S T U D I A   G E O M O R P H O L O G I C A   C A R P A T H O - B A L C A N I C A
VOL. XXXII   KRAKÓW 1998   PL ISSN 0081-6434

DAN BĂLTEANU, MIHAI IELENICZ, NICOLAE POPESCU (BUCUREŞTI)

GEOMORPHOLOGY OF THE ROMANIAN CARPATHIANS
NEW TRENDS AND EVOLUTIONS

INTRODUCTION

The greatest part of the Carpathian chain and the largest tectonic Intracarpathian depression — the Transylvanian Depression — lie on Romanian territory. Both units have a concentrical layout and, together with the Pericarpathian, piedmont and hilly regions, cover over 50% of the country's area (Fig. 1).

Apart from the traditional Geographical Departments involved in geomorphological researches and located in Bucharest, Cluj-Napoca and Iaşi, a number

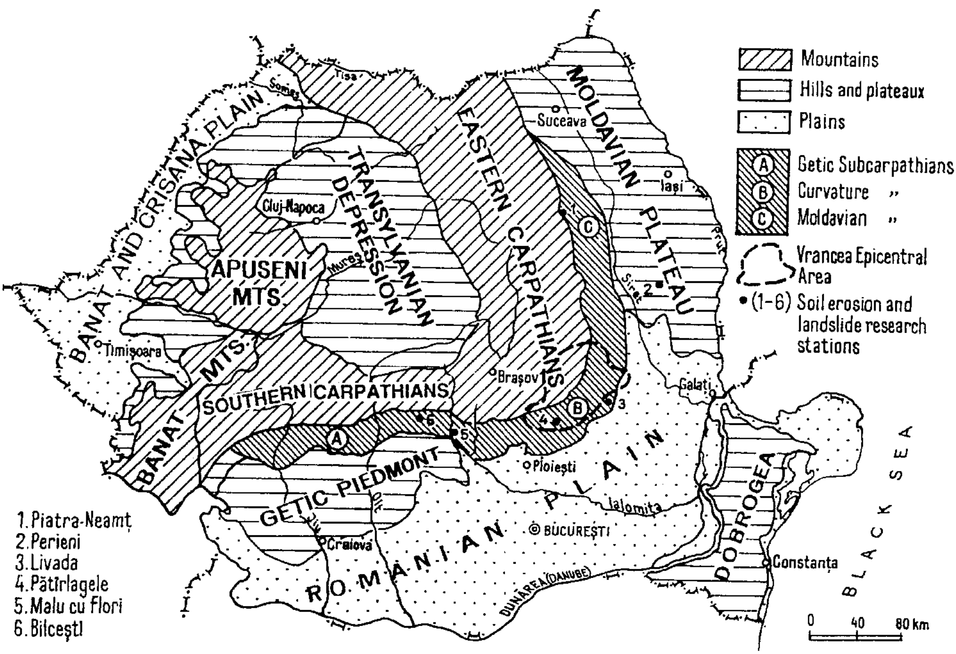


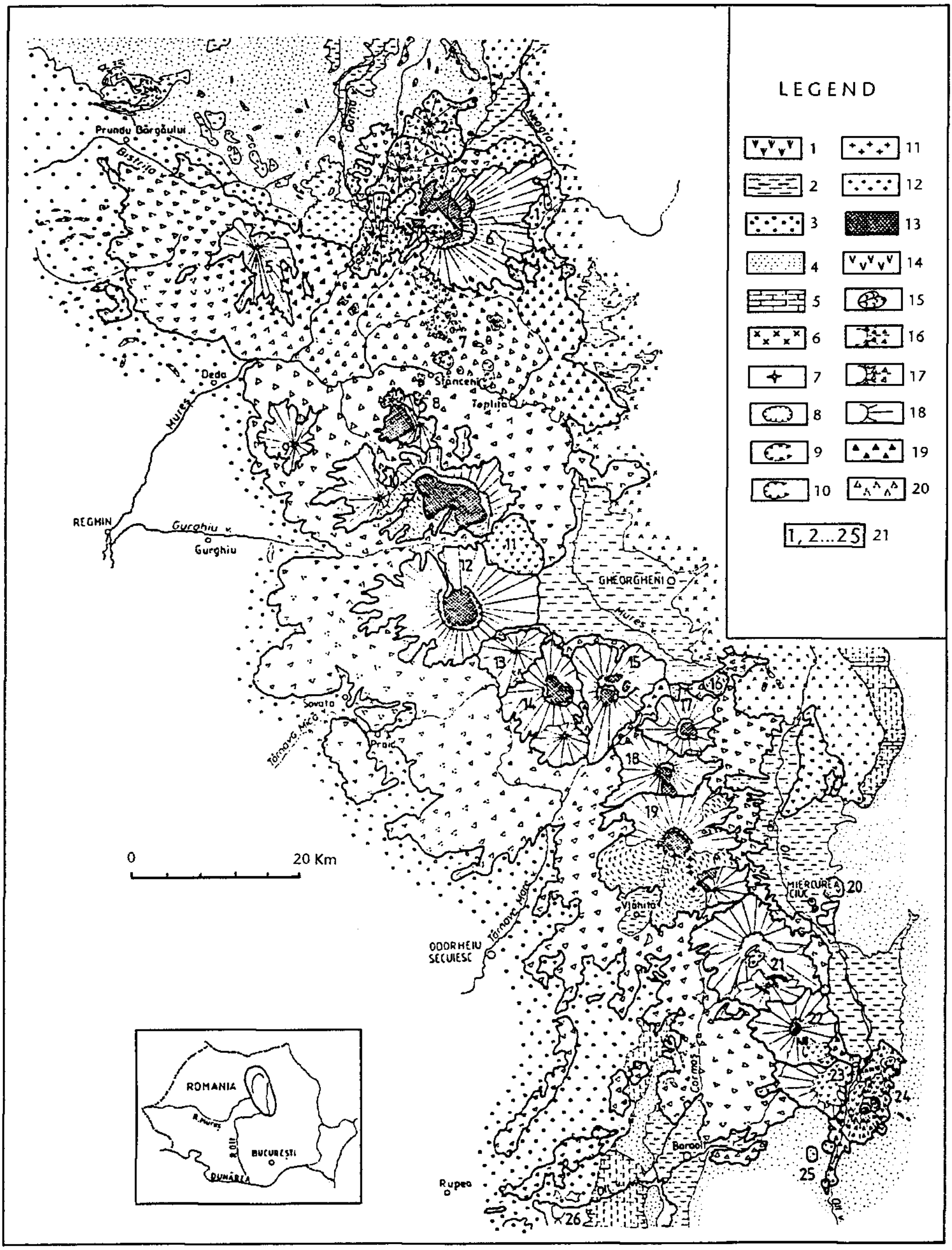
Fig. 1. Main geomorphological units of the Romanian Carpathians

Ryc. 1. Główne jednostki geomorfologiczne Rumunii of new departments have been set up at the Universities of Timişoara, Oradea, Suceava, Craiova and Târgovişte. Significant contributions to the debates concerning Carpathian issues have been made by annual geomorphological symposia and by bilateral workshops (Romanian–Bulgarian and Romanian–Italian). Among the outstanding works published over the past decade is the last two-volume Romanian Geography treatise which provides a synthesis of the essential geographical issues raised by the Carpathian space. The relief represents the most extensive part of the treatise (Geografia României. IV, 1992). Of particular interest are the fundamental contributions to the evolution of the Romanian Carpathians within the general geotectonic context of Europe's Alpine chains (Săndulescu 1984) and the outline of the main features of Vrancea Seismic Region (Constantinescu and Enescu 1985).

The endeavour of the Institute of Geography and of the main universities in this country came to fruition in 1994, when the geomorphological mapping of the whole Carpathian chain in Romania (on the scale of 1 : 200,000) was

Fig. 2. Volcanological map of Călimani–Gurghiu–Harghita Mountains (East Carpathians). 1 — Quaternary swamp or lake deposits, 2 — Tertiary postvolcanic and synvolcanic sediments, 3 — Tertiary prevolcanic molasse sediments of Transylvanian basin, 4 — Cretaceous-Tertiary sediments of the East Carpathian Flysch zone; 5 — East Carpathians: late Palaeozoic-Cretaceous sediments; 6 — East Carpathians Crystalline-Mesozoic Zone, Precambrian-Palaeozoic metamorphic and plutonic rocks, 7 — Neck, 8 — Crater, 9 — Caldera-like depressions, 10 — Collapse calderas (caldera fault), 11 — Porphyritic intrusive rocks, 12 — Fine porphyritic intrusive rocks, 13 — Volcanic core complexes, 14 — Extrusive domes, 15 — Lava flows, 16 — Pyroclastic cone, 17 — Stratovolcanic cone, 18 — Effusive cone, 19 — Coarse pyroclastic rocks — proximal facies, 20 — Mudflow, debris avalanche, debris flow and ephemeral stream epiclastic volcanic rocks, 21 — Volcanic edifices and areas: Călimani Mts; 1 Drăgoiasa, 2. Lucaciul, 3. Tămăul, 4. Rusca–Tihu, 5. Moldovanu, 6. Călimani, 7. South Călimani vocanic field, Gurghiu Mts; 8. Jirca, 9. Obârşia, 10. Fâncel, 11. Bacta, 12. Seaca–Tătarca, 13. Borzont, 14. Şumuleu, 15. Ciumani-Fierăstraie, North Harghita Mts; 16. Răchitiş, 17. Ostoroş, 18. Ivo–Cocoizaş, 19. Vârghiş, South Harghita Mts; 20. Şumuleu Ciuc, 21. Luci-Lazu, 22. Cucu, 23. Pilişca, 24. Ciomadul, 25. Bicsad–Malnaş volcanic field (Şandulescu et al. 1995)

Ryc. 2. Mapa wulkanów gór Călimani–Gurghiu–Harghita w Karpatach Wschodnich. 1 — czwartorzędowe osady bagienne i jeziorne, 2 — trzeciorzędowe osady post- i synwulkaniczne, 3 — trzeciorzędowe przedwulkaniczne molasy w Kotlinie Transylwańskiej, 4 — kredowo-trzeciorzędowe osady fliszowych Karpat Wschodnich, 5 — Karpaty Wschodnie: osady późnopaleozoiczno-kredowe, 6 — strefa krystaliczno-mezozoiczna Karpat Wschodnich, prekambryjsko-paleozoiczne skały metamorficzne i plutoniczne, 7 — neki wulkaniczne, 8 — kratery, 9 — obniżenia kalderopodobne, 10 — zapadnięte kaldery, 11 — porfirytowe skały intruzywne, 12 — drobnoziarniste porfiryty, 13 — wulkaniczne zespoły korzeniowe, 14 — kopuły ekstruzywne, 15 — spływy lawowe, 16 — stożki piroklastyczne, 17 — stożki stratowulkanów, 18 — stożki zbudowane ze skał wylewnych, 19 — gruboziarniste skały piroklastyczne — facje proksymalne, 20 — spływy błotne, lawiny gruzowe, spływy gruzowe i utwory efemerycznych potoków rozmywających skały wulkaniczne, 21 — obszary wulkaniczne gór Călimani; 1. Drăgoiasa, 2. Lucaciul, 3. Tămăul, 4. Rusca-Tihu, 5. Moldovanul, 6. Călimani, 7. Obszar wulkaniczny południowej części gór Călimani, g. Gurghiu, 8. Jirca, 9. Obârşia, 10. Fancel, 11. Bacta, 12. Seaca-Tătarca, 13. Borzont, 14. Şumuleu, 15. Ciumani-Fierăstraie, góry pn. Harghita, 16. Răchitiş, 17. Ostoroş, 18. Ivo-Cocoizaş, 19. Vărghiş, góry pd. Harghita, 20. Şumuleu Ciuc, 21. Luci-Lazu, 22. Cucu, 23. Pilişca, 24. Ciomadul, 25. Obszar wulkaniczny Bicsad-Malnaş (Sandulescu et al. 1995) finished (Badea and Sandu 1992). It was followed by the geomorphological mapping on the scale of 1 : 50,000 (in progress) and by the elaboration of a set of special maps, e.g. a many-scale karst map (Sencu 1992). Traditional preoccupations are related to the levelled surfaces, terraces, neotectonic movements, the structure- and rock-controlled relief, and its current and Quaternary evolution.



STRUCTURAL SETTING AND SEISMICITY

The Carpathian Orogene, a sector of the Tethyan Chains, is the main structural-tectonic unit of Romania which is imposing a concentrical amphitheatre-like layout of all geomorphological units. They consist of discontinuous crystalline massifs with areas of Mesozoic deposits, Palaeogene and Cretaceous flysch and Neogene volcanism. The hilly regions, rising up to 300–800 m, are built dominantly of Neogene molasse and comprise the Transylvanian Depression, the Subcarpathians and two piedmont areas and the Getic Piedmont the Banat Hills. The volcanic arc, situated in the internal part of the Eastern Carpathians (Fig. 2, 3), is of a Neogene age and was generated by the consumption of thinned and oceanic-type crust (Săndulescu et al. 1995). The Arc is related to the westward subduction of the oceanic crust beneath the Transylvanian microplate. The Căliman–Gurghiu–Harghita massifs are in an early stage of residual volcanic formation. The Oaş Gutâi Mts are in the stage of residual and skeletal volcanism.

Composite volcanoes represent the dominant type. A great diversity of structural forms, corresponding to the well-conserved volcanic cones (with craters and calderas) were outlined for the Harghita Mountains (Schreiber 1994).

Romania is characterised by a high-level seismic activity which, from time to time, shows up in violent earthquakes and related disasters. There are several high seismic regions located in Vrancea, Făgăraş, Banat and Maramureş. Vrancea Seismic Region, the most active sub-crustal earthquake province in Europe, is responsible for the seismic regime of Romania. This area, relatively small-sized, is located in the Curvature Carpathians between two important fractures which cross the foreland: the Peceneaga–Camena fault (in the North-East) and the Intramoesian fault (in the south-east). The litosphere panel, situated between the two fractures, had moved and is still moving towards the Carpathians, determining a compressive field connected with Vrancea seismicity (Săndulescu 1997).

Vrancea Seismic Region is characterised by three seismic peaks of activity every century and by a predominantly North-East to South-West seismic wave propagation (Constantinescu and Enescu 1985). The seismic shocks of strong earthquakes, like those in 1941 and 1977 (magnitude $M > 7$), had marked effects on slopes, particularly in the Curvature Carpathians where large rockfalls, debris flows and landslides were recorded.

EVOLUTION OF THE ROMANIAN CARPATHIANS

With a view to acquiring a better knowledge concerning the reconstruction and dynamic of the palaeoenvironments, the paleogeographical studies into the evolution of the Carpathian realm performed over the last decade have been aimed at gathering information about the extension, age and

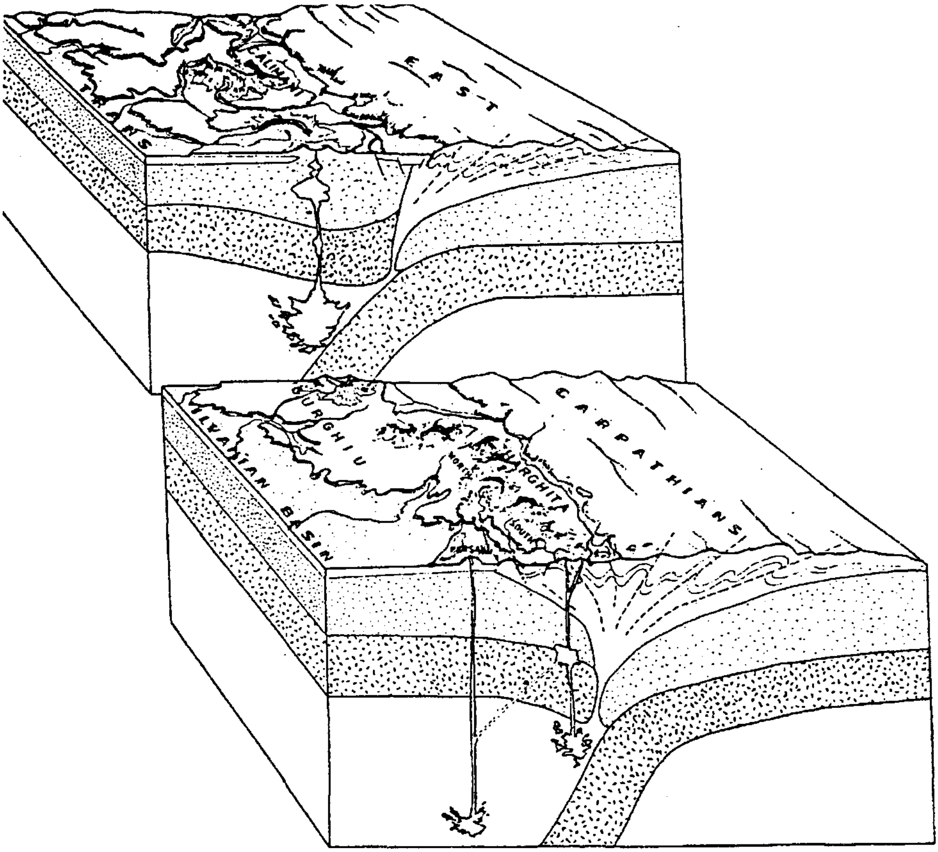


Fig. 3. Hypothetical block diagram of inferred present-day tectonic setting of the volcanic chain (Săndulescu et al. 1995)
Ryc. 3. Hipotetyczny blokdiagram tektonicznych założeń łańcucha wulkanicznego (Săndulescu et al. 1995)

morphoclimatic conditions governing levelled and accumulation surfaces — pediplanes, pediments, erosion glacis, perimontane piedmont glacis.

It has been assumed that planation surfaces and levels are the best expression of the long-lasting and complex evolution of the relief, representing a marker of the temporal succession and regional disparity of denudational processes under the specific structure and tectonics of the Carpathian space and its limitrophe territories.

The outcome of this research was the elaboration of a more complex and unitary concept which views these distinct morphogenetic surfaces as epochs, stages, or phases of evolution, enclosing the palaeogeographical history of the respective region over a longer or shorter period of time. In this way, another 7–9 levelled steps (from the Palaeogene to the Lower Pleistocene) have been identified, compared to only three big complexes of planation surface (Palaeogene, Miocene and Pliocene with various regional names) that had been distinguished before. Their counterparts in the limitrophe sedimentary basins (Transylvanian Basin, and Getic Basin) are a number of sedimentary series and sequences, the morphogenetic type of which bespeaks the existence of distinct climatic conditions.

The Carpathian levelled relief (about 15%–22% of the area) gives the landscape a peculiar geomorphological physiognomy, e.g. smooth summits or intermediary steps even, levelled along the valleys in the form of small semi-horizontal plateaus, or pediment-like inclinations (Posea 1997). In nearly all of the crystalline massifs (Rodna, Maramureş, Făgăraş, Parâng, Retezat, etc.), these levelling "surfaces" are rather concentrically laid out on the summits of the main interfluves, stretching out there of towards the upper part of the valleys in the form of levelled "valley steps".

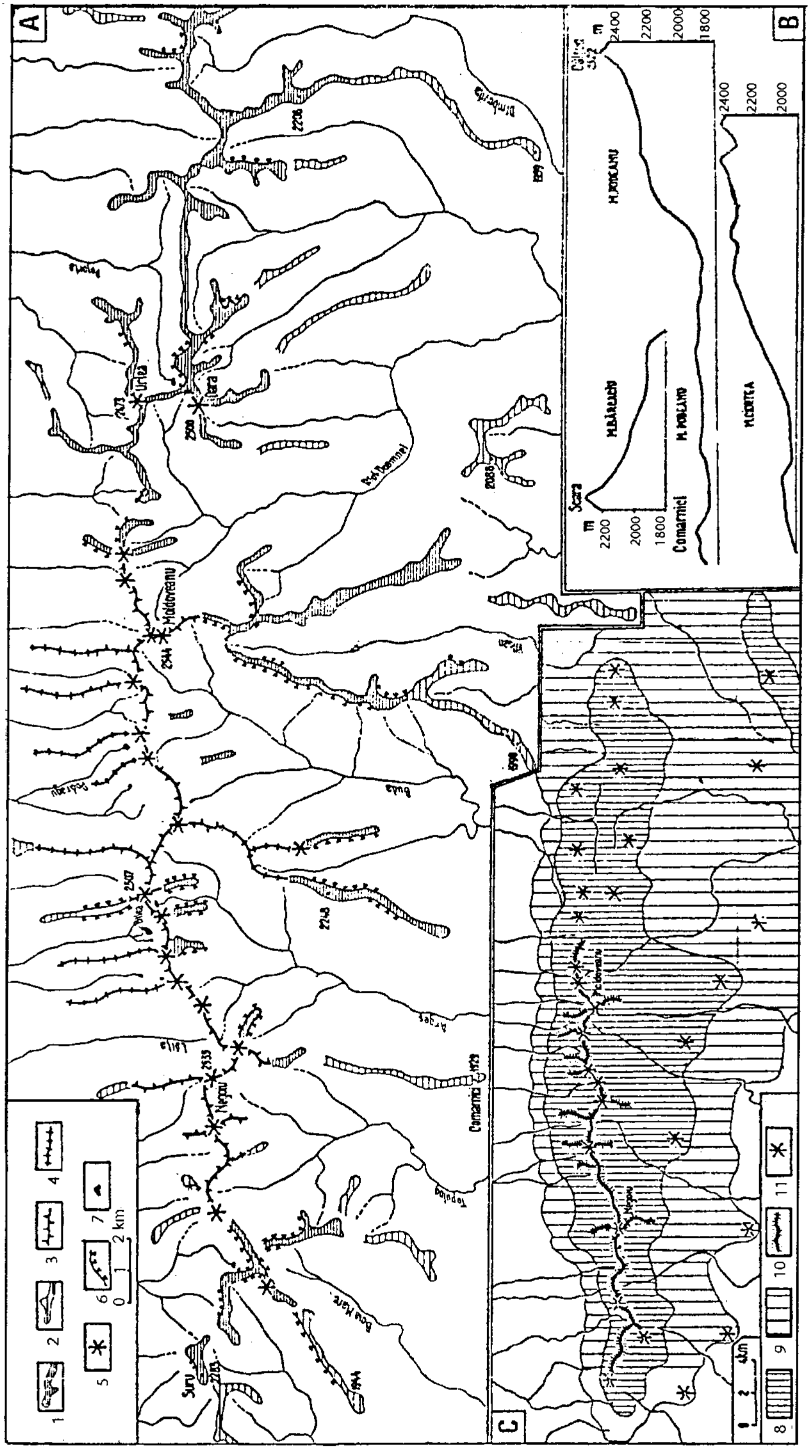
The Carpathian palaeoreliefs are frequently grouped by four complex levelled surfaces: the Carpathian Pediplane (S_I), the Medium-high Carpathian Planation Surface Summits (S_{II}), the Carpathian Marginal Planation Surface (S_{III}), and the Carpathian Valleys levels (S_{IV}). Each morphogenetic complex consists of 2–3 altimetric steps of different rock structure or tectonics (Posea et al. 1974; Posea 1997).

The Carpathian Pediplane (S_I) covers no more than 2% of the mountainous relief in Romania. It is found only in the crystalline massifs and is the smoothest of all planation surfaces (ca 3–5°). The levelling time in the Carpathian massifs varies in terms of the tectonic events unfolded within a lapse of 30–40 million years ("surfaces" modelled during the Danian and Eocene, and surfaces modelled up to the end of the Oligocene, respectively) (Posea 1997).

The longitudinal profiles of summit fragments (0.5–6 km long) found in the Făgăraş Mountains at heights of 1,850 and 2,350 m look like typical pediments: a mildly dipping (3–5°) levelled surface, taking a sharp bend in an over 45° erosion slope. The lateral dip of these pediments of uneven extension and altitude (100–200 m level differences) reconstructs the general features of the higher surface of the Făgăraş. The crest linking pediments could be interpreted

Fig. 4. Carpathian pediplane in the Făgăraş Mts. A: levels; 1— 2,200 -2,300 m, 2 — 1,500–2,000 m, 3 — glacial and periglacial crests above the pediplane, 4 — crests crossing above the pediplane, 5 — residual peaks, 6 — slope retreat through periglacial processes to the detriment of the pediplane, 7 — glacial lakes, B: Topographical profiles in the Carpathian pediplane, C: Reconstruction of the Carpathian pediplane in the Făgăraş Mts: 8 — upper level, 9 — lower level, 10 — intersecting crests; residual peaks (Popescu 1984)

Ryc. 4. Karpackie pedypleny w górach Fogaraskich. A: poziomy. 1 — 2200–2300 m, 2 — 1500–2000 m, 3 — grzbiety o genezie glacjalnej i peryglacjalnej wznoszące się ponad pedyplenę, 4 — grzbiety wyniesione ponad pedyplenę, 5 — wierzchołki ostańcowe, 6 — stoki peryglacjalne utworzone kosztem cofania pedypleny, 7 — jeziora polodowcowe, B: profile przez pedyplenę karpacką, C: rekonstrukcja pedypleny karpackiej w górach Fogaraskich, 8 — górny poziom, 9 — dolny poziom, 10 — grzbiety na przecięciu zboczy; wierzchołki ostańcowe (Popescu 1984)


A
B
C
Urlea
Moldoveanu
Negoiu
Comarnicel
Suru
Scara
M. Moldoveanu
M. Negoiu
2 km
4 km

as a succession of positional monadnocks. From the regional distribution of fragments preserving a relict relief, it appears that the pediplane of the Făgăraş Mts geomorphological build-up represented a hilly landscape with delevellings of 100–200 m up to 300–400 m, its lateral side extending as far as the Palaeogene domains of the Transylvanian and the Getic Basins (Fig. 4). During the Oligocene and the Middle Miocene tectonic movements distorted the Carpathian pediplane through tectonic fragmentation (forming the Intracarpathian depressions), and erosion-induced fragmentation (further deepening of the valleys). In the Făgăraş Mts, Savian movements (Middle Miocene) led to a tectonic uplift and the beginning of erosional fragmentation of the pediplane corresponding to fluvio-littoral sedimentation in the Aquitanian–Burdigalian phase and the formation of some vast marginal piedmonts.

Later tectonic events resulted in the uneven uplift of the Carpathian pediplane, hence the relict relief occurs at altitudes varying from 600–1,000 m (in the West of the Banat Mts and the Apuseni Mts) to 2,200–2,300 m (in the Southern Carpathians). In the high massifs (Făgăraş, Retezat), Pleistocene glaciation, and periglacial morphogenesis, in particular have changed the early relief of levelled summits to a significant extent. The strong retreat of slopes turned them into periglacial crests (Popescu 1984; Urdea 1993).

Medium-high Carpathian Summits Planation Surface (S_{II}) has a large occurrence in the Carpathian space, extending to the Eastern Carpathian Cretaceous Flysch as well. The relief of this palaeogeomorphological stage, resulting from the fragmentation of a big pediment, represents about 12–15% of the levelled summits in the Romanian Carpathian chain (Posea 1997).

In the Cretaceous Flysch Carpathian massifs (Eastern Carpathians, Apuseni Mts) the planation surface develops on the highest summits (1,200–1,700 m) (Ielenicz 1984). This relief formation stage, marked by a subtropical climate with Mediterranean influences that favoured a pediment-type erosion, lasted throughout the Miocene (ca 15–20 million years) and had a different impact on various massifs.

The Carpathian Marginal Planation Surface, with rounded summits that go up to 300–400 m above the PeriCarpathian hills (Transylvanian Tableland, the SubCarpathians), represents 8–10% of the whole Carpathian relief. In this morphogenetic stage, the relict relief was built under altogether different conditions than those extent before. Beginning with the Upper Sarmatian, the inland seas bordering the Carpathians generated three distinct base levels: the Pannonian Basin in the West, the Transylvanian Basin in the Central part and the Moldavian and Getic Basins on the Eastern and Southern flanks.

The Carpathian Marginal Planation Surface (S_{III}), e.g. marginal pediments, intertwining with two–three abrasion steps and extending inside the Carpathian valleys in the form of lateral valley pediments, was built in the Lower Pliocene, a process continuing sometimes against a temperate Mediterranean climatic background as late as the Dacian.

Assessments concerning the Carpathian orography in various stages of evolution, the relief volumes, the volume of eroded material and the average erosion rates in the respective periods relied on detailed mappings of the relief. For example, the modelling of the Medium-High Carpathian Summits Planation Surface in the Retezat Mountains (Southern Carpathians) entailed the erosion of 5.3% of the initial relief volume at a rate of 74.45 mm/10^3 years. The Quaternary modelling of the Carpathian Marginal Planation Surface took place at a rate of 116.1 mm/10^3 years (Urdea 1992). In the Upper Pliocene and the Pleistocene, the Carpathians were subjected to intense erosion-induced fragmentation, a process stimulated also by the uplifts of the Walachian phase.

The Carpathian Valleys levels (S_{IV}) were modelled between the Upper Pliocene and the Villafranchian. They are represented by two steps emerged from the fragmentation of some lateral valley pediments situated at 200–400 m above the present thalwegs (Posea 1997). It indicates alternations in the Carpathian valley modelling trends (dominated by lateral erosion through sedimentation and deep erosion) in emerging of the Transylvanian and the Moldavian basins. Modelling continued during the silting of the Getic and the Pannonian basins. It is the time when relief-building processes began extending from the Carpathian realm proper to the PeriCarpathian regions, but with distinct morphogenetic trends. So, in the South of the Meridional Carpathians, in the Getic Basin, where the Carpathian valleys went on subsiding, an accumulation relief emerged in the form of vast piedmont plains, subsequently uplifted and being fragmented by the rivers (e.g. the Getic Piedmont) (Fig. 9). On the other hand, the regions of greater tectonic stability, e.g. the Transylvanian Tableland and the Moldavian Plateau, were dominated by erosional processes.

All these morphogenetic events that marked the formation of the Carpathian valleys occurred against the background of a general uplift of the Carpathians imposed by the Walachian (Romanian–Villafranchian) and Passadenian (Medium Pleistocene) tectonic movements (Badea 1996). The accelerated erosion of the Carpathian valleys during that interval has been stated in the valleys of the Danube Defile. Calculations of the volume of eroded material and the rate of erosion were referred to the stages of relief evolution. The findings showed that mean specific erosion increased from 5 cu. m/sq. km/year during the Badenian–Romanian to 19 cu. m/sq. km/year from the Romanian (when the upper terrace of the Danube was built) to the present day.

It follows that it took three million years for the Carpathian mountainous relief to come to its present aspect, from the moment marked fragmentation had begun by the accelerated deeping of the valleys (Popescu 1989).

Relief Modelling in the Transylvanian Tableland started right after its emerging in the Pontian. Recently, several authors have tackled the subject highlighting the role of the climate, lithology and structure in shaping the present relief (Popescu 1990; Grecu 1992; Mac 1994). The higher tableland summits were formed in the Pontian-Lower Pliocene. During the Middle Pleistocene, after the present drainage network had emerged (representing a first fragmentation of the relict relief on the tableland), extended lateral valley glacis, now hanging over the present thalweg at a height of 100–150 m, began forming (Popescu 1985). From the Upper Romanian, when the Transylvanian Tableland started being cut by rivers, to the present time, the mean volume of river-eroded material has amounted at 130,000–140,000 cu. m/sq. km, at an average rate of 60–70 mm/10^3 years (Popescu 1985).

The modification of the climate, begun in the Early Pleistocene and continued with greater intensity in the Upper Pleistocene, brought about changes in the morphogenetic tendencies of the contact zone between the Transylvanian Tableland and the Făgăraş Mts (Popescu 1990, 1985). Strong lateral erosion and accumulation developed, with large alluvial-proluvial fans (fluvio-glacial fans) being deposited at the foot of the mountain.

A number of four generations of fluvio-glacial fans (piedmont glacis and terrace-glacis), formed during the Riss — Wurm III stages, have been identified in the Piedmont Plain of the Făgăraş Depression (Fig. 5).

At the base of fluvio-glacial fans III, the coal horizon — X-ray dated at 26,995 + 360 years BP, is an indication that the soils were deposited during Würm II glaciation; the fluvio-glacial fan (terrace) IV is even less extended, developing rather as a terrace of the Olt River (4–12 m). It belongs to the last Würm stage (Würm III–Tardyglacial).

The above picture points to the morphogenetic relationship between the glacial phases in the Carpathians and the formation of levelled fluvio-glacial terraces representing the Piedmont Plain of the Făgăraş Depression.

GLACIAL AND PERIGLACIAL RELIEF

The Quaternary glaciation was an insular event, affecting only heights above 1,850–1,900 m in the Eastern Carpathians and over 2,000 m in the Southern Carpathians (Fig. 6). The Apuseni Mountains show glacio-nival cirques, at heights of 1,800 m, an altitude that represents the lower limit of Carpathian glaciation. The best developed glacial landforms occur in the Southern Carpathians, which the French geographer Emmanuel de Martonne named the Alps of Transylvania. The largest glacier was Lăpuşnicul Mare (18.1 km long, covering 40.1 sq. km), other glacial valleys being no longer than 6–8 kilometres. Much more numerous are the Pyrenees-type small glacial cirques developed on the fringes of the Borăscu modelling surface. A number of 37 Pyrenees-type glacial cirques were detected in the Ţarcu Mountains (2,000–2,190 m), formed in one single glacial phase (Niculescu 1994).

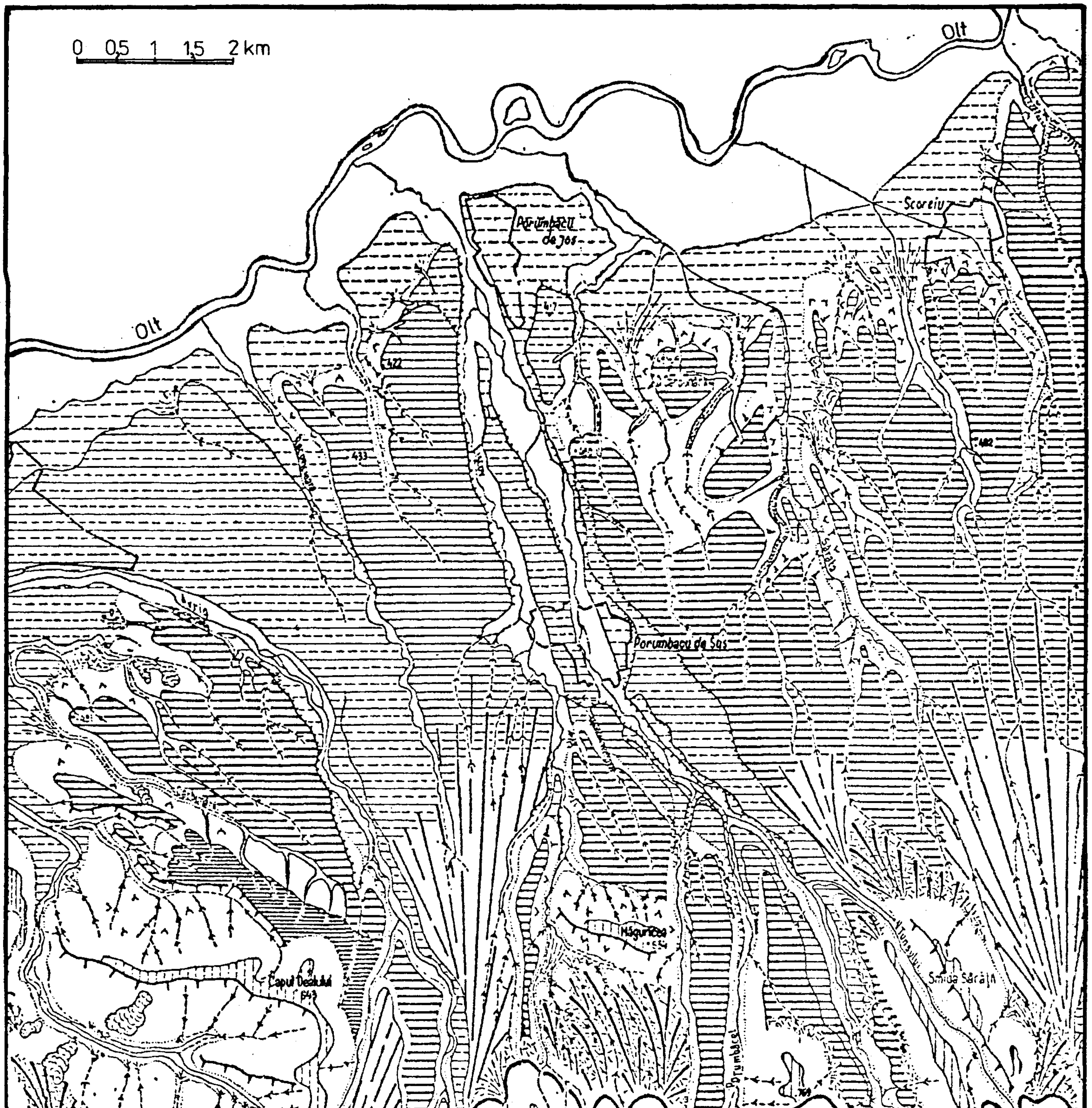


Fig. 5. Glacis and fluvio-glacial fans in the Făgăraş Depression. 1 — Carpathian marginal planation surface, 2 — valley levels, 3 — upper piedmont glacis — fluvio-glacial terrace (two steps), 4 — fluvio-glacial terrace II, 5 — fluvio-glacial terrace III, 6 — fluvio-glacial terrace IV (4–12 m high terrace of the Olt River), 7 — floodplain, 8 — alluvial fan, 9 — slope terminal glacis, 10 — fluvio-glacial fan, 11 — landslides, 12 — sheet erosion (Popescu 1990)

Ryc. 5. Glacis i stoki fluwioglacjalne w Kotlinie Fogaraskiej. 1 — karpacka, brzeżna powierzchnia zrównania, 2 — poziomy dolinne, 3 — górne glacis — terasa fluwioglacjalna (dwa stopnie), 4 — terasa fluwioglacjalna II, 5 — terasa fluwioglacjalna III, 6 — terasa fluwioglacjalna IV (4–12 m w dolinie Aluty), 7 — równina zalewowa, 8 — stożek aluwialny, 9 — końcowe glacis stokowe, 10 — stożki fluwioglacjalne, 11 — osuwiska, 12 — erozja powierzchniowa (Popescu 1990)

On the basis of the levels at which moraines and glacial cirques occur, most researchers use to distinguish two glacial phases.

Recent investigations conducted in the Retezat Mountains have revealed the presence of a four-stage Riss and Würm glaciation, and a presumable Mindel glaciation (Urdea 1989, 1993), dated by radiometrical methods and pollen analyses. At the time of the maximum expansion of glaciation (Riss II), the Retezat glaciers covered 101 sq. km, that is 22.3% of the whole surface of these mountains; nearly 40% of the Retezat Mountains falling into the glacial and supraglacial belt.

At the end of the Pleistocene, Romania's territory was situated in the domain of the discontinuous continental permafrost. Research into the periglacial relief has focused on the Southern Carpathians, where the alpine and sub-alpine belts are very much extended.

The postglacial interval, extended between the Old Dryas and the Boreal, was favourable to the formation of rock glaciers, widespread in the alpine belt of the Southern Carpathians (Urdea 1995).

Significant disparities among the different relief units in what concerns the distribution of rock glaciers have been pointed out. The about 300 rock glaciers of the Southern Carpathians occur largely in the Retezat, the Parâng and the Ţarcu massifs on granites and granodiorites affected by intense desegregation processes. In the Făgăraş Mountains, built on crystalline schists, their spread is reduced, as solifluction and ploughing blocks represent the dominant processes.

An incipient form of rock glaciers of the protalus-rampart or lobate type is seen in the Godeanu Mountains, the lobate type prevailing in the Parâng. Most rock glaciers lie on the northern slopes in the perimeter of glacial cirques. Fossil rock glaciers extend below 2,000 m and are covered with *Pinus Mugo*. They were formed between Würm III and the Little Ice Age.

Sporopollinic and dendrochronological analyses have revealed that the most favourable phases for the formation of rock glaciers and of cryoplation terraces were Dryas I, II, III and the Preboreal. The Postglacial featured by the following succession of processes and forms: ablation complexes; debris-covered glaciers; ice-cored rock glaciers; debris rock glaciers (Urdea 1991, 1995).

RIVER TERRACES AND NEOTECTONIC MOVEMENTS

Terrace studies carried out during the past two decades have concentrated on at least four directions, namely, the complex analysis of the relief of various-order drainage basins; the Quaternary evolution of some geographical regions; syntheses (regional or national) of terraces, and the space organisation of major valley corridors (Ielenicz 1997). The present geographical literature lists over 300 such works (from simple valley sector analyses to detailed studies of main

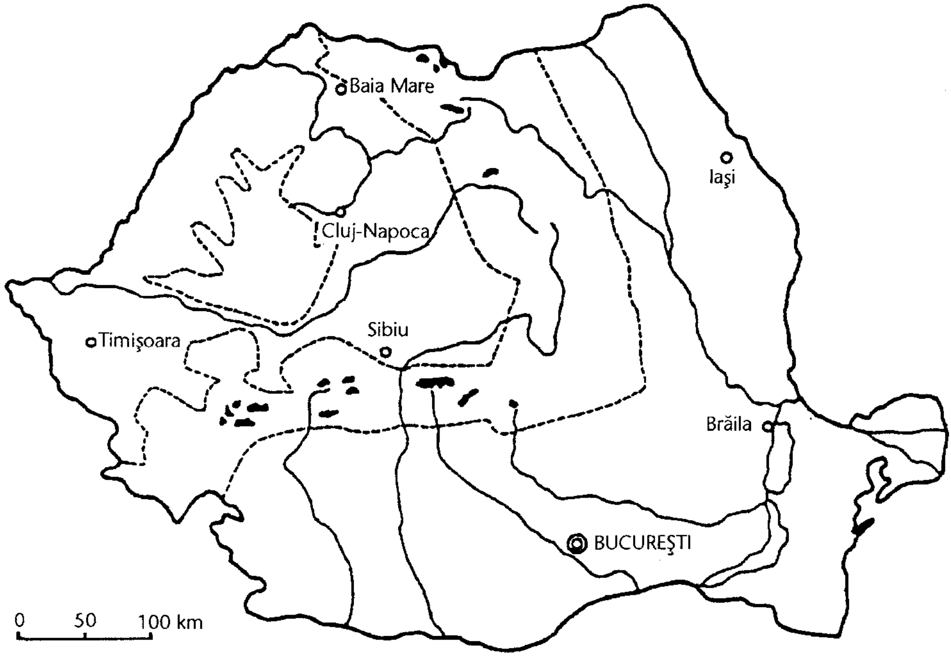


Fig. 6. The glacial relief in the Romanian Carpathians (Niculescu 1994)
Ryc. 6. Rzeźba glacjalna Karpat rumuńskich (Niculescu 1994)

relief units with emphasis on the number and layout of terraces, their structure, age, genesis and place in the Quaternary evolution).

Among the generations of valleys crossing the Carpathian realm, two have greater significance for the terrace system: those traversing the whole realm and those running through limitrophe tablelands and hills. All of them, except for the defiles, represent large corridors (0.5–5 km) with wide terraced expanses (20–80%). These terraces are extremely favourable to the cultivation of crops and the building of settlements.

The fact that they cross geographical units of varied geological make-up and structure and morphological evolution is reflected in the characters of these terraces. Here are some relevant situations in the Carpathian mountains:
— narrow valley sectors developed in crystalline massifs or in Meso-Cretaceous Flysch: few terraces (2–5), little extended (occurring discontinuously, usually in the main junction points and in depressionary basins; villages are small);
— larger valley sectors on Palaeogene Flysch with numerous terraces (3–8), the lower ones being more extended (under 50 m). They are of alluvial origin, with frequent wide alluvial fans overlying the sediment layer; sometimes, local neotectonic movements have increased their number to 10–12 units (Bistriţa);

— in the very extended erosion-induced intra-mountainous depressions there are up to five terraces; the lower ones (under 50 m) are very wide and shelter settlements, communication routes and some crops;
— in the tectonic and volcanic barrage depressions subjected to subsidence and intense alluvial deposition, terraces are either missing altogether or very reduced numerically (1–2), occurring at low levels only; the relief is dominated by alluvial plains, or extended, overlapping or interlocked alluvial fans at the contact with the mountain;
— in the depressions lying on the West flank of the Western Carpathians with a wide opening to the West Plain, the number of terraces decreases from East to West, passing into the plain in the form of two–three glacis steps.

In the major valleys, or the limitrophe Carpathian hills, entrained in an uneven uplift movement which varies from one unit to the other, the number of terraces is variable (Badea 1997). In the Hills of Transylvania and in the Subcarpathians we usually find 6–8 terraces (with 3–6 terraces more in the Subcarpathian anticline sectors, but with fewer ones in the areas subjected to subsidence). In the West Hills and the Getic Tableland, emerged and gradually uplifted in the Pleistocene, the 3–5 terraces decrease numerically towards the edge of the plain. In the Carpathian mountains and hills, the extension and number of terraces based in the secondary valleys decreases. But, whatever the case, they cover the greatest part of the lower valley sector.

The relative altitude at which terraces have developed differs in terms of the valley generation they belong to, from 2–5 m to 200 m in the major valleys (sometimes at over 200).

The fossil remains identified in some deposits of the Transylvanian Hills, the palaeobotanical data yielded by sporo-pollinic analyses in the Olt Basin, the interpretation of fossil soils from deluvial deposits and the link established between terraces and the Lower Romanian — Quaternary gravel sheets in the Getic Tableland and the West Hills, as well as other determinations have enabled the elaboration of morphochronological schemes by drainage basin and big relief units. Three reference terraces have been distinguished in the Transylvanian Tableland: 2–5 m Lower Holocene; 25–35 m Würm and 90–115 m end of the Lower Pleistocene.

HOLOCENE AND PRESENT-DAY GEOMORPHOLOGICAL PROCESSES

The Romanian Carpathians and the adjacent hilly regions are affected by a great diversity of geomorphological processes differing in terms of geological structure, terrain configuration, seismic activity climate and human pressure (Bălteanu et al. 1987).

Several studies emphasise the impact of geomorphological hazards upon human activities (Bălteanu et al. 1996; Balteanu 1997). The potential risk phenomena related to mining activities, like breaking down the old galleries, waste dumps instability and soil pollution, are outlined for different areas (Mac 1991).

Mass movements represent one of the major processes in the Romanian Flysch Carpathians and in the hilly regions formed of Neogene molasses. Their spread and diversity depend on climate, tectonics and lithology, but also on land use structure and territorial planning.

Quantitative evaluations of slope denudation indicate that landsliding is very active in the Subcarpathian region (4.7–4.8 t ha^{-1} $year^{-1}$), and in the Transylvanian Depression (4.5 t ha^{-1} $year^{-1}$). There are significant regional differences among the types of mass movements, the delivery coefficients of materials from the slopes into the channels and the risks posed by different human activities (Bălteanu 1997). In the SubCarpathians, formed of folded and faulted Neogene molasse deposits, the most frequent types are translational slides, rotational slides and mudflows.

Long-term investigations of 500 active landslides in the Eastern Carpathians have revealed their higher incidence in areas with colluvial deposits, consisting of 35–62% clays. The action of streams and of human activities put the lower part of slopes at greatest risk (Surdeanu 1994). As a rule, sliding occurs up to maximum 700–900 m alt. North of the Trotuş River, and up to 1,000–1,100 m South of it. Some authors speak of a 30-year cyclic reactivation of deep-seated landslides and of 9–11 years for the smaller ones (Surdeanu 1997).

However a recent survey carried out in the Moldavian Plateau on some 400 landslides registered during the 1829–1994 interval show the non-periodic character of reactivations (Fig. 7, 8).

One of the big slides is the one at Taşbuga (1984–1989) in the Trotuş Basin, which dislodged over three million cum. Studies have shown that during its active phase it moved at a speed of 40–50 meters/day.

A recent survey of the Moldavian Subcarpathians shows that over 70% of the slides have developed on the old sites that date probably from the Atlantic or Subatlantic phases (Lupaşcu 1996). What caused landsliding in the Cracău-Bistriţa Depression is excessive humidity (30%), the erosion of the foot of the slope associated with overmoisture, and deforestation.

It has recently been appraised that most of the Holocene slides occurred in the Atlantic and the Subatlantic (Grecu 1992; Lupaşcu 1996; Bălteanu 1997).

Detailed investigations conducted into the Curvature SubCarpathians highlight the effects of gulling and sliding material on the vegetal cover (Pătroescu 1996; Muică and Bălteanu 1995). In a first stage of colonisation of landslide slopes, the plant cover presents a marked mosaic structure (in terms of floristic composition

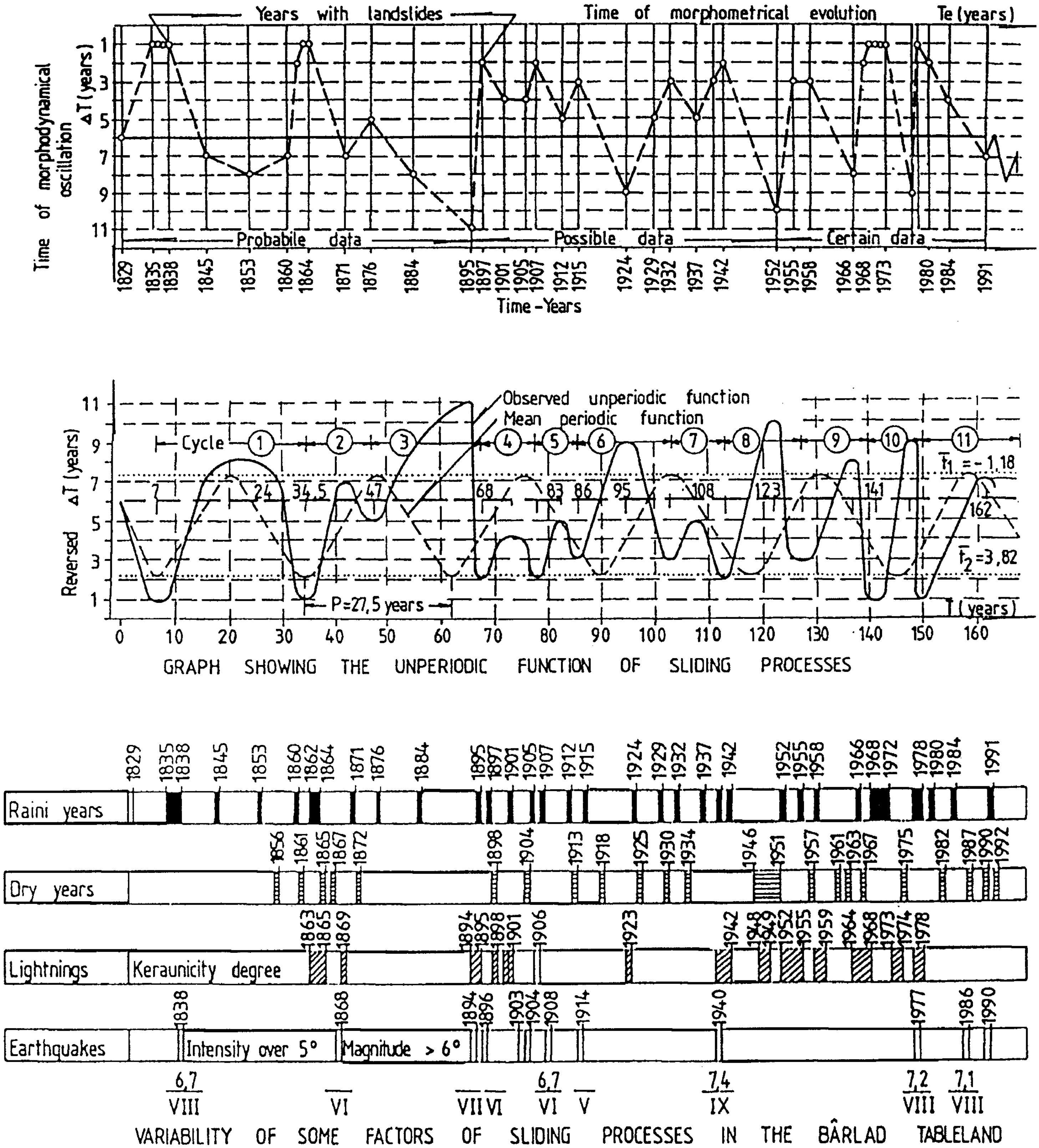


Fig. 7. Variability of sliding processes in the Bârlad Tableland in the 1829–1992 interval (Pujina and Ioniţa 1996)

Ryc. 7. Zmienność procesów osuwiskowych na wyżynie Bârlad w latach 1829–1992 (Pujina i Ioniţă 1996)

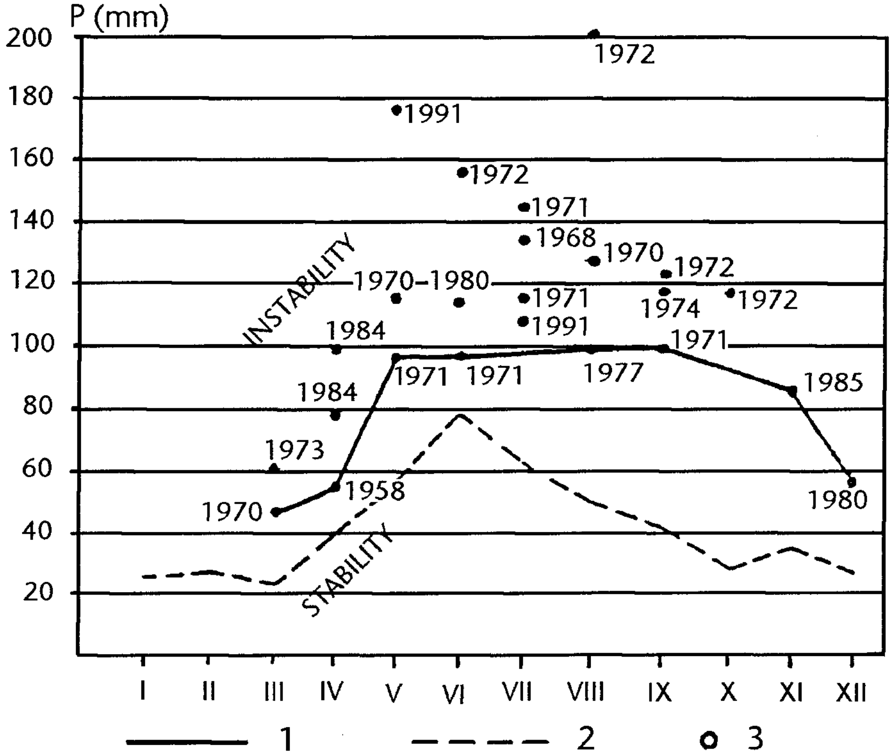


Fig. 8. Pluviometric limits of landslide triggering in the Bărlad Tableland. 1 — lowest monthly mean of rainfall for triggered landsliding, 2 — mean monthly rainfall over a 53-year period (1941–1994), 3 — years with sliding processes (Pujină and Ioniţă 1996)

Ryc. 8. Progowe wartości pluwiometryczne wywołujące osuwiska na wyżnie Bărlad. 1 — najniższy średni miesięczny opad uruchamiający osuwanie, 2 — średni miesięczny opad za okres 53 lat (1941–1994), 3 — lata występowania procesów osuwiskowych (Pujina i Ioniţă 1996)

and density), tending to becoming progressively more homogeneous when sliding ceases or has a very low intensity. In time, the highly resistant pioneer species have been replaced by plants specific to the respective zonal vegetation.

Two generations of valleys have been identified in the Transylvanian Depression (Mac 1997). A first generation, of wider valleys, is correlated with the Riss and Würm glaciations, the solifluction processes having been essentially involved in their formation. A second generation, of narrower derrasion valleys, emerged during the interglacial periods.

Sheet and gully erosion. Sheet erosion is active in the Curvature Subcarpathians, the North of the Getic Piedmont and the West of the Transylvanian Tableland. Large areas are affected by gully erosion. Worst affected are the Curvature Subcarpathians (with potential soil losses of 12.5 to 24.4 t ha^{-1} $year^{-1}$) and the Getic Subcarpathians (8–8.5 t ha^{-1} $year^{-1}$) (Moţoc 1982).

F l u v i a l p r o c e s s e s. The study of fluvial processes brought into the limelight a number of aspects concerning differences in the mainstream channel beds, sediment dynamic in the channel-bed and sediment sources, as well as the impact of human activity. With a view to assessing the characteristics of sediment load discharge in the small basins of Romania (up to 150 sq. km), a sample of 20 representative basins and 113 hydrometric stations were being investigated (M i ţ ă 1996). At the same time, new erosion appraisal models for the small drainage basins were devised (M o ţ o c 1983). Researches carried out at the Piatra Neamţ Research Station, as well as the proceedings of the "Source and Sediment Delivery Ratio" symposias organised beginning with 1986, have provided deeper insights into the space and time disparities of fluvial processes.

The Carpathian Mountains cover 21% of the country's surface area and yield 66% of the mean out-Carpathian runoff volume. What prevail are the gravel bed rivers which reflect differently the petrographical types of source areas (I c h i m et al. 1996).

The drainage network is characterised by high vertical and horizontal river bed mobility, which varies in terms of lithological units (I c h i m 1992). Thus, the crystalline area is dominated by degradation processes and a low sediment yield (under 100 t km^{-2} $year^{-1}$).

In the flysch area, river bed elevation oscillates between 50 and 100 cm, the sediment yield increasing up to 800 t km^{-2} $year^{-1}$. Maximum vertical mobility reaches 3 m in 35 years, river bed elevation registering a cyclic evolution (R ă d o a n e and I c h i m 1992). The highest sediment yield occurs in the SubCarpathians (2,000–3,000 t km^{-2} $year^{-1}$ and more), on molasse deposits.

Sediment delivery ratios are controlled by two main factors: rock erodibility and the runoff regime (I c h i m 1990). There is an inverse relationship between sediment delivery ratios and drainage basin order (Strahler's system). The sediment yield in sixth and higher-order drainage basins ranges between 29 t km^{-2} $year^{-1}$ on volcanic and crystalline rocks and 3,000 t km^{-2} $year^{-1}$ on molasse deposits. A sediment yield multivariate statistical analysis of 27 third-order drainage basins on flysch and molasse deposits indicates that gross erosion is four times higher in the Vrancea SubCarpathian area than in the flysch mountains, where over 50% of the sediments, originating in small catchments, are deposited in third-order basins (I c h i m and R ă d o a n e 1986).

Long-term measurements carried out on a third-order catchment in the Getic Piedmont have revealed that debris avalanches and rock falls are the most common processes of sediment transfer on the slopes (B ă l t e a n u and T e o d o r e s c u 1985).The specific rate of sediment transfer determined on the basis of the sediments retained behind the dams was of 6,446 t km^{-2} $year^{-1}$. Approximately 35% of the total amount of the alluvial material transported are contributed by the slopes, the rest represents the store of alluvial materials deriving from the channel and the banks, as well as from channel erosion (Fig. 9).

According to some recent estimates, more than 80 million cu. m of rough sediments are exploited from river beds, with consequent channel imbalances.

Mining activities, including coal preparation and sorting plants, influence sediment transfer, leading to 7–10 and even 50-times increases of sediment yield above normal limits (Rădoane et al. 1995).

The effects of damming on the relief dynamics involve the development of a new lacustrine morphodynamic system; an upstream river bed morphodynamic

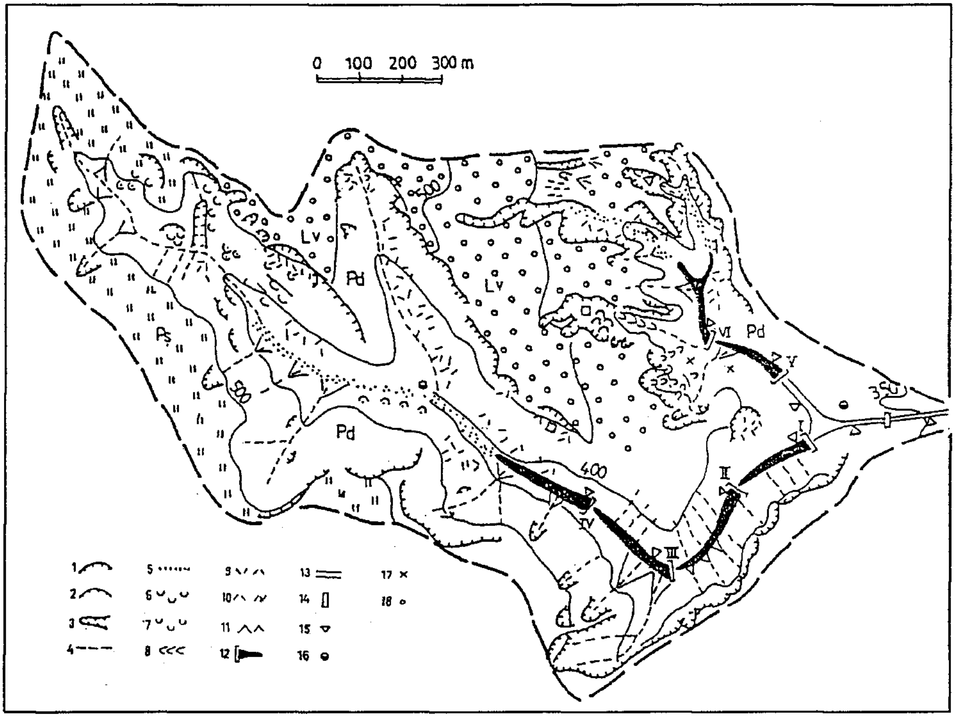


Fig. 9. Nandra catchment, Getic Piedmont. Present-day geomorphological processes and measurement points. 1 — active scar, 2 — fixed scar, 3 — active gully, 4 — channel erosion, 5 — alluvial store in the channel, 6 — active landslide, 7 — fixed landslide, 8 — mudflow, 9 — active gravel and sand talus, 10 — fixed gravel and sand talus, 11 — fan, 12 — alluvial fill at dams, 13 — concrete channel, 14 — hydrological measurement section, 15 — measurement point, 16 — rain recorder, 17 — stake profiles, 18 — rockfall measurement point (Bălteanu and Teodorescu 1985)

Ryc. 9. Zlewnia Nandra, Piedmont Getycki. Współczesne procesy morfogenetyczne i punkty pomiarowe. 1 — aktywne strome stoki, 2 — utrwalone strome stoki, 3 — aktywne żłobiny, 4 — erozja korytowa, 5 — aluwialna depozycja w korycie, 6 — aktywne osuwisko, 7 — stabilne osuwisko, 8 — spływ błotny, 9 — aktywne hałdy żwirowe i piaszczyste, 10 — utrwalone hałdy żwirowe i piaszczyste, 11 — stożki, 12 — aluwialne wypełnienia za zaporami, 13 — koryta betonowe, 14 — przekroje hydrologiczne, 15 — punkty pomiarowe, 16 — stacje opadowe, 17 — profile kołkowe, 18 — punkty pomiaru odpadania (Bălteanu i Teodorescu 1985) system with a new local base level and a downstream river bed system subordinated to a diminished input of sediments and water (Rădoane et al.).

Downstream these dams, over varied distances (40–50 km on the Someş; 100 km on the Argeş, and 150 km on the Siret), rivers tend to deepen by 0.50–0.70 m. Most of the hill-based reservoirs got silted, fact that has intensified denudational processes. An analysis of 138 reservoir lakes in areas where sediment transport averages over 100 km^2 $year^{-1}$ has revealed that, irrespective of the transit regime of sediments, the silting ratio tends to decrease simultaneously with the increase of the reservoir sediment volume.

The sediment transited by the big rivers — the Olt, the Siret, the Argeş and the Someş has significantly decreased through the construction of dams. The lower quantity of sediment carried by the Danube to the Black Sea is the main cause of the shoreline tendency to retreating.

Chemical erosion. The total volume of dissolved substances and processes of chemical erosion on the Romanian territory amounts to over 14,7 million tons annually, that means a mean chemical erosion rate of 68 t km^{-2} $year^{-1}$ and an average chemical denudation of 27 mm 10^{-3} year, chemical erosion representing almost 25% of the total erosion mean (Trufaş et al.1988).

The lowest chemical erosion value (under 50 t km^{-2} $year^{-1}$) is registered in the Neogene volcanic mountains of Gurghiu and Harghita and is related to a reduced ion concentration and a diminished liquid load. Moderate chemical erosion (50–100 t km^{-2} $year^{-1}$) affects the greatest part of the Carpathians and almost all the hilly and tableland areas.

High chemical erosion (100–200 t km^{-2} $year^{-1}$) is related to the presence of carbonate and saliferous rocks, to the areas built of Cretaceous and Palaeogene flysch deposits and Miocene molasses and to mining sites. Investigations into chemical denudation in the Anina Mts revealed linear values in the range of 10–149 mm 10^{-3} years, with maximum records in June and minimum ones in August, September and October. Seasonal denudation registers 45 mm 10^{-3} years in the hot season and 72 mm 10^{-3} years in the cold season, with a multiannual mean of 58 mm 10^{-3} years (Sencu 1990). Highest chemical erosion values (over 300 t km^{-2}, over 80 mm 10^{-3} year), due almost exclusively to the presence of saliferous rocks, are registered in the Curvature SubCarpathians and in the Târnava Mică basin. Despite high chemical erosion in the SubCarpathians, the total erosion percent is small, with a high mechanical erosion score.

Dan Bălteanu
Institutul de Geografie
Dimitrie Racoviţă 12 Str.
70307 Bucureşti 20
Mihaii Ielenicz, Nicolae Popescu
Facultatea de Geografie
N.Bălcescu 1, Bd.
Bucureşti
Romania

REFERENCES

Badea L., 1996. *Sur l'évolution morphologique des monts entre Olt, Jiu et Strei (Carpates Méridionales) dans le cycle pliocéne,* [in:] *Carpates Méridionales et Stara Planina*, Geogr.Intern. Seminars, Bucureşti, 7–12.

Badea L., 1997. *Rolul morfogenetic al mişcârilor neotectonice*, Rev. de Geomorfologie 1, 31–38.

Badea L., Sandu M., 1992. *The general geomorphological map of Romania on a medium scale* (1:200 000) Rev. Roum. de Géogr. 36, 31–40.

Bălteanu D., 1997. *Mass movements and climate in Romania.* [in:] *Rapid mass movement as a source of climatic evidence for the Holocene*, Ed. J. A. Matthews, D. Brunsden B. Frenzel, Gläser & M.Weiß, Stuttgart, 128–135.

Bălteanu D., Cioacă A., Dinu M., Sandu M., 1996. *Some case studies of geomorphological risk in the Curvature Carpathians and Subcarpathians*. Rev. Roum. de Géogr. 40, 51–59.

Bălteanu D., Ozenda P., Kuhn M., Kerschner H., Tranquillini W., Bortenschlager S., 1987. *Impact analysis of climatic change in the Central European mountain ranges.* European Workshop on Interrelated Bioclimatic and Land Use Change, Vol. G, Noordwijkerhout, 42.

Bălteanu D., Teodorescu V., 1985. *Elements for the Sediment Budget of a Small Catchment (The Getic Piedmont, Romania).* Rev. Roum. Géogr. 29, 73–78.

Constantinescu L., Enescu D., 1985. *Cutremurele din Vrancea în cadru ştiinţific şi tehnologic.* Ed. Academiei Române.

Geografia României. 1992. *IV Regiunile Pericarpatice: Dealurile şi Câmpia Banatului şi Crişanei, Podişul Mehedinţi, Subcarpaţii,* Piemontul Getic, Podişul Moldovei, Ed. Acad. Române, 580.

Grecu F., 1992. *Bazinul Hârtibaciului. Elemente de morfohidrografie.* Ed. Acad. Române, Bucureşti, 167.

Ichim I., 1990. *The relationship between sediment delivery ratio and stream order: a Romanian case study*, [in:] *Erosion, Transport and Deposition Processes*, Ed. D. E. Walling and Berkowicz S., Yair 1, 189, 79–85.

Ichim I., 1992. *Progress in the knowledge of the sediment system in Romania.* Rev. Roum. de Géogr. 36, 41–45.

Ichim I., Rădoane M., 1986. *Efectele barajelor în dinamica reliefului, Ed. Academiei Române, Bucuresti,137.*

Ichim I., Rădoane M., Rădoane N., 1996. *Carpathian Gravel Bed Rivers in Recent Time.* A Regional Approach, Transactions, Japanese Geomorphological Union, 17, 3, 135–157.

Ielenicz M., 1984. *Muntii Ciucas-Buzâu. Studiu geomorfologic*, Ed. Acad. Române, Bucureşti, 183.

Ielenicz M., 1997. *Terasele din regiunile de dealuri şi podişuri,* Rev. de Geomorfologie 1, 57–66.

Josan N., Grecu F., 1996. *Riscurile naturale şi aşezârile omeneşti din Podişul Târnavelor,* Rev. Geogr. 2–3, 91–93.

Lupaşcu Gh., 1996. *Depresiunea Cracău-Biştriţa. Studiu Paleogeografic.* Ed.Corsova, Iaşi, 196 pp.

Mac I., 1991. *The mining on Toroioaga Massif and its impact upon environment.* An Univ. Oradea, Geogr. 5–13.

Mac I., 1994. *Processes formations and quaternary morphoclimatic stages on the Hilly Regions of Romania,* Rev. Roum. de Géogr. 38, 21–31.

Mac I., 1997. *The geomorphological landscape of derasion. A model from Romania.* Geogr. Fisicae Dinamica Quater. 19, 225–258.

Miţă P., 1996. *Representative Basins in Romania.Research Achievements.* National Inst. of Meteorology and Hydrology, Bucureşti, 33.

Moţoc M., 1983. *Ritmul mediu de degradare a solului în R.S.România.* Bul. Inf. Acad. St. Agricole şi Silvice 12, 47–65.

Muică C., Bălteanu D., 1995. *Relations between landslide dynamics and plant cover in the Buzău Subcarpathians.* Rev. Roum. de Géogr. 39, 41–47.

Niculescu G., 1994. *La recherche du relieef glaciaire et cryo-nival dans les Carpates Roumaines*, Rev. Roum. Géogr. 38, 11–20.

Pătroescu M. N., 1996. *Subcarpatii dintre Râmnicu Sărat şi Buzău. Potential ecologic şi exploatare biologică.* Ed. Carro, Bucureşti, 125 p.

Popescu N., 1984. *La pédiplaine carpatique dans les Monts Făgăraş.* Anal. Univ. Bucureśti, Geogr. 33, 47–53.

Popescu N., 1986. *Evaluarea eroziunii fluvio-torentiale pentru câteva vai din Piemontul Getic.* Anal. Univ. Bucuresti, Geogr. 35, 46–52.

Popescu N., 1989. *Evaluari cantitative ale eroziunii fluviatile În partea de sud a Munţilor Banatului.* Anal. Univ. Bucureśti, Geografie 38, 56–60.

Popescu N., 1990. *Ţara Făgăraşului. Studiu geomorfologic.* Ed. Acad. Bucureşti, 180.

Posea G., 1997. *Pedimentele şi glacisurile*, Rev. de Geomorfologie, 1, 67–74.

Posea G., 1997. *Suprafeţe si nivele de eroziune.* Rev. de Geomorfologie, 1, 11–29.

Pujina D., Ioniţă I., 1996. *Present-day variability and intensity of the sliding processes in the Bârlad Tableland.* Proceedings International Conference on Disasters Mitigation, vol.I, Madras, 35–40.

Posea G., Popescu N., Ielenicz M., 1974. *Relieful României*, Ed. Stiinţifică, 483.

Rădoane M., Ichim I., 1992. *Contemporary trends of river bed formation in the Eastern Carpathians*, Stud. Geomorph. Carpatho-Balcanica, 25–26, 182–194.

Rădoane N., Rădoane M., Ichim I., Miclăuş C., 1995. *Influentele mineritului asupra tranzitului de aluviuni pe râul Jiu, amunte de Sadu.* Stud. Cercet. Geogr. 42, 63–72.

Săndulescu M., 1984. *Geotectonica României*, Ed. Tehnica, Bucuresti, 334.

Săndulescu M., Mărunteanu M., Popescu G., 1995. *Lower-Middle Miocene Formations in the Folded Area of the East Carpathians.* Guide to Excursion B_1 (Post-Congress), Xth Congress RCMNS, Romanian J. of Stratigraphy 76, 5, 32.

Săndulescu M., 1997. *Geotectonic framework of the Vrancea Seismic Area*, [in:] *International Workshop on Vrancea Earthquakes, Bucharest.*

Schreiber W. E., 1994. *Munţii Harghita. Studiu geomorfologic*, Ed. Acad. Bucureşti, 134.

Sencu V., 1990. *Variaţia denudării carstice În Bazinul Caraşului (Muntii Aninei)* Stud. Cercet. Geogr. 37, 61–66.

Sencu V., 1992. *Propuneri pentru legenda hărţii geomorfologice a carstului la scări mari.* Stud. Cercet. Geogr. 39, 11–36.

Surdeanu V., 1994. *Le risque naturel relativ aux glissements de terrain dans les Carpates Orientales.La Zone du Flysch* [in:] *Environment and Quality of Life in Central Europe. Problems of Transition.* Ed. Albertina, Icome, Praha, 7.

Surdeanu V., 1997. *La repartition des glissements de terrain dans les Carpates Orientales (Zone du flysch).* Geogr. Fisica e Dinamica Quater. 19–1996, 265–271.

Trufaş V., Popescu N., Pătroescu M., 1988. *Chemical erosion and denudation in Romania's territory. Rev. Roum. Géogr.* 32, 3–11.

Urdea P., 1989. *Munţii Retezat. Studiu geomorfologic.* Rezumatul tezei de doctorat, Univ. Cuza, Iaşi, 27 p.

Urdea P. 1991. *Rock glaciers and other periglacial phenomena in the Southern Carpathians*, An. Univ. Oradea Geogr. 13–26.

Urdea P., 1993. *Consideraţii asupra manifestării glaciaţiei cuaternare În Munţii Retezat.* Stud. Cercet. Geogr., 40, 65–72.

Urdea P., 1995. *Quelques considerations concernant les formations de pente dans les Carpates Méridionales*, Permafrost and Periglacial Processes 6, 195–206.

STRESZCZENIE

D. Bălteanu, M. Ielenicz, N. Popescu

GEOMORFOLOGIA KARPAT RUMUŃSKICH. NOWE TRENDY I EWOLUCJA

W pracy przedstawiono główne kierunki badań geomorfologicznych w uniwersyteckich ośrodkach Rumunii oraz w Akademii Rumuńskiej w okresie ostatnich 10 lat. Powstało wiele opracowań regionalnych oraz duża dwutomowa synteza pt. *Geografia Rumunii* wydana w roku 1992. Po części wstępnej omówiono cechy strukturalne i sejsmiczność Karpat rumuńskich, a następnie podsumowano aktualne poglądy na temat ewolucji rzeźby, w tym powierzchni zrównań oraz warunków ich formowania. Następnie pokazano wpływ zlodowaceń górskich na przekształcenie rzeźby przedczwartorzędowej najwyżej wyniesionych nad poziom morza części Karpat. Nowe badania wykorzystujce datowania bezwzględne i analizy palinologiczne zmierzają do ustalenia ilości zlodowaceń oraz roli morfogenezy glacjalnej i peryglacjalnej, w tym określenia warunków formowania lodowców gruzowych. Osobny kierunek badań stanowią studia teras rzecznych i ich relacji do ruchów neotektonicznych. Wielkie zróżnicowanie strukturalne, geomorfologiczne, sejsmiczne oraz klimatyczne Karpat rumuńskich sprawia, że góry te są współczesnie modelowane przez procesy morfogenetyczne o różnej intensywności. Szczególną rolę we współczesnej morfodynamice łuku karpackiego odgrywają ruchy masowe. Praca prezentuje główne wyniki tych badań i ilustruje je szeregiem ilościowych wskaźników tempa denudacji.