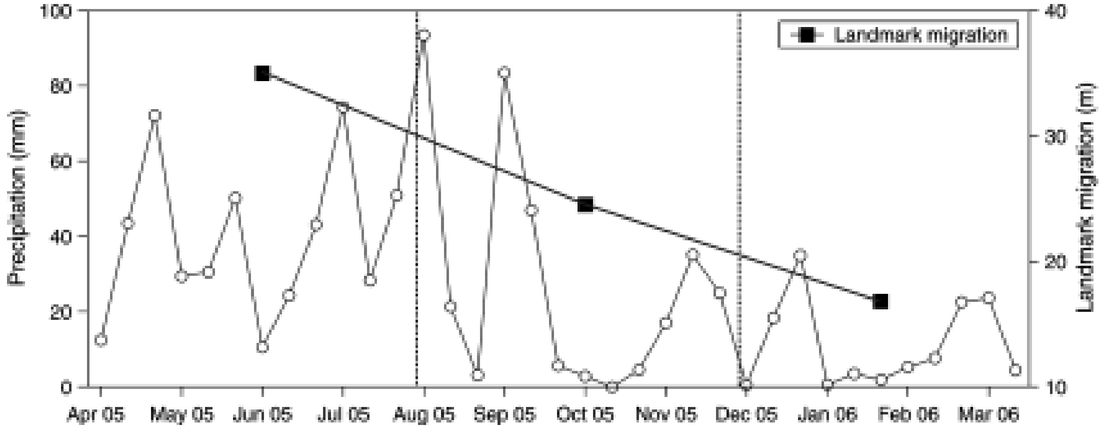

Fig. 7 **The co-evolution of precipitation regime and mudflow dynamics. The landmark migration** (black squares) **was computed for each monitored interval** (delimitated by dot line)

During the late summer - autumn period, even if the rainfall quantity diminishes, the water remains a long period in the body of the flow, which has a plastic movement, confirmed by the medium displacement velocities (6.1 m/month) and by the presence of largely developed friction lens along the lateral pressure ridges. This means that the speed decreases but it lasts long, having a more continuously pattern. Winter proved to be the most stable season, with a mean displacement velocity of 4.8 m/month, the movement being slowed by the freezing of the water in the mudflow's body.

As our data illustrate, the morphological answer to heavy rainfalls is much faster in case of mudlows (hours and days) than to landslides where significant time lags (weeks) occur (Malet et al., 2000; Armas et al., 2004). Moreover, the seasonal measurements of deep-seated landslides displacement velocities show, in some cases, as being an out-of-phase between the precipitation regime and landslide annual dynamics (Brânduş et al., 2004).

As a conclusion, the analysis of the Valea Viei mudflow dynamics, based on accurate, successive topographical surveys, allows the correlation of its dynamics with the lithological, morphometrical and morphostructural characteristics of the relief and also with the precipitation regime. The seasonal distribution of the rainfall, regarded as the main triggering factor, imprints the flowing/sliding character of the movement, which further controls the morphology of the mudflow.

The results presented herein have a preliminary character, as the study was undertaken for just one-year; they are necessary for a general view on the framework in which appear and develop the mudflows from the Curvature Subcarpathians. For a better understanding of the mechanisms that states the occurrence and further evolution of a such complex mass displacements process, the future activities have to increase the monitoring interval and, probably more important, to include and other investigations techniques: piezometric surveys in order to correlate the mudflow evolution with the groundwater level variations, probes for pore water pressure, soil and air temperature variations, and percussion drills to have a better image of the deposition and depth of strata, in order to realize a numerical modeling of Valea Viei mudflow future behavior.

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