RIVER UNDERCUTTING AND INDUCED LANDSLIDE HAZARD. THE JIU RIVER VALLEY (ROMANIA) AS A CASE STUDY

SANDU BOENGIU, OANA IONUŞ*, DANIEL SIMULESCU*, LILIANA POPESCU**

Sandu Boengiu, Oana Ionuş, Daniel Simulescu, Liliana Popescu: River undercutting and induced landslide hazard. The Jiu River valley (Romania) as case study. Geomorphologia Slovaca et Bohemica, 2, 2011, 10 figs., 42 refs.

The paper aims at synthesising the geomorphologic background for the evolution of the right slope of the Jiu River valley. The investigation of numerous landslides helped to decipher the mechanisms that trigger them and influence the spatial distribution of areas vulnerable to mass movements. For the analysis of mass movements processes, there were used geological and climatic data, as well as topographic measurements, geomorphologic mapping; based on the aerial surveys from different periods, the changes that occurred were analysed. Topographic measurements carried out within the areas with fossil and active landslides and along the right bank of the Jiu River valley, in the sectors with strong lateral erosion, were carried out twice a year, beginning with the spring of 2006. When some of the landslides were reactivated or there were high flows of the Jiu River, measurements were also carried on, apart from the regular ones in spring and autumn.

From the confluence with the Motru River until flowing into the Danube River, the Jiu River is undercutting the right slope of the valley. During the Quaternary, the Jiu River had a tendency to deviate to the west due to the different elevation speeds, higher in the east and lower in the south, recorded in the western compartments of the Moesian Plate. The base level lowered, causing the deepening of the valley up to 130 m and climatic fluctuations lead to the loess deposition and oscillations in the flow. All these facts cause river undercutting. The encountered structures are monoclinal with inclination from north-west to south-east in the Getic Piedmont and tabular in the Romanian Plain, and lithologically they belong to the sedimentary complexes formed of often cemented sands and gravel in alternation with marls and clays.

The violent erosion of the right slope has lead to a total change in the geomorphologic systems mainly by increasing the slope energy, by beheading the tributary valleys and by deepening the river bed below the level of grey clays and marls of Romanian age. Currently the entire slope is affected by mass movements (slumps and landslides) with a common mechanism: where the convex part of the meanders approaches the slope, its vulnerability increases and leads to slumps and landslides and where the slope is far from the course or near the concave part of the meanders, the vulnerability decreases and the slope tends to become a glacis. In most cases the Jiu River moves away from the right slope next to the confluences with tributaries on this side, because immediately afterwards, it returns close to the slope. This slope is under the direct influence of the Jiu River, which regularly unbalances the slope, maintaining a fast dynamic and an increased geomorphologic risk on the settlements, agricultural land and infrastructure.

Key words: landslides, river undercutting, neotectonics, the Jiu River

INTRODUCTION

The Jiu River hydrographical basin unfolds within the Southern Carpathians and the Getic Subcarpathians in the north, up to the Getic Piedmont and the Romanian Plain in the south. The present paper focuses on the sector beginning at the confluence with the Motru River up to where it flows into the Danube River, where the Jiu River valley cuts through the southern part of the Getic Piedmont and the Romanian Plain. The main characteristic of this sector is given by the asymmetric valley, as a result of the Jiu River general tendency to build its floodplain along the left side and to wear away the right bank by river lateral erosion. The literature abounds in analyses of the geological characteristics (BADEA 1996, ENCIU 2007), geomorphologic (ROMANIAN ACADEMY 1992, ROŞU 1956, COTEŢ 1957, ROMANIAN ACADEMY 1969, STROE 2003, ROMANIAN ACADEMY 2005, BOENGIU 2008, BADEA 2009, BOENGIU and AVRAM 2009) and hydrologic (SAVIN 1990, 2000, PLENICEANU 1999) features of the limitrophe regions that the valley crosses through. Still, these papers dealt with regional studies and did not aim at a thorough analysis of the processes that affect the right slope.

Similar processes, such as the relation between water effect and landslides induced by the river actions towards the slopes and the

* Geography Department, University of Craiova, Al.I Cuza 13, Craiova, Romania,
e-mail: sboengiu@central.ucv.ro; oana_ionus@yahoo.com; simu_daniel@yahoo.com; popescu_liliana25@yahoo.com

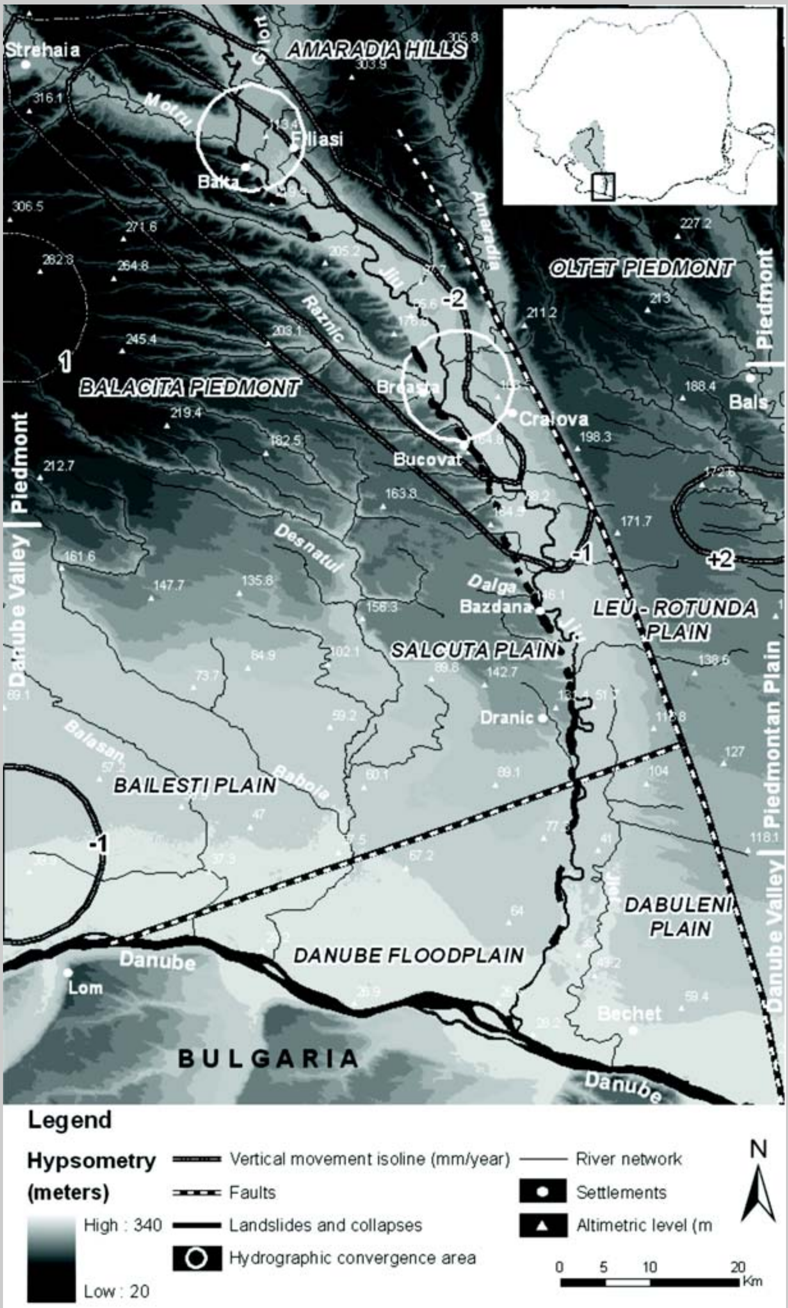

Fig. 1 General map of the studied area

evaluation of landslides hazards and risks, were analysed by papers that focus on the Danube basin in Romania and Hungary (LÓCZY et al. 1989, PÉCSI et al. 1987, SZABÓ 2003, FÁBIÁN 2003, FÁBIÁN et al. 2006, LÓCZY et al. 2007, MICU and BĂLTEANU 2009, BĂLTEANU et al. 2010, BUGYA et al. 2011).

Observations on the right slope of the Jiu River can befound in various PhD theses on the Olteț Piedmont (AUR 1996), Bălăcița Piedmont (STROE 2003, BOENGIU 2008) and the Oltenia Plain (COTEȚ 1957), but these are regional geomorphologic studies which only mention the peculiar problems of this slope. Minute research was carried out for the Jiu-Motru-Gilort Rivers confluence area (ROȘU 1956), the author intuits a probable neotectonic influence, describes the landslide at Bâlta and an outcrop. There are also regional hydrological studies of the water resources in the floodplain, valley dynamics and phreatic waters (SAVIN 1990, PLENICEANU 1999), which include the Jiu River hydrographic basin. Other papers include geomorphologic sketches and complex cross-section profiles for the landslides at Bucovăț (BOENGIU 2004), Bâzdâna and Padea (BOENGIU et al. 2011), pointing out to a similar behaviour in terms of triggering processes and evolution. In order to analyse how the climate influences the gravitational processes which affect the valley within the piedmont sector (BOENGIU et al. 2009), the map of landslide susceptibility was drawn in GIS DEM and correlations between precipitations, temperature and mass movements between 1990 and 2008 were done.

The present paper capitalizes the previous experience and brings new data for the geomorphologic background which influences the right slope, and especially mass movements that are the most frequent and have the major contribution to the undercutting process. It also investigates some of the aspects of the relationship between landslides and the Jiu River slope undercutting.

GENERAL SETTINGS

The Jiu River valley stretches from the confluence with the Motru River up to the Danube River along 140 km, with two clear sectors: the first one stretches from Filiaşi to Podari, the valley consequently crossing the Getic Piedmont, 4 to 5 km in the north, while the other one, from Podari to its water mouth, crosses piedmont and terrace plains within the Romanian Plain and is 5 to 8 km wide where it flows into the Danube River. The depth of the valley decreases from 137 m at Bâlta to 95 m near Craiova, reaching only 26 m at its confluence with the Danube River; the floodplain generally lowers by 0.8 m/km (SAVIN 1990), (**Fig. 1**).

The Jiu River channel is very dynamic due to the correlation between the morphometric and hydraulic elements in the cross section with the water flow and level, as it can be seen from the parameters registered at the three hydrometric stations located within the analysed sector (the confluence with the Motru River up to where it flows into the Danube River): Filiaşi (F – 5239 kmp, average hight – 563 m), Podari (F – 9253 kmp, average hight – 446 m), Zăval (F – 10046 kmp, average hight – 417 m), (AQUAPROIECT 1992).

The river course divides into two sectors from the geologic and geomorphologic point of view; this impinges upon the morphometric elements which characterize the river channel morphology: mean width – 195 m, Ω med (mean active section) - 392 m^2 for Filiaşi-Podari sector; mean B (mean width) - 232 m, mean Ω (mean active section) - 524 m^2 for Podari – Zăval sector (SAVIN 1990).

In this sector, the river channel is well-cut, with banks that rise at 2 to 4 m above the water level. However, for some short sectors lying between the settlements of Bâzdâna and Zăval sector (SAVIN 1990), the right bank of the river channel is the very slope of the valley, with relative heights of 10 to 30 m (SAVIN 1990).

Downstream of Podari, there are simple meanders with very broad bends (sinuosity index: Filiaşi – 2.13, Podari – 1.96, Zăval – 1.25), as well as wide direction changes, the river course moving underneath the right slope. When comparing the course of the Jiu River on the cartographic materials (topographic map from 1979 and ortophotomaps from 2008), this is also obvious, and especially for the areas affected by landslides: Bâlta 97m, Breasta 46 m, Bucovăţ 94 m, Drănic 125 m.

The intensity of erosion process varies from one section to another depending on the geologic structure of the river channel, slope variation (Filiaşi – mean declivity is 8‰, Podari 7‰ and Zăval 6‰) and the size of modelling phases from the regime of multiannual flow (Filiaşi: mean Q – 64.6 cm/s, q – 12.3 l/s/km^2, R – 68.5 kg/s; Podari: mean Q – 87.4 cm/s, q – 19.4 l/s/km^2, R – 118 kg/s; Zăval: mean Q – 84.0 cm/s, q – 8.4 l/s/km^2, R – 40.4 kg/s) (PMBH JIU 2010).

Along this sector, the valley as a morpho-hydrographical watercourse has a strong depression character, forming a circle arc with concavity towards the west (AUR 1996, SAVIN 2000). The valley is asymmetric, the right bank being steep and very dynamic (**Fig. 2**), while the left one has a step profile, the flood plain width varying between 3 to 5 km on average (BOENGIU 2005).

On the left bank, there are 5 terraces, with the following relative altitudes: T_5 70 – 90 m, T_4 40 – 60 m, T_3 30 – 40 m, T_2 15 – 22 m, T_1 5 – 12 m. Generally, they unfold continuously and disappear into the Danube River terraces downstream of Padea-Mârşani (COTEŢ 1957). The broadest terraces are situated downstream the two river convergence areas, the first one where the Motru River and the Gilort River flows into the Jiu River, the other one at the confluence with the Amaradia River and the Rasnic River tributaries (**Fig. 1**). Within the piedmont sector, the Jiu River valley has a levogyrate terrace system on one bank, while within the southern sector it has a bilateral terrace system. This points to the direction of the influence under which they developed (COTEŢ 1957, BOENGIU et al. 2011). The upper terraces are covered by loess-like deposits, while the lower ones and the floodplain have sands and dunes.

On the left side, the floodplain is dominated by the 5 – 12 m terrace scarp, and on the right side there are steep slopes of more than 50 – 60 m. There is a monotonous morphology, except for the sectors with ancient braided channels or swampy areas and levees. Sometimes, the height increases by 2 or 3 m as a result of alluvial fans and sand dunes. Downstream of Rojiştea, on the left side of the Jiu River, there is the former valley of the river – the Jieț River.

The Jiu River valley cut into Romanian and Quaternary deposits; the Romanian ones outcrop on the lower terraces and slowly sink into the two convergence areas of the rivers at Filiaşi and Craiova (BADEA 1996, BADEA et al. 2010). The data gathered following the drill at Bâlta (ROŞU 1956), Cârligei (BOENGIU 2004) and Bâzdâna (BOENGIU et al. 2011) Hills pointed to successive alternations of marl-clayish strata with sand and gravel strata; thus, there are 3 – 4 marl levels, widening as the depth increases. Between them, there alternate sands and gravels with considerable width. There also intermingles 1 or 2 coal levels that are 0.3 – 0.4 m thick the most. The more recent formations have the same consistency and are covered by thick loess-like deposits.

The interpretation of the map of recent vertical crust movements on the Romanian territory (ZUGRĂVESCU et al. 1998) indicates that the neotectonic movements had decisively influenced the orohydrography (STROE 2003, ENCIU 2007); it moulded according to these distortions. Thus, reflexes of the movements in the neighbouring regions (the Carpathians and the Balkans) have drawn the basement differently, with direct results in the relief: there occurred the subsidence of the grabens (Filiaşi, Craiova, Lom), and upheaval of horsts (Balş-Optaşi, Bâcleşi) (**Fig. 1**). Generally, the morpho-structural elements have an inherited character (PARASCHIV 1965), no matter the rising or falling epirogenetic movements (BADEA 2009).

The neotectonic movements from Passadene phase (Middle Pleistocene) reactivated the Balş-Optaşi horst, which intermingled between the domains eastwards and westwards of this horst. As a result, the Jiu River cut its valley southwards and gradually descend towards south-west, carving terraces only on the left side (**Fig. 1**). The Danube River also glissaded towards south-west, carving terraces on-ly on the left slope of the valley (ROMA-NIAN A-CADEMY 1969, STROE 2003, BOENGIU 2008, ENACHE 2008).

METHODS

The geologic data were gathered following the analysis of borehole for the exploration of coal reserves, hydrogeological borehole and numerous natural outcrops or the ones generated by excavations for obtaining construction materials. The analysed boreholes are situated on Bâlta Hill 237 m, Cârligei Hill 165 m and Bâzdâna Hill 141.1 m along the scarp of the right slope, where the most important landsides developed. There were identified alternances of sandy and sandy-dusty levels with clay, clay-sand and marl strata in all the drills.

The analysis of the rainfall data (the multi-annual mean is 594.3 mm) pointed to the great variability of precipitations, the series of rainy years alternating with drought periods. Between 1991 and 2005 there were registered the highest oscillations of the precipitation regime (in 1992, there were only 293.5 mm of rainfall, while in 2005 it reached 1081.1 mm, which is a considerable difference of 788.3 mm) (BOENGIU et al. 2009).

The topographic surveys of cross-section of landslides (04.2006 – 04.2011), with a high precision level both for the planimetric coordinates (X and Y) and the absolute heights (Z) were carried out with the help of GPS Rover GNSS Smart S82-T. The registered points (for the landslide at Breasta) were sample points (with measured values) that were subsequently processed in Arc Gis 9.3 programme.

The applications included in the Spatial Anayst toolbox (Interpolation toolset) and 3D Analyst toolbox (Raster Interpolation toolset) allowed us to interpolate the values between the sample locations and to create some rasters for the monitored areas/landslides (GILI et al. 2000, JACKSON et al. 1996). From the various interpolation techniques, we chose the Kriging option for the creation of surfaces, since it is very useful when there is a high degree of spatial autocorrelation and a clear direction in the dataset.

In order to have clear results, rasters (DTM) were visualized using the ArcScene extension (without exaggeration of the vertical scale – BaseHights). This was very helpful in identifying the recent scarps that were correlated with the derivation of raster-new datasets for the characteristics of the landslide surface (such as declivity and aspect).

The geomorphologic mapping of the landslides was carried out on the field; we choose the scale 1:5000; the sketches that were achieved may be compared with the data in raster and vector format that were subsequently obtained.

The remote sensing data were used to evaluate the changes that occurred after the landslides, while for the estimation of geomorphologic evolution of the analysed area, aerial survey photographs were used from different periods: 1979, 1995, 2005 and 2008. Those last two ones are coloured digital aerial survey photographs and georeferenced in Stereo 1970 national system, with a spatial resolution of 0.5 m; they allowed an accurate evaluation of the changes that occurred from the geomorphological point of view, as well as for the infrastructure.

RESULTS AND DISCUSSIONS

Within this sector, the palaeogeographic evolution led to the development of a morpho-hydrographic couloir. The erosion of piedmont structures and the formation of a terrace plain occurred during the Pleistocene climatic oscillations, neotectonic movements, deviation of the Danube River towards the right and falling base level (BOENGIU et al. 2011).

The Jiu River repeatedly changed its course within the floodplain; its present course dates from 1879, when its watermouth was slided 15 km westwards during an exceptional flash flood. The Jieț River stream remained on the former course, flowing into the Danube River at Bechet. These changes are the result of climate variations, which reflect into the hydrologic regime of the Jiu River, testifying once more the neotectonic movements.

Geomorphologic processes of the study area can be divided into slope and floodplain affecting processes. Those on the slopes include landslides only on the right side and aeolian processes that affect only the left slope and the floodplain.

DISTRIBUTION AND MECHANISM OF LANDSLIDES

The permanent undercutting of the right slope and the Romanian-Pleistocene deposits made up of clays, marls and sands that alternate, led to the preservation of a steep slope, with more than 65°, which is very vulnerable to landslides. The Jiu River keeps its course near the right bank, moving away from it only at the confluences and downstream its tributaries that built alluvial fans into the floodplain.

Among the numerous landslides within the sector analysed in this paper, the most representative ones are those from Bâlta, Breasta, Bucovăț, Bâzdâna and Drănic.

The *landslide at Bâlta* is consequent, from west to east, in accordance with the monocline structure of the piedmont, with 1100 m in length, maximum width of 580 m, maximum height of 110 m, covering an area of 0.59 km^2. Considering these measurements, it is estimated that the slided mass has around 3 million cubic meters.

The landslide was triggered by the 1940 earthquake, when the first cracks parallel to the valley formed. Later on, they would become landslide scarps (ROŞU 1956). The materials at the bottom of the slope were washed away regularly by the lateral erosion, and thus the slope could not reach an equilibrium. Consequently, the landslide began delapsively and gradually reached the top of the slope.

The present morphology is the result of the three strata of sands that independently slide on the marly strata; in some areas, the mechanism becomes more elaborated due to the presence of two coal strata. Thus, there are three longitudinal steps that correspond to the three marl levels, accompanied by three landslide scarps (**Fig. 2**). The scarps, with an arch shape, are almost vertical, their height mirroring the thickness of sand strata (25 m, 19 m). The landslide steps alternate, their width decreasing from the top to the bottom, and are tilted towards the scarp, have numerous cracks, strains, micro depressions with humidity excess and even lakes.

The stabilization and afforestation degree, fading landslide scarps and appearance of concentrated flow (gullies and ravines), and even the presence of orchards and vineyards in the north indicate that the landslide began in the north and gradually spread southwards. Towards the south, the landslide presents more active sectors, the scarps are obvious, there is just a pioneer vegetation and the front of the landslide mass is much more bulging (**Fig. 3**). This evolution from north to south coincided with the evolution of the Jiu River meander.

Part of Bâlta settlement is dominated by this landslide mass, which ends abruptly at 30 – 35 m above the settlement. Within this landslide mass, the material is chaotically disposed and unstable; there are areas with humidity excess and mud flows, which indicate that underground and rain waters have penetrated and remained in the landslide mass.

The landslide at Breasta occurred as a result of the intensification of the Jiu River bank erosion, during some years with excessive rains. It had always sectors that reactivated during the years with high quantities of precipitations. The topographic profile achieved in 1994 (**Fig. 4**) points to the same three steps with three scarps, just as for Bâlta landslide. After 2006, vast sectors of the landslides were reactivated due to high quantities of precipitations, with almost 500 mm above the annual mean (594.3 mm) in 2005; more important, this quantity fell after five consecutive years with quantities below the annual mean. Following the GPS monitoring of the profile line since 1999, which began in 04.04.2006 and

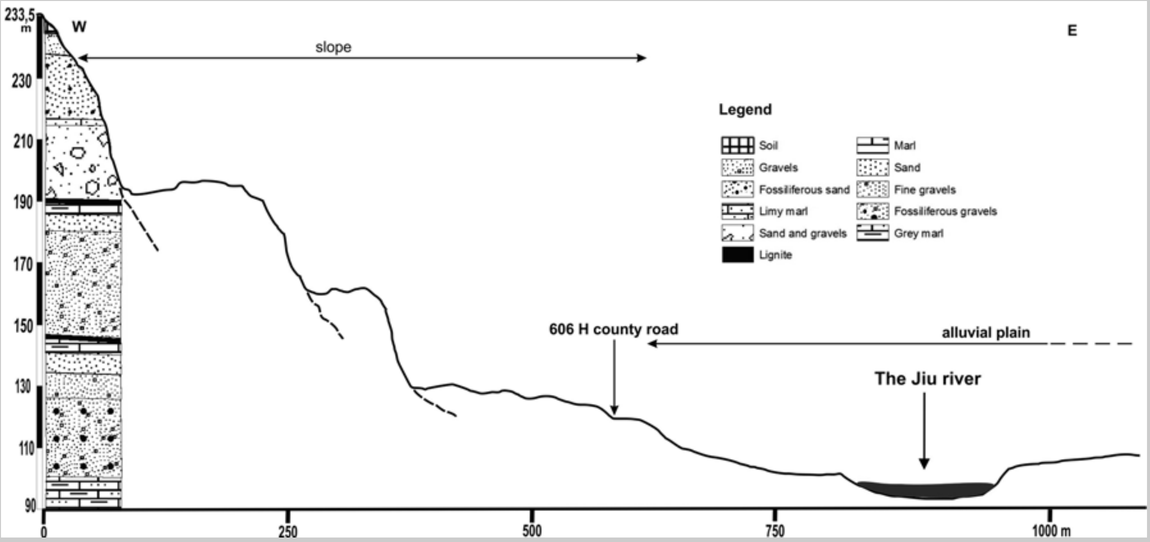

Fig. 2 Cross section in the Bâlta landslide (2011)

ended on 25.03.2011 (**Fig. 5**), it became obvious that the most important morphological changes occurred in the median and final sector of the landslide, the slope withdrew by 6 to 19 m, there appered some depression-like areas with humidity excess and the landslide partially throttled the Rasnic River channel.

The landslide permanent instability led to the appearance of the flood risk for Cotu and partially Breasta settlements. In case a larger

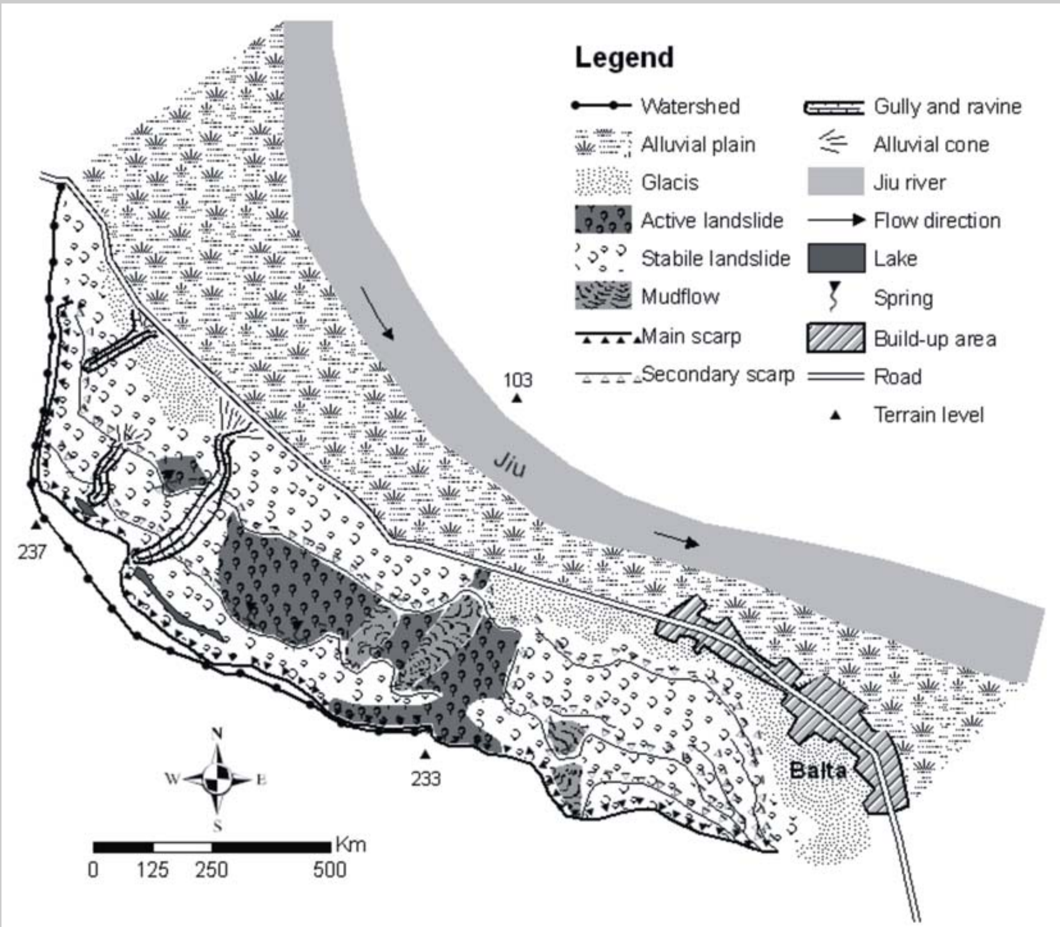

Fig. 3 Bâlta landslide sketch

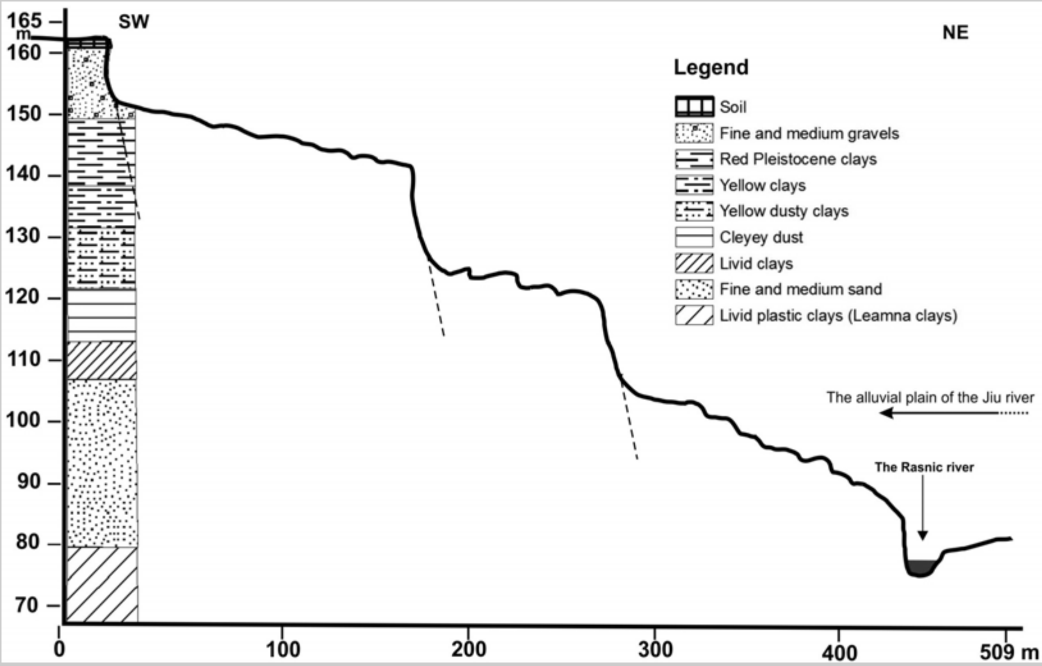

Fig. 4 Cross section in the Breasta landslide (1999)

part of the landslide becomes active, the Rasnic course is blocked, and upstream the newly-formed dam, the water level increases, flooding the floodplains of the Jiu River and the Rasnic River, where the two villages are situated. The GPS monitoring of the landslide began in the year 2006 (**Fig. 6**), when due to higher quantity of precipitation, above the annual mean, there were substantial reactivations. The GPS measurements helped us identify the landslide tendencies and areas with flooding risk in the floodplain and the built-up area, as well as find some solutions for avoiding the reactivation of the landslide and water evacuation using other floodplain channels, so that to prevent the floods.

The DEM of the central sector at Breasta landslide (**Fig. 7**) was generated following the 4986 points used by the GPS Rover GNSS Smart S82-T, minimum height 70.5m, maxi-

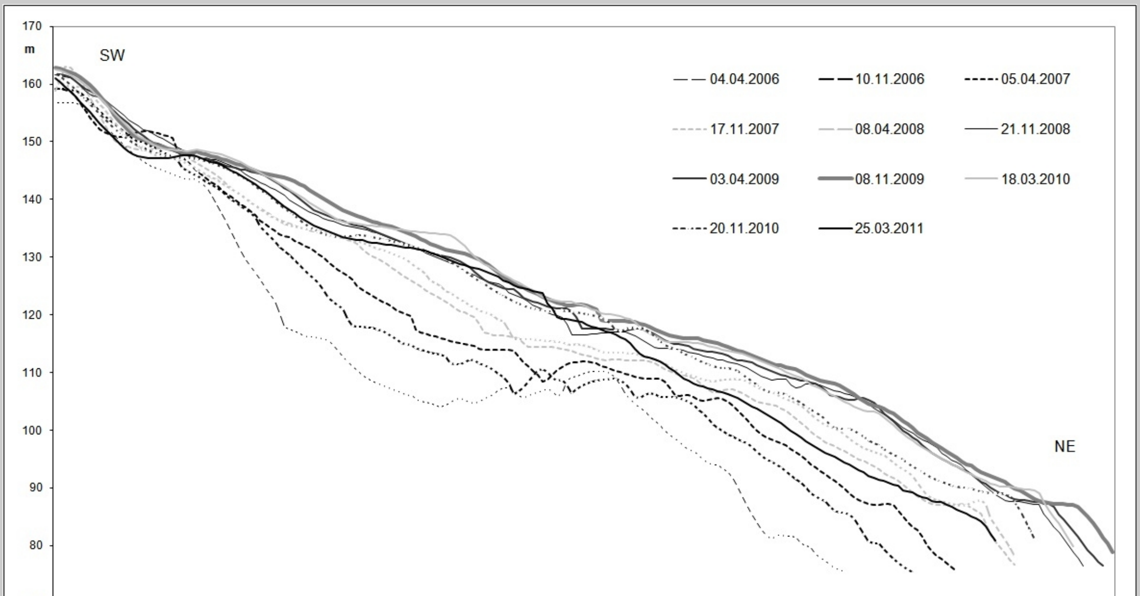

Fig. 5 GPS monitoring of the cross section profile within Breasta landslide

Fig. 6 The landslide at Breasta in the sector with reactivations since March 2011

mum height 167.5 m). By using the Kriging method, this sector was enclosed into a rectangle covering an area of 313.390 m^2, with an average height of 108 m. In order to have a clear view of the recent scarps (stretching between 80 and 115 m high), we choose 32 value classes with 5 m ecart. The sector presented in **Fig. 6** emphasizes the morphology of the landslide since 2011 in one of the „amphitheaters" which developed after the reactivation from 2006.

The Bucovăț landslide affects the right bank of the Jiu River along 1.5 km; its relief is characterized by a high cuesta-like slope. The escarpment slope is constantly at 150 – 165 m above the valley, with a maximum altitude of 165 m in Cârligei Hill and minimum of 75 m, there resulting an altitude of 90 m of the slope

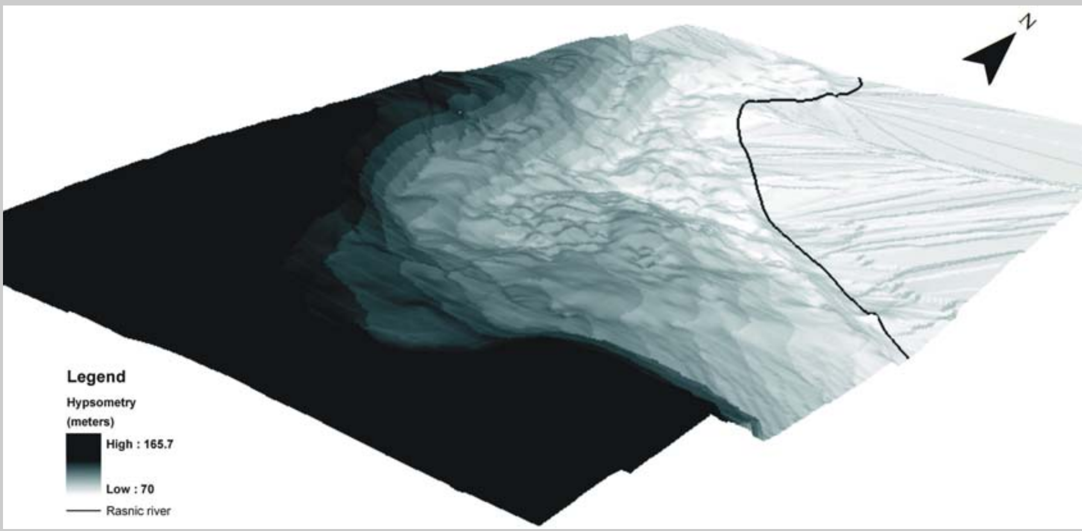

Fig. 7 DEM of the central sector of Breasta landslide

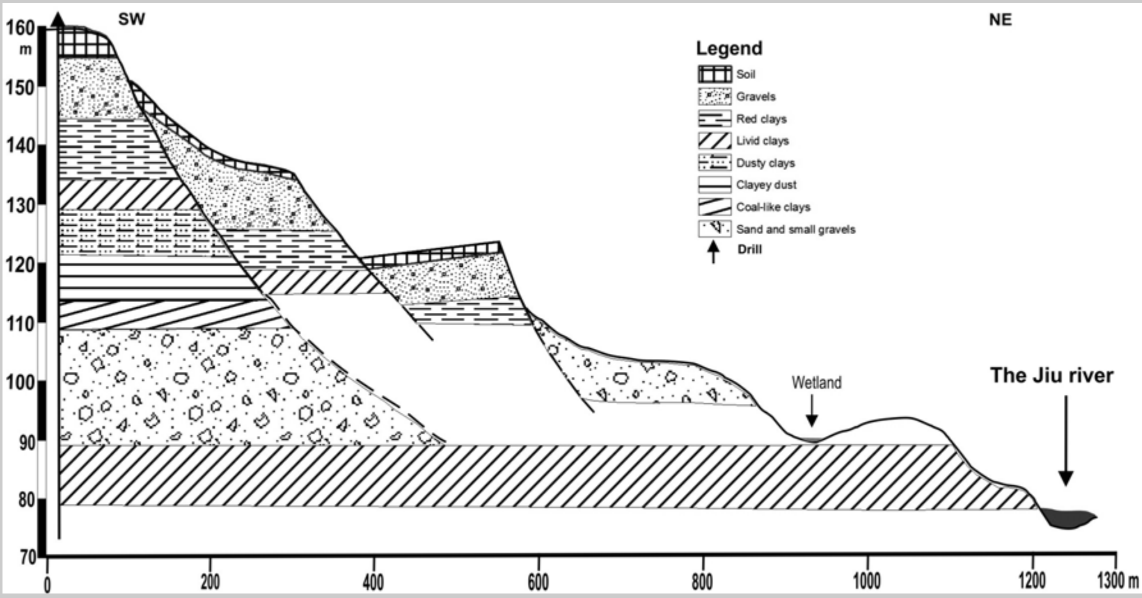

Fig. 8 Cross section in the Bucovăţ landslide (BOENGIU 2004)

from the Jiu River. The slope is tilted at around 55 – 60°.

The researches indicated the presence of three sliding steps (**Fig. 8**). The landslide scarp (8 – 10 m high) is quite obvious along its entire length, but especially in the south-eastern part, where the upper part of the stratigraphic column can be studied, with gravels and Pleistocene red clays.

It is characterized by the presence of two stabilized landslide steps. The second step has a well shaped landslide depression. At the lower part, there are strong strains and elongated monticles parallel to the Jiu River, behind which there are pools or wetlands, testifying for the recent movement of this step. This slide of fossiliferous sands occurred on top of plastic livid clays situated at the level of the Jiu River bank (BOENGIU 2004 and BOENGIU 2008).

The Bâzdâna landslide presents two areas separated by the Bâzdâna Rivulet. It is oriented west-east, starting at an altitude of 140 m, stretching up to the Jiu River bed, at 60 m, perpendicular to the convexity of one of the Jiu River meander. In the northern part, the Jiu River was pushed eastwards by the alluvial fan of the Dâlga Rivulet, but due to the immediate recurrence of the Jiu River below the slope, the landslide has a rhythmic evolution, depending on the riverbed dynamics. The more the lateral erosion washes away large quantities of materials, the more active the landslide is. These episodes are strongly correlated to the Jiu River flow, synchronized with the excessive wetting of the deposits from the landslide steps (BOENGIU et al. 2011).

The landslide is not unitary, in the north there are two steps emphasized by the two scarps. The first scarp is at least 22 – 25 m high (**Fig. 9**), 940 m in length and 80 – 95 m wide. This step slided almost without hindering the structure. The second scarp is 4.5 – 6 m high and only 380 m long, since in the spring of 2006, the front part of the landslide was reactivated and important quantities of material were worn away by the Jiu River.

In the southern part, there are three steps, with three clear landslide scarps: the first one is 5-6 m high, the second is 22-26 m high and the third is just 5 m high. The first step is 840 m long and maximum 70 m wide; the other two steps were destroyed in the spring of 2006 by vast reactivations.

Generally, for the upper steps, the structure is not in disorder, but just tilted, while the lower steps are in disorder, having the aspect of monticles at the landslide front.

The *Drănic landslide* is oriented from west to east, it begins at an altitude of 111 m, stretching up to 40 m (**Fig. 10**). It has an arch shaped scarp, 1800 m long and at least 20-30 m high. At its middle part, the landslide is 210 m wide, constantly shrinking towards the north and the south. The landslide mass is totally disrupted from the structural point of view, and is moving rhythmically, as small steps, furrows, monticles, towards the Jiu River valley.

This landslide is the result of the intensification of the Jiu River lateral erosion on the right slope, decrease of the slope drainage and over accretion of the river bed due to the low transport capacity of the river. Near this land-

Fig. 9 The landslide scarp and aspect of the material slided north of Bâzdâna

slide of approximately 2 km, the river bed has a tendency to untwine, having three channels with ever lower discharge towards the landslide front (BOENGIU et al. 2011).

CONCLUSIONS

From the confluence with the Motru River until flowing into the Danube River, the Jiu River has always had an action of undercutting the right slope of the valley. This is due to the main events of the Quaternary: the Jiu River tendency to deviate to the west due to the different elevation speeds, higher in the east and lower in the south, recorded in the western compartments of the Moesian plate; lowering the base level that caused the deepening of the valley up to 130 m and climatic fluctuations that lead to the loess deposition and oscillations in the flow. The encountered structures are monoclinal with inclination from northwest to south-east in the Getic Piedmont and

Fig. 10 The southern sector of the Drănic landslide

tabular in the Romanian Plain, and lithologically they belong to the sedimentary complexes formed of rarely cemented sands and gravels in alternation with marls and clays.

During the Middle Pleistocene, westwards of the Olt River, there begins an upheaval movement which is still active today. The general upheaval process was accompanied by folds generated by the local differentiation of some relief forms, intensity of slope processes development and lithology of river beds.

The effect of these movements varied depending on the existing faults, with the uneven upheaval of the different areas of the Getic Platform and accentuated erosion, while the Motru fault favoured the achievement of big confluence area at Filiaşi.

Within the Wallach Platform, the faults that delineated the Balş-Optaşi horst were reactivated during the same period, favouring its upheaval and inflection of covering strata, which led to the Olt River sliding eastwards and of the Jiu River westwards (BOENGIU and ENACHE 2002).

The falling movements along the Lom-Calafat line caused the graduate deviation of the Danube River towards the south and drawing of the Jiu River on the same direction (ENCIU 2007). Those from Filiaşi and Craiova distorted the terraces, becoming area of river convergence – the Motru River and the Gilort River, and the Rasnic River and Amaradia River respectively.

The right bank of the Jiu River south of Filiaşi is known for the frequent mass movements stimulated by the river undercutting. This slope is under the direct influence of the Jiu River, which erodes the bank, washes away the materials deposited at the landslide base and periodically unbalances the slope, a fact which is also favoured by the Jiu River cutting into the clay strata, the outflow of the phreatic water hanging above (BOENGIU 2004). Where the convex part of the meanders comes close to the slope, its undercutting is stronger and there occur collapses and landslides, and where the slope is far from the riverbed or neighbours the concave part of the meanders, there is no undercutting and the slope has a tendency to become alluvial fan (BOENGIU et al. 2011).

In most of the cases, the Jiu River moves away from the right slope near the confluences with the right tributaries, but immediately afterwards, it comes back near the slope. The Jiu River is pushed off by the alluvial fans built in the floodplain by the tributaries on this side; it flows near the slope under the permanent influence of crustal movements, being much more obvious near the confluences with the left tributaries.

As a result of the tilting of the piedmont monocline from north-west to south-east, all the landslides are consequent, and unfold according to a common mechanism synchronized with the excess of rainfalls and higher flows of the Jiu River.

The geomorphologic mapping pointed to the presence of numerous cracks, fissures and microdepressions where water accumulated. Moreover, there became clear that there were various lines of landslide scarps and steps, their configuration evolving continuously at microform level. There were identified torrential valleys and ravines with steep slopes that caused local landslides, cutting through sand levels and thus triggering the dynamic evacuation of the water from the divided sand lenses.

As a result of frequency, intensity, quantity and period when they occur, rainfalls influence directly the soil humidity and the vegetation. Climatic conditions, through the temperature regime (the mean annual temperature is 11.1° C), influenced the gravitational processes indirectly, since the high temperatures and the lack of precipitations impinges upon the development of vegetation, favouring the appearance of cracks and fissures that cause water to penetrate in depth.

The correlation between the morphological observations at Bâlta, Breasta and Bucovăț with the climatic data indicates that most of the landslides occurred in the years when the quantity of rainfall exceeded the annual mean, and especially when they followed drought years.

For the mitigation of the effects caused by slope undercutting, works for water-course regulation are highly necessary: cutting meanders, increase the flow velocity and consolidation of banks. Where landslides occurred and there are agricultural fields, infrastructure elements and human settlements that face collapses or floods, works must be carried on to ensure slope stability.

ACKNOWLEDGEMENTS

This study benefited by material and logistic support from the project Vulnerability of slopes and landslides in the Bălăcița Piedmont. The use of G.I.S. and the achievement of digital maps of vulnerability, CNCSIS code 2005/2008.

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