Chapter 10

Recent Landform Evolution in the Romanian Carpathians and Pericarpathian Regions

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Abstract In the Romanian Carpathians, developed on crystalline and volcanic rocks, the main geomorphological processes are rockfalls, debris flows, and topples. In the eastern part of the Eastern Carpathians, built up of Cretaceous and Paleogene flysch, landslides and mudflows are of major significance. High and middle mountain karst features and cave systems are also widespread. In the alpine area of the Southern and Eastern Carpathians, avalanches are common on the steep slopes of

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glacial cirques and valleys. Landslides also develop on high quarry slopes, waste dumps and tailing dams characteristic of the mining sites of the Apuseni Mountains. High discharges along the Carpathian rivers cause intense erosion and the undercutting of slopes, favoring landslides and flooding. Although in fluvial erosion channel incision is predominant (for half of all river sections studied), riverbed aggradation is also observed locally. On the agricultural lands of the Subcarpathians and in the Transylvanian Depression slopes are degraded by sheet and gully erosion, landslides, and mudflows. On the Moldavian Plateau soil erosion, gullying, and landslides are major exogenous geomorphic processes. The country-wide spatial distribution of these geomorphological hazards has been evaluated by several authors (e.g., Geografia României I. 1983; Bălteanu 1997).

Keywords Landslides • Soil erosion and gullying • Karst • Periglacial processes • Fluvial processes • Mining impact

10.1 Major Geomorphological Units

Dan Bălteanu

The Romanian section of the *Carpathian Mountains* occupies 66,303 km² (27.8% of the country's territory) and stretches along 910 km between the Tisza Valley and the Danubian Gorges, with an extension, the Apuseni Mountains, up to the Someş Valley (Romania. Space, Society, Environment 2006). The Carpathian arch is bordered by a hill and tableland region (the Subcarpathians, the Banat and Crişana Hills, the Getic Piedmont, and the Moldavian Plateau) and encircles the Transylvanian Depression. Average altitude is 1,136 m, the highest summit is Moldoveanu Peak in the Făgăraş Massif (2,544 m). This range has a very complex morphology and structure, being also very much fragmented. The Carpathians in Romania can be divided into the following distinct units (Romania. Space, Society, Environment 2006).

10.1.1 The Eastern Carpathians

The Eastern Carpathians (33,584 km²), between Romania's northern border and the Prahova Valley, are structured in three distinct longitudinal units: a *crystalline* unit in the central part, with the highest peaks in the Rodna Mountains (Pietrosu 2,303 and Ineu 2,279 m); a *sedimentary* unit in the east, built up from Cretaceous and Paleogene Flysch; and a *Neogene volcanic* unit in the west, at the contact with the Transylvanian Depression. In the southeast there are the Curvature Carpathian and Subcarpathian areas, where the Vrancea Seismic Region of high seismicity potential is located (three over 7 M Richter scale earthquakes/century on the average).

10.1.2 The Southern Carpathians

The Southern Carpathians (15,000 km²) extend from east to west between the Prahova Valley and the Timiş-Cerna Corridor. They represent the highest and most compact section of the Romanian Carpathians, with heights above 2,500 m, large denudational levels, and a characteristic alpine relief dotted with numerous glacial cirques and valleys. At altitudes above 2,000 m, extended alpine and subalpine meadows are found. These mountains are made up of crystalline schists and Mesozoic sedimentary deposits of distinct elevations. The main tectogenetic phase is dated to the Upper Cretaceous.

10.1.3 The Banat and Apuseni Mountains

The Banat and Apuseni Mountains (17,714 km²), spread out between the Danube and the Someş rivers, include two distinct subunits: the Banat Mountains in the south up to the Mureş Corridor, and the Apuseni Mountains (highest peak Curcubata, 1,847 m) north of the Corridor. They have a complex horst and graben structure, being built of crystalline rocks, limestones, and volcanic rocks with important ferrous and non-ferrous ore deposits.

10.1.4 The Transylvanian Depression

The Transylvanian Depression (25,029 km²) lies between the three units of the Romanian Carpathians. It is a tableland with heights of 400–800 m and has a tectonic origin. The basement is Carpathian with a post-tectonic mantle of Upper Cretaceous to Lower Miocene age. The depression is filled by clastic rocks, marine tuffs, a salt formation, marls, sands, and clays (Miocene to Pliocene), with monoclinal and dome-like structures (Romania. Space, Society, Environment 2006).

The *Pericarpathian region* includes the following units. The *Mehedinți Plateau* (785 km²) is situated in the southwest of Romania between the Danube and the Motru rivers, at heights of 500–600 m. It is actually a lower compartment of the Southern Carpathians and consists of crystalline schists and limestones. The *Subcarpathians* (16,409 km², 400–900 m altitude), which border the Carpathians on the east and south along 550 km length, are built up of folded-faulted Neogene molasses and are affected by neotectonic uplift (Zugrăvescu et al. 1998). Human pressure in the area is particularly severe and has contributed to an intense remodeling of stream channels and slopes. The *Getic Piedmont* (12,940 km²) is located to the south of the Southern Carpathians at altitudes of 200–700 m and consists of gravels and sands with intercalations of marls and clays. It was formed in the Romanian-

Quaternary interval and is basically a relict piedmont fragmented by large, consequent allochthonous valleys. Piedmont catchment basins are affected by gully erosion and landslides, their intensity decreasing from north to south. The *Moldavian Plateau* (23,085 km²) lies in eastern Romania and is developed on a platform basement covered by sedimentary formations deposited in several cycles. The *Banat* and *Crişana Hills* and *Plain* (28,640 km²) are situated in the western part of the Banat and Apuseni Mountains, are discontinuous and have a predominant piedmont character. The plain lies to the west and it was formed during several stages after the recession of the Pannonian Lake and the accumulation of the fluvio-lacustrine and lacustrine sediments.

10.2 History of Geomorphological Research

Dan Bălteanu and Marta Jurchescu

The research of geomorphological processes in the Romanian Carpathians has evolved differently for the various types of processes but more common features appeared in the phase of a more rapid development since 1990, corresponding to relatively suddenly opened access to international literature.

Landslide investigations have a long tradition in Romania. Landslide-related studies started especially in the 1920s (Mihăilescu 1926). In the following decades, numerous articles and books addressed this subject, in a more descriptive manner, either with the aim of classifying, presenting some local cases, or zoning landslides across geomorphic units or all over the country (e.g., Mihăilescu 1939b; Tufescu 1964, 1966; Morariu and Gârbacea 1968b; Ielenicz 1970). Regionally, the Curvature Carpathians and Subcarpathians, being among the most complex units in terms of lithological and structural conditions and part of the Vrancea Seismic Region with the most active subcrustal earthquake activity in Europe are intensely modeled by a wide range of landslide processes and benefitted from a long history of observations (e.g., Mihăilescu 1939a; Tufescu 1959; Posea and Ielenicz 1970). The relatively recent development could be summarized by a two-level analysis: regional assessments and site-specific studies. *Regional assessments* focus on study-areas ranging from small-size catchments to larger geomorphic units. In an earlier stage, direct qualitative methods and some of the first quantitative ones were employed, involving geomorphological classification and large-scale mapping (1:5,000, 1:10,000) (Bălteanu 1975, 1983; Ielenicz 1984). This was done repeatedly in the course of time, allowing to differentiate between annual, seasonal, and monthly changes, with the aim of assessing the morphodynamic trends of slopes and of elaborating morphodynamic maps (Bălteanu 1975). From 1980 to 2000, the research focus was placed on elaborating the methodology of general geomorphological mapping at regional scales of 1:25,000 and 1:200,000 and on synthesizing available landslide information over wider areas (e.g., Gârbacea 1992; Irimuş 1998; Surdeanu 1996, 1998; Bălteanu 1997; Dinu and Cioacă 2000). These regional studies were the precursors of the first landslide susceptibility and hazard maps produced after 2000. Direct susceptibility and hazard maps, based on expert judgment, have been elaborated on test areas at large scales. Indirect susceptibility assessments were based first on heuristic methods associated with the use of GIS techniques (Mihai 2005), and subsequently, with the constant construction or improvement of some landslide databases (e.g., Şandric and Chițu 2009), through statistical analyses of empirical data (Şandric 2005, 2008; Micu 2008; Bălteanu and Micu 2009; Micu and Bălteanu 2009; Chițu et al. 2009; Mihai et al. 2009; Constantin et al. 2011; Chițu 2010). In the last few years, quantitative research was also extended to other processes, like debris flows or rockfalls (Ilinca 2010; Pop et al. 2010; Surdeanu et al. 2010). Recently, by analyzing either the variability of rainfall as triggering factor or the historical frequency of landslides, it has been possible to make primary estimations on the temporal probabilities of landslide occurrence and produce landslide hazard maps (Dragotă et al. 2008; Micu 2008; Şandric 2008; Bălteanu and Micu 2009; Chițu 2010). Qualitative, expert-based hazard maps have also been drawn over wider areas (Micu et al. 2010). In some cases it has been proven that validated susceptibility and hazard assessments are in agreement with the detailed morphodynamic mapping made in the past (Bălteanu and Micu 2009).

Investigations at the *local scale* included repeated mapping projects, measurements, estimations of movement rates, collection of soil samples and determination of geotechnical properties (Bălteanu and Teodoreanu 1983; Bălteanu 1983, 1986), topographical, inclinometrical measurements (Surdeanu 1998), the analysis of internal landslide structures by geophysical techniques (Andra and Mafteiu 2008; Urdea et al. 2008b; Chițu 2010) and eventually the application of deterministic methods (Micu 2008; Constantin et al. 2010; Chițu 2010).

The landslide susceptibility map of Romania (Bălteanu et al. 2010), based on a semi-quantitative method, offers a general view on landslide occurrence in the Romanian Carpathians.

The study of *soil erosion* and *gullying processes* has focused on two major directions: (1) the long-term monitoring on some experimental plots, conducted at several research stations located in different environmental conditions, and (2) the inventorying of gullies, as well as repeated surveying of some representative gullies over longer periods of time. Experimental results on runoff plots enabled the formulation of empirical methods of *soil erosion prediction* (Moțoc 1963; Moțoc et al. 1975; Traci 1979; Dârja et al. 2002; Moțoc and Mircea 2002; Ionita et al. 2006), later tested in various areas (e.g., Patriche et al. 2006). The second field of investigation (e.g., Moțoc et al. 1979a; Mihai and Neguț 1981; Ichim et al. 1990; Rădoane and Rădoane 1992; Ionita 1998, 2000a, 2006; Rădoane 2002) covered both types of *gullies*, continuous and discontinuous (Ionita 2003), on which measurements of head regression and area and volume growth have been performed over time. Among the techniques used, the one involving ^{137}Cs isotope provided information on temporal variations in sediment deposition and soil erosion rates (e.g., Ionita and Margineanu 2000; Ionita et al. 2000). Furthermore, based on repeated surveys, it became possible to apply statistical and deterministic models to gully evolution (e.g., Rădoane et al. 1995, 1997; Ionita 1998, 2003, 2006; Mircea 2002; Ionita et al. 2006). Models capable to predict the initiation of future gully processes within a catchment have also been developed (Moțoc 2000 cited in Mircea 2002; Moțoc and Mircea 2005).

Moreover, total erosion and *sediment delivery* in small catchments were assessed either in an empirical or deterministic manner (Moțoc et al. 1979b; Ichim and Rădoane 1984; Ionita 1999, 2008; Mircea 2006).

The earliest maps or descriptions of *karst forms* (*caves*) on the present territory of Romania are as old as the late seventeenth up to the nineteenth centuries. Nevertheless, a systematic scientific research of karst forms and processes began with the establishment of the Institute of Speleology by E.G. Racoviță in the city of Cluj in 1920. Reorganization of the old Institute led to the elaboration of monographical studies devoted to different karst areas (Bleahu and Rusu 1965; Orghidan et al. 1965). Starting with 1965, simultaneously with the specialization of researchers in different areas of interest, the speleological activity was enriched by amateur contributions to cave exploration and survey (*sports speleology*). The unprecedented progress in discoveries occurred in close collaboration with researchers who constantly verified and standardized new data (e.g., Bleahu and Povară 1976; Goran 1980, 1982; Lascu and Sârbu 1987).

The more recent activity of the Institute of Speleology has been divided among several fields of theoretical and applied karstology and has developed both in Bucharest (e.g., Constantin 1992; Constantin et al. 2001) and in Cluj (e.g., Onac 2002; Racoviță et al. 2002; Perşoiu et al. 2011), using modern equipment and investigation methods (absolute datings, paleoclimate reconstitutions, chemical and drainage analysis of karst aquifers, etc.). Besides, an important element is the continuous updating of the Romanian cave inventory.

The first observations on some specific *periglacial elements*, though not defined as such, date back to the end of the nineteenth and the beginning of the twentieth centuries (de Martonne 1900, 1907; etc.). Corresponding to an international trend, a sudden concern for both actual and Pleistocene periglacial issues occurred only after 1955. An abundance of works followed, including some syntheses on the whole territory of the country (e.g., Niculescu and Nedelcu 1961; Niculescu 1965; Naum 1970; Schreiber 1974; Mihăilescu and Morariu 1957; Morariu et al. 1960; Ichim 1980). Until 1990, however, only the identification of specific phenomena, alongside the description and explanation of their occurrence and age, was aimed at. After that year, specific methods and techniques started being applied in the alpine areas of the Romanian Carpathians for various purposes. Rock glacier investigations, BTS-measurements and geophysical tomographies were performed and a solar radiation model was applied to investigate the presence of permafrost in the Carpathians (Urdea 1991, 1993, 1998a, 2000; Urdea et al. 2001–2002; 2008a). Using geophysical techniques the inner configuration of some periglacial deposits could also be analyzed (Urdea et al. 2008a, c). Dendrogeomorphological methods served to date periglacial landforms or reconstruct their evolution (Urdea 1998b). Local measurements of *active processes* included: the study of frost weathering in rocks by means of thermal infrared images; the monitoring of the movements produced by frost heave and frost thrusting, as well as by pipkrake, needle ice, and frost sorting processes, through the use of elevationmeters and cryometers (Urdea et al. 2004). Other periglacial phenomena, such as solifluction, the movement of ploughing blocks, talus and rock creep, or nivation-related processes were also monitored in order to estimate movement rates or the occurrence frequency of events (Urdea et al. 2004; Voiculescu 2009; Voiculescu and Popescu 2011).

The study of *fluvial* geomorphic *processes* took on a pronounced quantitative character when, starting with the 1960s, the necessary hydrometrical measurements increased in number and quality and mainly focused on the rivers draining the outer flanks of the Eastern Carpathians, and, to a lesser extent, on rivers crossing the Southern or the Banat and Apuseni Mountains (including the Danube Gorge). The aim was to identify the behavior of riverbed systems in relation to natural and especially to human controlling factors: man-made reservoirs (an earlier overview in Ichim and Rădoane 1986), river channelization (Hâncu 1976), river straightening, embankments, in-stream sand mining, etc. The major issues were the vertical and planform mobility of river channels, followed both in river *longitudinal profiles* and in *cross-sections*, statistically analyzed by employing databases on numerous cross-sections over short and long periods of time, in order to detect evolution trends (e.g., Diaconu et al. 1962; Ichim and Rădoane 1980, 1981; Bătucă 1978; Ichim et al. 1979; Bondar et al. 1980; Rădoane et al. 1991; Feier and Rădoane 2008; Perşoiu 2008); the contribution of slopes to riverbeds and *sediment budget estimations* by indirect methods (e.g., Gaşpar and Untaru 1979; Ichim et al. 1998; Rădoane and Rădoane 2003b; Dumitriu 2007; Feier 2007; Burdulea-Popa 2007); the past and future evolution of drainage basins in terms of the degree of *concavity* of the longitudinal profiles modeled mathematically (Rădoane et al. 2003); geometrical, physical and petrographic analyses of current stream *channel deposits* (Ichim et al. 1996, 1998) in the light of two distinct laws: downstream fining and channel material bimodality (Rădoane and Rădoane 2003a; Rădoane et al. 2008a), using specific field sampling and laboratory processing techniques.

10.3 Recent Landform Evolution in the Carpathian and Pericarpathian Regions

10.3.1 Landslides

Dan Bălteanu, Virgil Surdeanu and Marta Jurchescu

Landslides are among the most widespread geomorphological processes in the hilly regions built of Neogene molasse deposits, as well as in the mountainous regions of Romania developed on Cretaceous and Paleogene flysch. Primarily due to the presence of these sedimentary rocks consolidated to various degrees and to *tectonic influences*, landslides are most common in the Subcarpathian Region and in the Eastern Carpathians – particularly in the Curvature area of high seismicity and active neotectonic activity. The uneven incision of the drainage network has generated variable *relative relief* ranging from 50–350 m for smaller streams to 350–700 m for major rivers (like the Moldova, Bistrița, Trotuş, Buzău, and Prahova).

Annual average *precipitation*, ranging from 600 to 1,000 mm, falls within 85–125 days, the snow pack lasts for 100–180 days. The pluviometric regime alternates between wet and dry periods, triggering and maintaining the masses of earth in a dynamic state for a long period of time. In the last 130 years, the four intervals of pluviometric excess (1912–1913; 1939–1942; 1970–1972 and 2004–2005) led to a recrudescence of landslide processes in the flysch area (Surdeanu 1996).

As two-thirds of the flysch mountains are below 1,000 m altitude, large areas are accessible to human settlement and the development of *economic activities*. As a result, the equilibrium of their slopes has been upset. Although around 40% of Romania's forests are concentrated in the Eastern Carpathians, yet *deforestation*, gradually expanding from mountain foot to top during the Middle Ages and at even faster rates in the nineteenth, twentieth and twenty-first centuries, mostly in the mountain basins of the Buzău, Trotuş, Bistrița, Moldova rivers and in the Curvature area, has contributed to the reactivation of old slides. In many cases, the valleys of first to third order rivers, developed on marls and clays, are filled with landslide colluvia (the basins of the Buzău, Putna, Trotuş, Bistrița, etc.), and have a specific slide valley morphology.

Mining works, oil drilling, ever more densely *built-up areas* and *communication* routes (at densities of 6.4 km km^{-2} in the oil fields), as well as the hydrotechnical structures raised in the Buzău, Bistrița, Argeş, Olt, and Someş valleys have challenged the stability of slopes and extended landslide-prone areas, particularly on the slopes of reservoirs in the Buzău and Bistrița valleys and in the Trotuş Mountains oil fields. The mining areas of the Apuseni Mountains and the Eastern Carpathians present a special situation: some areas are affected by landslides related to waste dumps and tailings dams. Unstable waste dumps in the mining zones of Baia Mare, Ostra – Tarnița and Călimani (the Eastern Carpathians) and Certej – Săcărâmb (the Apuseni Mountains) pollute rivers over long distances. In the late twentieth and the early twenty-first centuries, *salt extraction* in the inner and sub-montane depressions (of Maramureş at Coştui, and of Târgu Ocna, respectively), as well as in the Carpathian Foreland (Ocnele Mari) led to the collapse of galleries, triggering large-scale sliding-collapsing processes.

The geomorphological mapping projects, field surveys and laboratory tests undertaken in the Carpathian area (Mihăilescu 1939a; Badea 1957; Donisa 1968; Barbu 1976; Posea and Ielenicz 1976; Ichim 1979; Untaru 1979; Surdeanu 1979, 1998; Bălteanu 1983; Ielenicz 1984; Micu 2008; Mureşan 2008, etc.) have revealed some *regularities* in the great diversity of mass movements:

- Most landslides would affect the surface deposits lying at the base of slopes of 35–62% clays and, as a rule, slides with a 1:20 to 1:50 length-to-width ratio prevail.

- In the mountain region, landslides occurring at 700–800 m maximum elevation have the greatest impact on landform evolution (given that human pressure, such as raw materials extraction, is also at its peak – up to 1,100 m in the Tarcău Mountains).
- Nearly 75% of the active landslides recorded in the mountains occur on deforested slopes. There are instances, however, when big landslides also develop on forested slopes (in the Ceahlău and the Buzău Mountains).
- Shallow slides last for a couple of weeks. Deep-seated slides may extend over years, scores of years with episodes of rapid and slower rates of material removal.

Having analyzed over 500 active landslides in the Eastern Carpathian Flysch zone north of the Trotuş River over the past four decades (Surdeanu 1979, 1987, 1996, 1998), the following features have been distinguished:

- *Translational shallow slides* with a 0.5–1.0 m circular scarp and a short dynamic phase (days), 55 m long and 22 m wide on the average;
- *Rotational slides* with a linear scarp, on the average 70 m long and 31 m wide;
- *Slumps* with a micromorphology of monticles and waves, and a 2–30 m high circular or linear scarp; on the average 95 m long and 25 m wide;
- *Valley slides*, developed in the upper part of drainage basins, with a 2–3 m high scarp, on the average 180 long and 90 m wide;
- The volume of material entailed is of the order of hundreds and thousands (sometimes even over one million) cubic meters;
- The landslide-induced *denudation rate* in the flysch mountains was estimated at 2–40 mm year^{-1} for slide-affected areas (Surdeanu 1998).

A special case is represented by the Curvature Carpathians, where tectonic uplift and the seismicity specific of the Vrancea area favor the occurrence of deep-seated landslides (Bălteanu 1983; Ielenicz 1984) (Fig. 10.1).

In the Subcarpathians, with a dominantly argillaceous Neogene molasse substrate and a high content of montmorillonite and illite (quick clays), landslides have a greater share in the modeling of the slopes. Shallow translational slides and moderate to very deep-seated rotational slides, alongside mudflows, are common.

Recent assessments (Micu and Bălteanu 2009; Bălteanu et al. 2010) have shown that the most affected areas lie in the Curvature Subcarpathians (Fig. 10.2). Besides rainfall, shocks induced by strong earthquakes (magnitude over 7 M on the Richter scale and return period of 35–40 years), localized in the Vrancea Seismic Region, play a major role in activating deep-seated slides, rockfalls and debris flows. In some areas denudation rates were estimated at 0.5–10 mm year^{-1} corresponding to years of high precipitation with a return period of 5–7 years (Bălteanu 1983). The slopes of this unit, mostly covered by landslide deposits, range from highly stable to unstable with an annual frequency in landslide reactivations. These affect primarily the lower part of slopes associated with the land use changes of the post-communist period and with the higher frequency of torrential rainfalls.

In the Getic Subcarpathians and the Getic Piedmont, the spatial distribution of slides shows a correlation to small catchments and gully erosion. In addition,

Fig. 10.1 Deep-seated landslide on the righthand slope of the Siriu Reservoir, Buzău Mountains (Curvature Carpathians) (*left*) and its scarp (*right*) (Photos: Dan Bălteanu)

Fig. 10.2 Active mudflow at Malu Alb, Pătârlagele (Curvature Subcarpathians), in 2010 (Photo: Laurențiu Niculescu)

degradation caused by coal and salt mining over large areas led to an increase of landslide susceptibility (Bălteanu et al. 2010) (Figs. 10.3 and 10.4).

A great diversity of landslides occurs on vast stretches of land in the Transylvanian Depression. In the Transylvanian Plain, mainly built of clayey rocks, shallow and

Fig. 10.3 Deep-seated slump at the margin of a coal quarry, Berbeşti (Getic Subcarpathians) (Photo: Marta Jurchescu)

Fig. 10.4 Waste dump affected by a recent deep-seated landslide, Mateeşti (Getic Subcarpathians) (Photo: Marta Jurchescu)

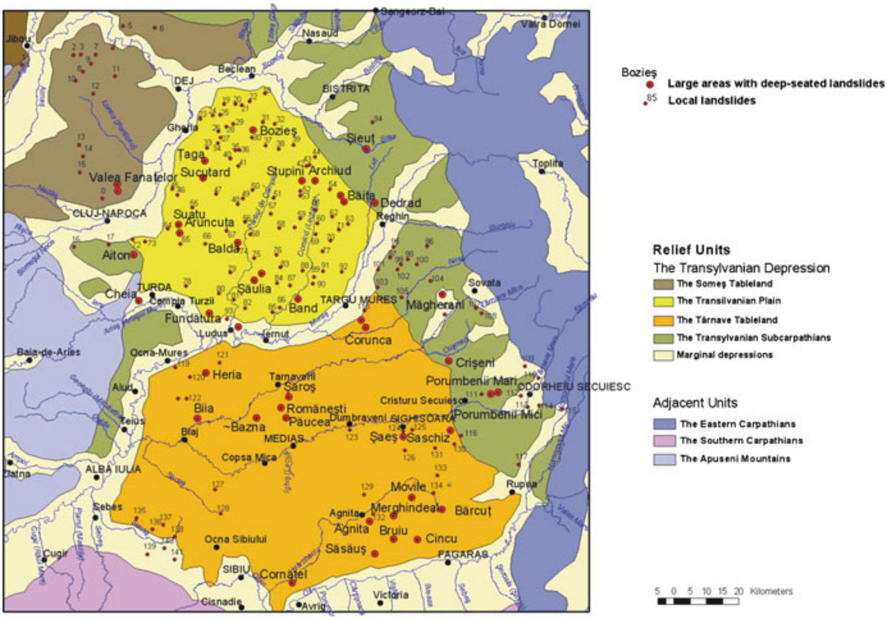

Fig. 10.5 Deep-seated landslides ("Glimee") in the Transylvanian Depression (based on over 50 scientific papers, books and PhD theses published between 1950 and 2002) (Bălteanu and Jurchescu 2008)

medium-deep slides prevail. In the central and southern part of the Depression we find large-sized, deep-seated landslides of *lateral spreading* type, produced on a substrate of marl-clayey complexes with intercalations of Sarmatian sandstone and sand. Spores and pollen analyses dated them to the humid Boreal stage (Morariu et al. 1964; Morariu and Gârbacea 1966, 1968a, b; Gârbacea and Grecu 1983; Grecu 1992; Gârbacea 1992, 1996; Irimuş 1996, 1998) (Fig. 10.5).

Landslides are also common for the homoclinal relief of the Moldavian Plateau, particularly on cuesta fronts. Pujina and Ionita (1996), investigating a time span of 170 years, found that periods of landslide reactivation outnumbered those with first time failures (Bălteanu et al. 2010).

10.3.2 Soil Erosion and Gullying

Ion Ionita

One of the most severely eroded *agricultural areas* in Romania is the Moldavian Plateau (27,000 km^2). Clayey-sandy Miocene-Pliocene layers with a gentle north-northwest to south-southeast dip of 7–8 m km^{-1} outcrop from the sedimentary substrate (Jeanrenaud 1971). The climate is temperate continental (mean annual temperature: 8.0–9.8°C; average annual precipitation: 460 mm at lower elevations in the south and 670 mm in the central and northwestern area rising to 587 m). Natural vegetation cover was drastically changed by human action, particularly over the past two centuries. Mollisols and argiluvisols (forest soils) used for crop production are the most common (arable land 58%, pastures and meadows 16% and forests 13%).

Currently soil erosion and gullying are assessed from long-term *monitoring* of experimental plots and repeated field surveys of *gullies*. The effect of soil cover on runoff and soil losses was studied on runoff plots over the period 1970–1999 at the Central Research Station for Soil Erosion Control Perieni-Bârlad. Substantial field databases have resulted from almost 20 years of monitoring representative gullies located in the southern part of the Moldavian Plateau near the city of Bârlad, using aerial photographs of the 1960 and the 1970 flights, classical leveling work and repeated surveys through a particular close stakes grid after 1980.

The Perieni runoff plots were established on the left valley side of Tarina catchment with 12% slope and slightly eroded mollisol. Generally, data collected here over a 30-year period on soil and water losses indicate the following (Ionita 2000a; Ionita et al. 2006):

- Mean annual precipitation is 504.3 mm, and the precipitation that causes runoff and erosion falls as rain during the growing season from May to October;
- About 26% (133.5 mm) of the annual precipitation induced runoff/erosion on continuous fallow and 18.5% (93.5 mm) for maize;
- Runoff ranges from 36.5 mm under continuous fallow with the peak of 12.0 mm in July and 17.7 mm under maize with the peak of 6.5 mm in June;
- Average soil loss is 33.1 $\mathrm{t\,ha^{-1}\,year^{-1}}$ for continuous fallow with the peak of 12.8 $\mathrm{t\,ha^{-1}}$ in July and 7.7 $\mathrm{t\,ha^{-1}\,year^{-1}}$ for maize with the peak of 3.7 $\mathrm{t\,ha^{-1}}$ in June.

It has to be remarked that on heavily eroded forest soils the value of the soil loss is doubled.

According to Moțoc and co-workers (1998) data collected from the continuous fallow plot and processed using a 3-year moving average revealed that over the period 1970–1999 there were three soil erosion peaks, in 1975, 1988 and 1999.

Radoane and co-workers (1995) identified two areas with a higher gully density: the first in the north, where mostly small discontinuous gullies have developed on clays and the second in the south, around the city of Bârlad, where, on loamy-sandy layers, valley-bottom continuous gullies prevail. Results on discontinuous gullies have indicated that during a variable period of 6–18 years the gully head retreated 0.92 $\mathrm{m\,year^{-1}}$ on average with a range from 0.42 to 1.83 $\mathrm{m\,year^{-1}}$. The mean growth of gully area was 17.0 $\mathrm{m^2\,year^{-1}}$ and varied between 3.2 and 34.3 $\mathrm{m^2\,year^{-1}}$. Both values indicate a slow erosion rate (Ionita 2000b, 2003, 2006; Ionita et al. 2006). Moreover, the annual regime of gullying shows great fluctuations and 60% of total *gully growth* took place in only 5 years (1980, 1981, 1988, 1991 and 1996).

Conventional measurements on sedimentation using check-iron plates along the floor of discontinuous gullies over the period 1987–1997, indicate a higher rate of aggradation in the upper half of the gully floor. This finding supports the development of a short steeper reach within the gully floor as a critical location for gullying renewal. Similar values were obtained from the ^{137}Cs depth profile. Furthermore, it was possible to date gullies at 23–48 years and to claim that discontinuous gullies deliver most of the sediment needed for their own aggradation. The evolution pulses reflect a dynamic balance between two simultaneous processes, erosion and sedimentation, within a single system. As for continuous gullies, linear gully head retreat, areal gully growth and erosion rates were established for three periods (1961–1970, 1971–1980 and 1981–1990). Results indicate that gully erosion has decreased since 1960 (Ionita 2000b, 2006; Ionita et al. 2006). Average gully head retreat ranged from 19.8 m year^{-1} in the 1960s and 12.6 m year^{-1} in the 1970s to 5.0 m year^{-1} during the 1980s. This decline is due to the rainfall distribution, and the increased influence of soil conservation. The mean gully head retreat of 12.5 m year^{1} over the 30-year period (1961–1990) was accompanied by a mean gully area growth of 366.8 m^{2} year^{-1} and a mean erosion rate of 4,168 t year^{-1}. The continuous gullies also developed in pulses. Gullying in the 1981–1996 period concentrated mostly on the 4 months from mid-March to mid-July in an area with mean annual precipitation around 500 mm. Another main finding of this 16-year stationary monitoring was that 57% of the total gullying occurred during the cold season, especially in March due to freeze-thaw cycles, with the remainder during the warm season. Of the total gully growth, 66% results from only 4 years (1981, 1988, 1991 and 1996) when precipitation was higher.

Field measurements performed in small catchments during flash streamflows allowed the identification of two types of sediment delivery scenarios, synchronous and asynchronous (Ionita 1999, 2000b, 2008). Even for very rare events, the synchronous scenario, mostly associated with quick thawing, shows very high sediment concentration, exceeding 300.0 g L^{-1} at the basin outlet and low values, up to 40.0 g L^{-1}, upstream of gullies in the upper basin. Gullying is the major source of sediment. The asynchronous scenario commonly occurs and is characterized by higher water discharges and fluctuating sediment concentration (Piest et al. 1975). Total erosion in the Moldavian Plateau of Eastern Romania averages 15–30 t ha^{-1} year^{-1} (Moţoc 1983).

Since 1991, by implementing the new *Land Reform* (Acts nos 18/1991 and 01/2000), the previous area under conservation practices was gradually converted to the traditional downhill farming system. Under these circumstances the rate of soil erosion and sedimentation doubled (Ionita et al. 2000).

10.3.3 Karst

Cristian Goran

The carbonate karst of the Carpathians occupies 3,700 km^{2}, representing 5.6% of the mountainous area and 82% of the total karst area of Romania. Karst areas occur in all Carpathian units, being the most extensive in the central and northern parts of

Fig. 10.6 The distribution of karst regions in the Romanian Carpathians (Modified after Bleahu and Rusu 1965)

the Eastern Carpathians, in the west of the Southern Carpathians and in the Banat and Apuseni Mountains (Fig. 10.6). The karst terrains are distributed as follows: 16% in the Eastern Carpathians, 27% in the Southern Carpathians, 26% in the Banat Mountains and 31% in the Apuseni Mountains (Bleahu and Rusu 1965). Karst-prone rocks mainly outcrop in the Mesozoic mountain massifs in contact with uplifted blocks of crystalline schists. The widest limestone outcrops, relatively unitary, are located in the Reşiţa–Moldova Nouă Syncline from Banat (over 600 km^2), in the Bihor Massif and in the Pădurea Craiului Mountains. Karst structures were identified up to a maximum elevation of more than 2,400 m (in Negoiu, Făgăraş Mountains) and down to a minimum elevation, reached under the sea level (in the Danube Gorges, Almăj Mountains).

The distribution of the karst units is correlated with the morphology and the structure of limestone areas (Fig. 10.7). Following the stages of tectonic uplift, the Mesozoic carbonate platforms were divided into *morphotectonic types*: *plateaus* (in the mountains with elevated crystalline basement), *limestone bars* (along the margins of mountains borders or along the tectonic corridors) and *isolated massifs* (in the area of high ridges, by the outcropping of crystalline limestones and around tectonic depressions, by the fracturing of the limestone cliffs). These morphotectonic types were further diversified during the Quaternary morphohydrographical

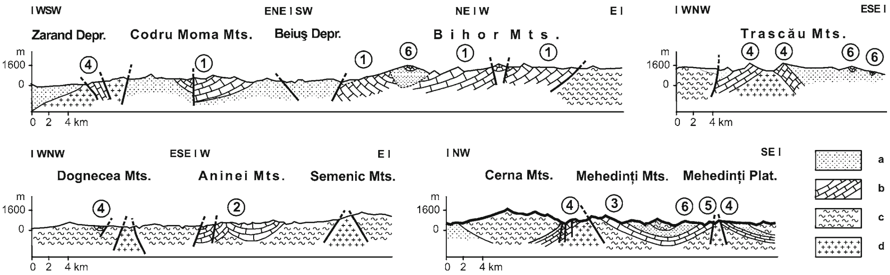

Fig. 10.7 The relationship between the mountain area massiveness and the distribution of the karst types in the Apuseni Mountains, Banat Mountains and the west of the Southern Carpathians (Modified after Goran 1983). 1, unitary elevated plateaus; 2 dissected elevated plateaus; 3, unitary bars; 4, fragmented bars; 5, leveled bars; 6, isolated massifs; a, non-carbonate sedimentary rocks; b, carbonate rocks; c, crystalline schists; d, magmatic intrusions

and karst evolution, producing the following genetic-evolutive types of karst massifs (Goran 1983):

1. Unitary and elevated karst plateaus (Pădurea Craiului Mountains, Bihor, Vaşcău);
2. Elevated and hydrographically divided karst plateaus, represented by the karst of the Reşița-Moldova Nouă Synclinorium (Banat Mountains);
3. Subsided karst plateaus, located around the mountainous area (Romanian Plain, Western Plain and Hills);
4. Unitary limestone bars (Hăghimaş, Piatra Craiului, Buila-Vânturarița, Mehedinți and Scărița-Belioara);
5. Fragmented limestone bars (Trascău, Cerna Valley, Cernădia-Cerna Oltețului area and Casimcea Plateau);
6. Leveled limestone bars (Mehedinți Plateau and Moneasa area);
7. Isolated limestone massifs (located in the majority of the mountainous units); according to their morphology, they are further divided in *isolated ridge massifs* (Maramureş, Rarău and Giumalău Mountains), *isolated slope massifs* (Postăvaru, Trascău) and *isolated valley massifs* (Perşani, Ciucaş, Bucegi, Leaota).

The present-day karst inherits some of the Mio-Pliocene paleokarst features and structures, but was mainly formed due to the Quaternary uplift and fragmentation of the Carpathians. Related also to the Quaternary evolution is the partial covering of the karst terrains with detrital deposits or soil, epikarst areas being limited to mountain ridges or isolated massifs. From this point of view, the karst of Romania can be considered a transitional, moderately developed karst, which evolves now in pluviokarst regime (elevated or isolated authigenic karst units) and in fluviokarst regime (allogenic, hydrographically dissected karst units).

From the point of view of the karst systems recharge and of the intensity of the dissolution processes, a high-mountain karst (developed at elevations above

1,500–1,700 m), with water recharge from snow and rain, mainly as authigenic (unitary) karst, with well-represented epikarst, and karst areas of medium and low mountains, hydrographically divided, with lower relief energy, binary karst functioning and covered by forests, meadows and limited arable land, can be identified. *High-mountain karst* presents the following genetic types: limestone ridges (Piatra Craiului, Buila–Vânturarița, Oslea, Scărița–Belioara), unitary and elevated plateaus (Hăghimaş, Retezat, and Bihor–Vlădeasa) or isolated ridge massifs (mountains such as Maramureş, Rodna, Bistrița, Postăvaru, Bucegi, Făgăraş, Parâng, and Bihor). On this karst landscape, there are extensive areas occupied by karren and large sinkholes, while the endokarst consists mainly of potholes, genetically related to underground drainage networks of a few kilometers in length. Among the high mountains karst units of the massifs rise higher than 2,000 m and provide evidence for the presence of Quaternary glaciers (Rodna, Făgăraş, Parâng, and Retezat). There are also nivokarst structures, represented by karren, chimneys, dissolution arches, and sinkholes continued with shafts in the Bihor, Retezat, Piatra Craiului, and Bucegi Mountains. Another feature of the high-mountain karst is the presence of potholes and caves sheltering perennial ice deposits, also affected by the glaciokarst or nivokarst processes (Scărişoara Glacier Cave, Borțig Pothole, Glacier from Zgurăşti, Zăpodie Cave from the Bihor Mountains, the potholes from Stănuleți, Retezat, Soarbele, and Albele Mountains). The landscape of the *middle and low mountains* is marked by planation and recent debris deposits. The limestones outcrop in isolated peaks and ridges or on surfaces where the clay or soil cover has been eroded. This landscape pertains to the Pericarpathian erosion levels (Râul Şes and Gornovița), consisting of unitary and elevated karst plateaus (Pădurea Craiului Mountains, Vaşcău and Dumbrăvița plateaus from the Codru-Moma Mountains, Vf. lui Stan–Domogled Ridge from the Mehedinți Mountains, the west of the Şureanu Mountains), elevated and fragmented plateaus (Banat and Vâlcan Mountains), dissected limestone bars (Trascău Mountains,"Ciucevele" and "Râmnuțele" from the Cerna Valley, Galbenul–Olteț–Cerna Vâlceană area), leveled limestone bars (Mehedinți Plateau) and many isolated massifs. On the karst surface, sinkhole fields or valleys with sinkholes are frequently developed, while along the massif margins, at the inlets, along the lithological contacts, blind valleys and fluviokarst depressions are formed. The endokarst is represented by outlet and multilevel caves, located on the valley slopes.

Over 12,000 *caves* have been recorded in the Romanian Carpathians (cavities more than 5 m long), this figure accounting for 96% of the caves of Romania (Goran 1982). The distribution of the caves on mountain units is depending on the size of the karst area and on the intensity of the karst processes. Therefore, from the Eastern Carpathians, 810 caves have been registered, from the Southern Carpathians, 5,697 caves, from the Banat Mountains, 1,553, and from the Apuseni Mountains – 3,960 caves. An exceptional concentration of caves is found in the Bihor Mountains (1,299), Retezat Unit (more than 2,800), Anina Mountains (1,041) and Pădurea Craiului Mountains (800). The Vântului Cave (Pădurea Craiului Mountains) is the longest (more than 50 km long) cave, while the V5 Pothole (Bihor Mountains) is the deepest (−641 m).

10.3.4 Periglacial Processes

Petru Urdea

Romanian geoscientists agree that the landscape of Romania finally took shape in the Quaternary period. In this complex process, periglaciation played a decisive part – especially in the mountains. The relict elements have to be distinguished from present-day periglacial processes. Obviously, *in lowlands and hills* periglacial elements have a *relict* character, in contrast to *uplands* (alpine regions), where some of the *recent periglacial elements* have reached their climax.

The *climatic conditions* in the periglacial zone of the Romanian Carpathians are exemplified by a mean annual air temperature of 3°C at Cozia (1,577 m), 1.0°C at Vlădeasa, 0.2°C at Bâlea Lake (2,038 m), −0.5°C at Țarcu (2,180 m) and −2.5°C at Omu (2,505 m), where the absolute minimum temperature is −38°C. Mean annual precipitation is 844.2 mm at Cozia, 1151.3 mm at Vlădeasa, 1,246 mm at Bâlea Lake, 1,180 mm at Țarcu and 1,280 mm at Omu. The continentality index according to Gams (CIG) is over 50°. Snow depth is highly variable, between 50 and 370 cm, according to the wind action. About 60–75% of precipitation falls as snow, and the snow cover in the region lasts 150–210 days of the year. The 3°C mean annual isotherm, i.e., the lower limit of periglacial environment, runs at ca 1,700 m elevation. In the periglacial region there are three zones, the *solifluction zone* between the 3°C and 0°C isotherm, the *zone of complex periglacial processes* between 0°C and −3 (−2)°C isotherm, and the *cryoplanation zone* of intense mechanical weathering between the −3 (−2)°C and −6°C isotherm. From the Peltier diagram the morphoclimatic systems are periglacial system with physical dominance for Omu and Bâlea Lake and boreal system for Țarcu (Urdea and Sîrbovan 1995).

BTS measurements and the low water temperatures (<2°C) of rock glaciers outlets prove the existence of *permafrost* in rock glaciers and scree deposits. It was an interesting and amazing discovery that permafrost is also present at low elevations, at 1,100 m at Detunata Goală (Apuseni Mountains) (Urdea 2000), proved by the solar radiation model (Urdea et al. 2001–2002). Recently, the existence of permafrost was documented by geophysical investigations, especially for rock glaciers (Urdea et al. 2008a).

Periglacial deposits, important paleoclimatic indicators, are formed by freeze-thaw action (blockfields, talus cones, scree, stone streams, rock rivers), by solifluction and aeolian deposition (loess, nivo-eolian deposits). For scree slopes at Bâlea Lake and Văiuga, geoelectrical DC tomography (Urdea et al. 2008a), based on the Wenner–Schlumberger array layout configuration, shows the presence of distinct layers specific to stratified slope deposits (Sass 2006), in fact "*éboulis ordonée*" (Urdea 1995). The resulted models for the solifluction lobe Paltina, in dipole-dipole configuration (suitable for vertical structures), and at an equal distance of 1 m between the electrodes, permit a differentiation of distinct layers of 40–50 cm and undulating solifluctional layers (Fig. 10.8). In the case of the *fossil patterned ground* Paltina–Piscul Negru, the 2D electrical resistivity tomography model in Wenner

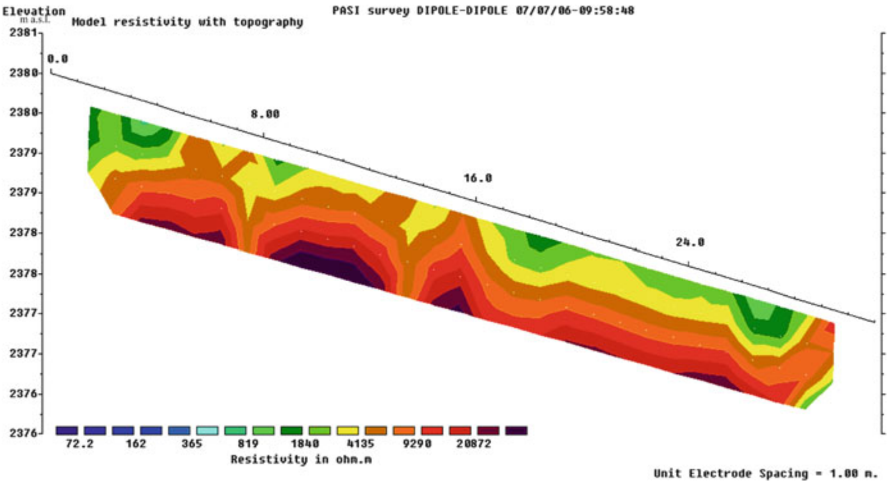

Fig. 10.8 Electrical resistivity tomography profile (inversion model) on the solifluction lobe Paltina (Făgăraş Mountains) (Urdea et al. 2008d)

configuration, presents distinct layers with a special undulating and pocket design formed by frost heaving and frost sorting. For *rock glaciers* (Ana and Pietrele in the Retezat Mountains, Capra Tunnel and Văiuga in the Făgăraş Mountains) electrical tomography reveals typical structures. In the bottom part high resistivity (>700 kΩ m) points to rock bodies rich in ice (Urdea et al. 2008a).

Although the alpine area of the Romanian Carpathians belongs to the periglacial and boreal morphoclimatic altitudinal zones, present-day geomorphological processes are very complex (Urdea et al. 2004). *Frost weathering* is regarded as a particularly effective geomorphic agent, a combination of frost shattering and frost wedging. The occurrence of freshly split blocks, gravelly and sandy regolith in the granitoid massifs (Retezat, Parâng, Vârfu Pietrii, and others) with tors indicates that the process of grussification and rock weathering, and the production of coarse loose debris, monitored in the Lolaia Mountain area (Retezat Mountains) and in the Transfăgărăşan area, are still active and continuous under present-day climatic conditions. The information obtained from thermal images (a thermoinfrared camera Fluke Ti20) confirms surface temperature variations between minerals in granitoid rocks under short-term (diurnal) temperature fluctuations controlled by color and crystal size. Surface temperatures variations between minerals (quartz, feldspar, mica, amphibole) cause differential thermal expansion, strain and disintegration and, with the contribution of nivo-eolian processes, cavernous weathering or the formation of *honeycomb* microforms (Fig. 10.9). The predominantly upward directed frost heaving and predominantly lateral frost thrusting, induced by ice segregation in the ground, produce *pipkrakes* or needle ice, which can heave stones as large as cobbles and frost sorting, very active on the surfaces of the solifluction terraces. Sorted patterned ground is characteristic of the strandflats of glacial lakes (like Ana and Valea Rea, Retezat Mountains) (Fig. 10.10).

Fig. 10.9 Honeycombs on Lolaia Mountain (1,750 m, Retezat Mountains)

Fig. 10.10 Frost sorting on the Ana Lake strandflat (at 1,975 m in the Retezat Mountains)

The monitoring of two areas on the Muntele Mic Mountain, i.e., a field of periglacial earth hummocks at the 1,765 m and an area with flat surface at 1,774 m elevation, using elevationmeters BAC and Danilin cryometers, shows the values between 30 and 72 mm for earth hummocks and between 8 and 35 mm for flat ground (Urdea et al. 2004). The differential downslope displacement of colluvial deposits and rocks through *gelifluction processes* and frost creep produce a range of landforms, like gelifluction lobes, gelifluction sheets, gelifluction benches, and plowing blocks. The movement of the plowing blocks was monitored on Muntele Mic and Parângul Mic Mountains (Table 10.1).

Frost creep is controlled by the number of freeze-thaw cycles, slope angle and ground moisture content. The talus cones and scree slopes affected by frost creep have a distinct aspect. Creep is also important for rock glaciers (Fig. 10.11). The rock debris of scree cones on Lolaia Mountain and "stone banked lobes" or "rocky lobes" (e.g., on Gemănarea Mountain in the Parâng Mountains) show differentiated rates of movement for the different parts, ranging from 1.22 to 3.78 cm year^{-1} (Urdea et al. 2004).

Nivation, embracing all processes associated with enduring snow patches, transport debris by snow creep and slopewash by melting snow. Monitored in the Muntele Mic area, it has been found still active in the present-day morphodynamics of the Carpathians periglacial belt (Urdea et al. 2004). The combination of nivation and other periglacial processes is responsible for the development of erosional features, such as nivation hollows, benches, niches (Fig. 10.12), cryoplanation terraces and others. In the Romanian Carpathians, *avalanches* affect steep slopes with a frequency of 2–20 events per year.

10.3.5 Fluvial Processes

Maria Rădoane and Nicolae Rădoane

In Romania there are over 250 reservoirs, with ca 500 km branches and supplies and 16,000 km of river embankments. Thus, fluvial processes have been a major concern of the researchers in the last 30 years (Diaconu et al. 1962; Grumăzescu 1975; Hâncu 1976; Panin 1976; Pascu 1999; Bondar et al. 1980; Armencea et al. 1980; Ichim et al. 1989; Ichim and Rădoane 1990; Rădoane et al. 1991, 2003, 2008a, b, c; Amăriucăi 2000; Rădoane 2004; Rădoane and Rădoane 2005; Dumitriu 2007; Burdulea-Popa 2007; Canciu 2008; Feier and Rădoane 2008; Perşoiu 2008).

Quantitative research of fluvial geomorphology has focused mainly on the main rivers in the eastern part of Romania, respectively the Prut and Siret rivers with their major tributaries and drainage basins of over 70,000 km^2.

The geomorphological analysis of longitudinal profiles (Rădoane et al. 2003) involved mathematical models and coefficients of variation to select a *concavity index* (Fig. 10.13). The index values tend to increase from north to south in the Eastern Carpathians. The explanation for this situation has called for a review of

Table 10.1 Results of monitoring ploughing blocks in the Parângu Mic area

#	Altitude (m above sea level)	Slope (°)	Block size				Block movement (mm)			Block azimuth (°)		
			Length (m)	Width (m)	Height (m)	Relative volume (m^3)	2000–2001	2001–2003	Annual	2000	2001	2003
1	2,035	26	1.45	0.54	0.115	0.09	11.4	25.6	12.3	195	195	199
2	2,037	18	2.26	0.69	0.25	0.38	9.9	14.1	8	202	198	202
3	2,050	16	1.83	1	0.25	0.45	12.6	22.4	11.6	228	220	226
4	2,045	15	2	0.91	0.16	0.29	6.2	8.8	5	213	212	217

Fig. 10.11 Talus rock glaciers at Ştirbu (Retezat Mountains) affected by frost creep

Fig. 10.12 Nivation niches on Țarcu Mountain at 2,020 m above sea level

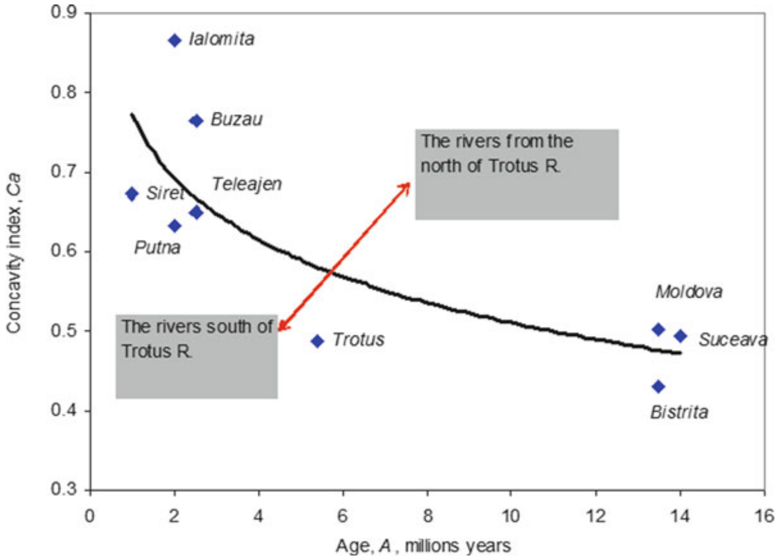

Fig. 10.13 Illustration of the relationship between the shape and the age of longitudinal profiles for the rivers in the eastern and southeastern part of Romania (Rădoane et al. 2003)

ideas on the stages of evolution of the drainage network in the region. The relationship between river age and longitudinal profile shape shows that the geomorphologic evolution of the river has not made a footprint in a decisive way on the shape of the longitudinal profile as, for instance, the Davisian erosional cycle concept suggests. The rivers from the north of Trotuş river (ages of 13–14 million years on the same course) have longitudinal profiles apparently less evolved (reduced concavity, increased slope) (Fig. 10.13). In contrast, the rivers south of Trotuş (Putna, Buzău, Prahova, Ialomiţa), whose courses have undergone major changes, interruptions, tectonic uplift, subsidence in the approximately 2.5 million years of evolution, are characterized by highly concave longitudinal profiles. However, in accordance with the classical Davisian conceptual and modern models (Snow and Slingerland 1987), the latter profiles should have a much higher concavity coefficient. The linear–exponential equilibrium expresses a balance between erosion and accumulation, therefore, it is a characteristic *profile of transport*, with a high slope, which the rivers north of Trotuş have preserved, with some variations, for 14 million years. In accordance to Hack's dynamic equilibrium theory, a form of relief preserves those characteristics that ensure a state of equilibrium in the exchange of mass and energy with other forms of relief (Hack 1960). This applies to the shape of the longitudinal profiles of rivers in the Eastern Carpathians.

The geomorphic analysis of longitudinal profiles is linked to the processes of downstream fining and *channel material* bimodality. These processes were studied for the six major Carpathian rivers (Rădoane et al. 2008a). The investigations on the bed material variability of the Siret Basin rivers were mainly focused on verifying the

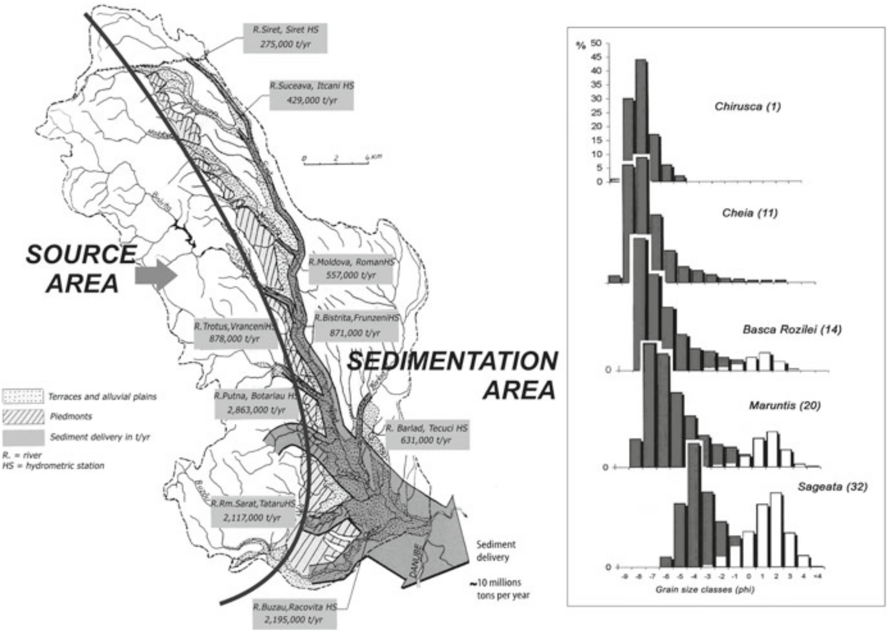

Fig. 10.14 Map of suspended sediment transport in the Siret drainage basin. The transport of fine sediment represented by arrows is superimposed on coarse sediment transport, identified by the extension of piedmonts and alluvial terraces. The central line divides the two main areas of the sediment system: source area and sedimentation area (*to the left*). Bimodality is seen at the intersection of both distributions on the example of the Buzău River. *Numbers* indicate sampling sites from source to mouth (*to the right*) (Rădoane et al. 2008a)

exponential model of reduction in the *sediment size* along the river, according to Sternberg's law, which shows that the river bed particles reduce their dimension proportionally with the mechanical work made against friction along the river. Depending on the length of the river, the median diameter (D_{50}) is reduced overall exponentially, but on important lengths of the rivers this exponential decrease is acutely disturbed. From this point of view as well, the Eastern Carpathian rivers record many deviations from the conceptual model. The Trotuş and Siret Rivers even show an increase in the material's dimension along most of their lengths. The only rivers that nearly relate to the exponential model on their entire length are the Suceava and the Moldova. The main cause for which the Sternberg model does not fit to the other four rivers lies in the contribution of the tributaries with a massive sediment input in the rivers in question, a lot greater than their ability to modify (Fig. 10.14, left).

The bedload has a distinct *bimodality*, the two peaks in the grain size distribution curve being separated by a small gravel fraction of 1–8 mm diameter. This bimodality of fluvial deposits may be explained by the different origin of the bedload. For the Carpathian tributaries of the Siret River, coarse gravel joins a unimodal distribution presenting a right skewness with enhanced downstream fining. The source of the coarse material is the river channel itself. A second distribution with a sandy mode is, in general, skewed to the left. The source of the second peak is the amount of sand that reached the riverbed from erosion on hillslopes. The tails of the histograms skewed to the right (for the gravel) and skewed to the left (for the sands) intersect. The intersection of the two modes occurs in the area of fractions from the 0.5–8 mm range. This explains the penury of particles between 0.5 and 8 mm. For the rivers where the sources of fine sediment are low, the 0.5–8 mm fractions are more frequent than the factions under 1 mm (Fig. 10.14, right). For the Siret River itself, bed sediment bimodality is greatly enhanced due to the fact that the second mode represents more than 25% of the full sample. As opposed to its tributaries, the source of the first mode, of gravel, is allochthonous to the Siret River, generated by the massive input of coarse sediment from Carpathian tributaries, while the second mode, of the sands, is local.

The riverbed material is subject to *vertical mobility* in the longitudinal profile and in cross section. Change in the bed elevation of alluvial rivers, in a positive or a negative way as related to a reference point, is a direct response to a sediment-supply deficit or surplus. Data from 63 cross sections of the Siret River basin were analyzed, in particular those from the right side of the river. From monitoring bed elevation in the cross sections for a period of over 70 years, degradation (100–120 cm) was found in almost half of the cases and aggradation (80–100 cm) in less than 30% of cases. Stability of the riverbed, the vertical oscillation of the riverbed below the value of 50 cm, characterizes a little over 20% of the cases.

The most abrupt *human intervention* into the river systems is the construction of dams and reservoirs. There are ca 250 reservoirs in Romania, mainly on the Bistrița, Siret, and Prut Rivers. On the Prut River, for instance, a dam was built at Stânca–Costeşti (Fig. 10.15), resulting in capturing almost all (over 95%) the sediment load in the upper drainage basin. Consequently, immediately downstream the dam, river is entirely devoid of *suspended load*. Along the next 500 km downstream the river attempts to compensate for the sediment load lost, but only achieves to raise its suspended sediment transport to 63%, as measured at the river mouth. The amount of water discharge, however, has not been affected by dam construction, only the regime was modified through human regulation.

Current measurements at seven gauging stations on aggradation-degradation processes along the Prut River are available for the period 1975–2005. Naturally, upstream of Stânca Reservoir, the riverbed shows slight aggradation, probably as a response to sediment storage at the end of the reservoir. Immediately downstream of the dam, degradation is the dominant process as a direct effect of a drastic reduction of sediment load. *Incision*, however, is not linear, but there are also areas where the riverbed is slightly aggrading. Overall, the effect of the dam is transmitted downstream the Prut riverbed over a distance of 400 km, with an incision rate of over 4 m^3 $year^{-1}$. Only towards the confluence with the Danube the rate drops below 0.5 m^3 $year^{-1}$ (Fig. 10.15).

In conclusion, the fluvial processes in Romania follow the *tendencies* observed for European rivers under prolonged human impact (Petts et al. 1989). At the beginning of the nineteenth century, the process of aggradation was dominant, while in the twentieth century the complexity of anthropogenic interventions resulted in a

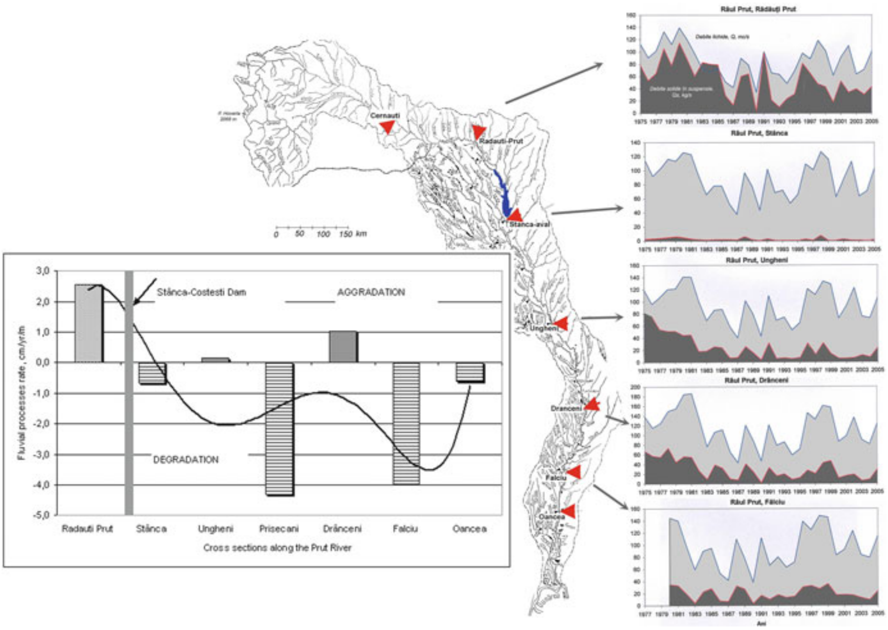

Fig. 10.15 Rate of fluvial processes (aggradation or degradation) along the Prut River

deepening and narrowing of riverbeds. In Romania, however, there is a certain delay in channel response. Although the incision is dominant (for over 50% of all sections studied), riverbed aggradation is still present.

10.3.6 Mining Activities and Environmental Impacts

Mihaela Sima

The Romanian Carpathians are rich in mineral deposits, some having been exploited since ancient and even pre-historical times (e.g., gold in the Apuseni Mountains) (Fig. 10.16). Although mining is practiced on a fairly small scale, its *environmental impact* is extremely severe: contamination of waters with heavy metals from the exploitation and processing of non-ferrous ores; acid drainage from coal mines and metallurgical plants; suspended load mainly from coal mines; radioactive ores; air pollution related to flotation, burning and processing plants (sulfur and nitrogen oxides, carbon-dioxide and methane); *topographic changes* (waste dumps, tailings ponds, and underground galleries) affecting the environmental and degrading lands, soils, flora and fauna and, most importantly, human health.

After 1990, Romanian mining industry experienced a major restructuring: the majority of mines, still economically efficient, were gradually closed down, an action

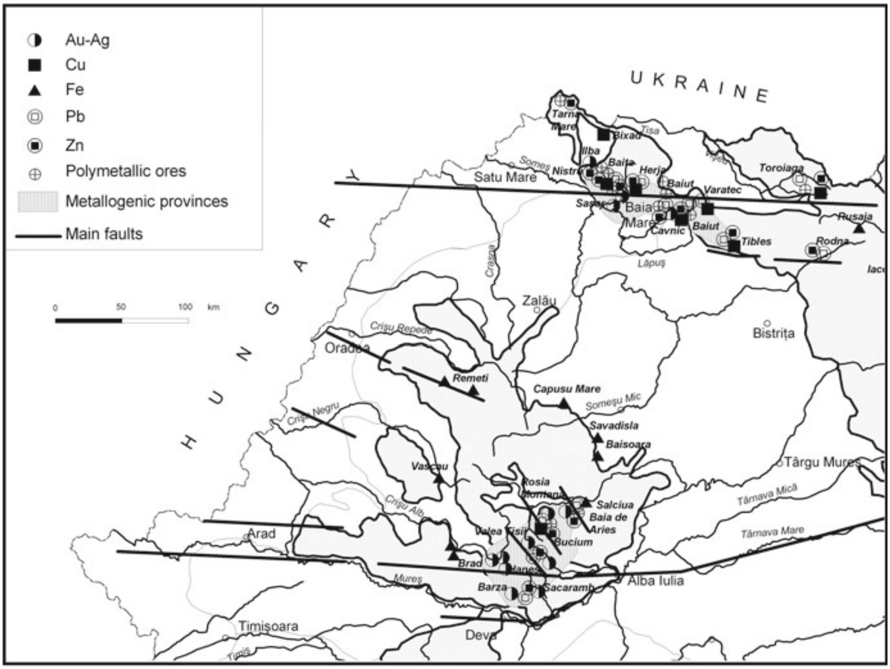

Fig. 10.16 Distribution of ore deposits in north-western Romania (Şerban et al. 2004)

that continued after 2000 and particularly in 2006–2007. Most mining sites are under *environmental rehabilitation*, but, because of money shortage, during the past few years rehabilitation programs were either not launched, or implemented only in certain areas. In 2001 technological *accidents* in the tailing dams of Maramureş Country had a significant cross-border impact. The loud international response led to fundamental changes in European legislation (e.g., the Seveso II Directive on the control of major accidents involving dangerous substances covers also mining activities). In the course of the accidents several rivers (the Lăpuş/Someş, Novăţ/Vişeu, the Tisza and the Danube) on the territory of neighboring countries were polluted. One of the main results obtained by studying the situation in those regions is that the pollution found at all the major observation points of Maramureş and Satu Mare counties and from the Apuseni Mountains, was caused by waste spills from active mines being either untreated or their waste water treatment plants were out of operation (Fig. 10.17). The contamination, especially of surface and groundwaters, with pollutants of mining origin extends only up to 5 km from the observation point, affecting a corridor some 1 km wide along the river channel. In general, between these observation points, both river and groundwater lie within EU quality standard limits, although the metal concentrations found in the river and floodplain sediments are somewhat higher due to historical pollution (Brewer et al. 2002; Macklin et al. 2003; Bird et al. 2003, 2008; Şerban et al. 2004).

Fig. 10.17 River affected by acid mine drainage in the Southern Apuseni Mountains, Romania

Under the current technical and technological conditions mining is no longer economically efficient, and many pits are already exhausted. Unfortunately, mines that have been closed down do not benefit from ecological rehabilitation programs or from adequate conservation measures either and continue to yield high quantities of pollutants, thereby being detrimental to the environment. However, there are companies that have maintained or even plan to extend their activity (e.g., at Roşia Montană). Non-ferrous metal ores are no longer extracted or processed in Romania for lack of state subventions to update obsolete technology. Unless countermeasures are taken, environmental degradation is expected to go on for scores and hundreds of years with a serious long-term impact.

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