

Present-Day Geomorphological Processes and Geomorphological Risk in the Sibiu-Apold Depressionary Passageway (Sw Transylvanian Tableland)*

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Abstract. The contact area between the Southern Carpathians and the Transylvanian Plateau is marked by a number of depressions, between the valleys of the Olt in the east and the Sebeş in the west: Sibiu, Sălişte and Apold, a contact depressionary passageway (80 km long and 700 sq.km). The Sibiu-Apold depressionary passageway is characterized by a great morphological complexity. This complexity results, on the one hand, from the position and the location of a chain of depressions at the morphostructural contact between the two units and, on the other hand, from the division into two hydrographic basins: of the Mureş River, through the Secaşul Mare, and of the Olt River through the Cibin, which have distinct drainage conditions and underwent major hydrographic changes in the Quaternary, very likely in its early stage.

The Sibiu – Apold depressionary passageway is affected by a great diversity of geomorphological processes, the frequency and magnitude of which could be better explained if viewed within in the framework of global environmental change. Quantitative evaluations of the present-day mass movements, and gully erosion show significant regional differences which relate to recent extreme climatic events and landuse changes.

Therefore, the very dynamic character of slopes is a major characteristic of the Apold Depression, which represents the western sector of the passageway. It covers one third of the passageway (the sector connected with the lower base level of the Mureş River). On the other hand, in the Sălişte and the Sibiu depressions, which represent the central and the eastern sectors of the passageway (connected with the Olt Basin), the relief is insignificantly affected by denudation, most of the slopes being in a very stable state. In general, instability on slopes produces landslides associated with gully processes. The extension, frequency and intensity of present-day geomorphological processes depend on such factors as precipitation, categories of slope and human activity (deforestation, land uses orchards, crops).

The frequency and intensity of present-day geomorphological processes have lead to the identification of three classes of geomorphological risk: high, moderate and low.

Present-day modelling and the factors influencing it

Present-day geomorphic processes are triggered either by general factors (affecting all of the Sibiu-Apold depressionary passageway), or by local ones. The contact area between the Southern Carpathians and the Transylvanian Plateau is marked by a number of depressions, between the valleys of the Olt in the east and the Sebeş in the west: Sibiu, Sălişte and Apold, a contact depressionary passageway (80 km long and 700 sq.km) (Fig. 1). The Sibiu-Apold depressionary passageway is characterized by a great morphological complexity. This study is the result of field investigation, as well

as of the correlations established among several factors: climatic (with focus on the precipitation regime - 600-700 mm/year), geological, morpho-hydrological (surface and underground waters, categories of slope, aspect and length of slopes, relief energy, density of relief fragmentation), biological (degree of vegetation coverage) and anthropic.

Climatic factors

The climate of the depressions is moderate continental with temperate shades, the geographical position of these depressions accounting for a greater opening towards the north-west and west

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increases the circulation of the masses of maritime air from the west. So, in summer, the weather is unstable, cool, with much nebulosity and rainfall, in winter temperatures and air moisture register higher values (Bogdan et al., 1981).

Local factors affect differently the main variables registered by the three depressions in terms of the characteristic relief of each of them. Mean air temperatures in the December-February period are negative (with -4.2°C in Sibiu and -3.7°C

C in Sebeş in the coldest month); from March through to November the mean temperatures are 3.5°C and 23°C respectively, top values being registered in July (19.4°C in Sibiu and 19.9°C in Sebeş). The lowest annual temperatures may drop below -30°C with an absolute record of -31°C in Sibiu and -30°C in Sebeş. The highest annual temperature may exceed 30°C and so may the absolute value: 37.4°C in Sibiu on July 3, 1952.

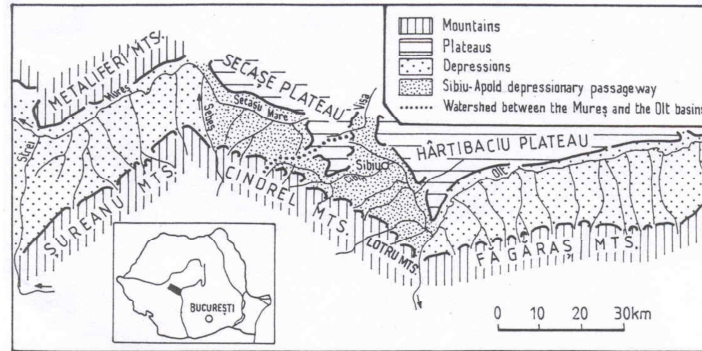


Fig. 1. The Sibiu-Apold depressionary passageway between the Olt Valley in the east and the Sebeş Valley in the west

Freeze-thaw phenomena play a secondary role in present-day modelling processes, occasionally influencing creep and piping on the lefthandside slopes of the Mag and the Cibin valleys (between the settlements of Guşteriţa and Tâlmăciu on the Cibin) and on the righthandside slope of the Secaşul Mare (between Apoldu de Jos and Sebeş), etc.

It is precipitation that enhances and accelerates those processes. Mean quantities go up to 600-700 mm/year, and even higher: Sibiu 653.4 mm/year, Sălişte 697.4 mm/year and southwards, at the contact with the mountain (817 mm/year at Boiţa, 781.2 mm/year at Răşinari, etc.), but decreasing northwards, on the contact line with the tableland (Şura Mică 613 mm/year, Apoldu de Jos 571.6 mm/year and Sebeş 568.7 mm/year. The wide monthly, seasonal, annual and multiannual

variations, visibly influence the relief modelling regime. Maximum rainfall/24 hrs occurs in July and August (between 40-80 mm), highest quantities being registered in the warm season (April-September) – with a maximum in June (over 100-120 mm), and occasionally in July. Unperiodical climate variations registered excessively rainy years (1966, 1969, 1970, 1975, 1991, 1997, 1998, 1999, 2005), followed by the reactivation of landslide and erosion, very significant in some cases. A very important element in unleashing them is the substrate.

A synthesis of the main climatic variables is based also on the Péguy climograms (Fig. 2) revealing the effect on modelling processes of snow which, accumulating in the cold and humid season begins to thaw and flow as temperatures suddenly rise during the warm humid months.

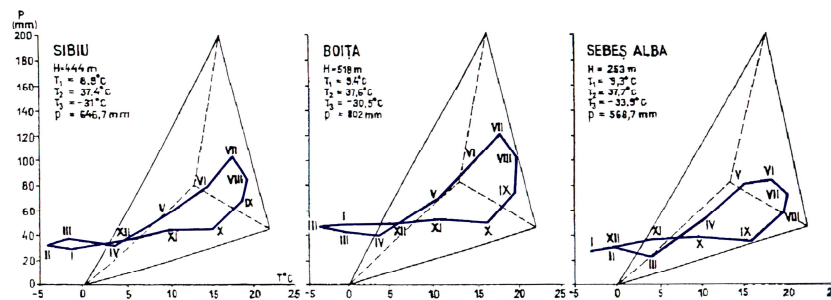


Fig. 2. Péguy-type climograms: H, absolute altitude. Temperature: T1, annual mean in the air; T2, abs. max; T3, abs. min; P, annual amount of precipitation

Morpho-hydrographical factors

One of the main factors influencing the intensity and rate of relief modelling (slopes, channel-beds) is the discharge regime. Notable differences in this respect occur between torrential basins and permanent basins. Thus, the Secaşul Mare cuesta, the scarps on the lefthandside of the Mag and the Cibin valleys (between Guşteriţa and Tălmăciu) are cut by small 2nd and 3rd-order basins that have a pluvial regime. The 5th and 6th – order basins (Horton-Strahler classification) – the Sălişte, Sibiel, Seviş, Cislădie, Sadu, etc., which cross the three depressions, have a pluvial-nival regime. The increased discharge and suspended sediment load on these watercourses across the three depressions is different: an average multiannual value of 4.72 cum/sec for the Cibin and only 2.37 cum/sec for the Secaşul Mare.

Looking at discharge rates by season, differences appear to be very great indeed, fact that affects the channel-bed modelling regime. On the Cibin, the lowest monthly averages (1.42-1.63 cum/sec) were recorded in winter (December-March) with a maximum in spring and summer (April, 3.5 cum/sec; July, 10.2 cum/sec). Since comparative data for the Sălişte and the Secaşul Mare are not available, interpreting rates, discharge and channel-bed modelling is a difficult task. So, channel dynamics could be assessed only by field investigations, which nevertheless are not sufficient for establishing correlations. Speaking therefore of the Cibin we would say that the most likely interval for erosion processes to develop is April-June, when high spring waters and floodwaves set in after the snow melts and the rains begin to fall. In summer, high floodwaves are produced only by very intense torrential rains.

The Secaşul Mare (42 km long) drains the Apold Depression from east to west along a distance of 30 km. Its major lefthandside tributaries are the Apold, Dobârca, Gârbova, Pustia, Călnic and Răhău (intermittent or semi-permanent streams). A similar discharge regime have the righthandside tributaries originating from the Amnaş and the Secaşu plateaus: the Amnaş, Boz, Draşov, Cut, and Daia. Summer floods have a greater impact on erosion and sediment transport.

The underground waters of the depressions lie in Pannonian and Quaternary deposits of sand and gravel at depths of 30-70 cm in some parts of the Cibin, Sălişte, and Secaşul Mare floodplains and at over 10 m in the southern hills. Unlike the waters in the north of Sibiu which lie on a carbonate bed and

are salty, these underground waters have a very low mineral content (Bălăceanu, 1970).

South-west of Veştem settlement, there is somehow increased water mineralisation due to the Badenian strata; very small surfaces of salt efflorescences are seen on the right and lefthandsides of the Sărata Valley and the Tocile Brook, respectively (Sibiu Depression) and around Miercurea Sibiului Băi (spa resort) in the Apold Depression.

The density of relief fragmentation is an important factor in the dynamics and frequency of modelling processes. It is the resultant of drainage channel density, hence of linear erosion. Without entering into details, we would say that the highest values are registered in the sub-montane hills from the southern flank of the depressions, with differences among them between 3-5 km/sqkm.

The relief energy varies from 80 to 90 m in the hilly zone of the depressions, overlapping areas with frequent geodeclivities of 15°-25°. High values (>25°) are characteristic of cuestas, slide scarps and the steep scarps in the source area of torrential basins. The declivity of semi-horizontal depressionary surfaces is 0°-2°.

The length and aspect of slopes are decisively influencing the overland flow. Moderately long slopes (80 m-150 m up to 250 m in some places) are characteristic of scarps of terraces and cuestas, and of slopes underlain by sandy rocks. On the other hand, structure-controlled surfaces, slopes developed on marl-clays and marl-sands are over 200 m, frequently 250-350 m long. The slopes with a southern aspect, forming the Secaşul Mare cuesta or the lefthandside of the Cerna Vodă, have a high insolation index which accelerates snowmelt, and enhances overland flow, landsliding and gullyng. In the hills extending on the southern flank of the depressions, on slopes with eastern, western and southern aspect, differences are annulled by the vegetation of the forests of Tufari and Mohu (Sibiu Depression); Bercu Roşu and Dumbrava hills (Sălişte Depression) and those covering the Gârbova, Albele and Reciu hills (Apold Depression).

Geological factors. Sedimentary formations are of a Badenian, Sarmatian, Pannonian and Quaternary age; they occur in alternation of impermeable (marls and clays) and permeable strata (sands, loosely-cemented sandstones) with a monocline structure and general SW-WE orientation (Vancea, 1960). The dominance of marl-clays and clay-sands favours landsliding and gullyng.

Vegetation and the anthropic factor. In the Sibiu-Apold depressionary passageway there was a wealth of oak forests (*Quercus robur* and *Quercus petraea*) that used to cover large areas in the past. What has been left of them are a few scores of hectares. There is more forest land in the Sibiu Depression (18%) than in Sălișe (16%) and Apold (5.4%). As the trees were felled, their place was taken by secondary hydro- and mezophile meadows with *Molinia coerulea*, *Agrostis stolonifera*, *Alopecurus pratensis*, etc., or by cultures and plantations of a weaker protective value. Pasturelands were degraded by overgrazing (Căplan, Coșcani, Gârbova and the other hills), so that their anti-erosional role has gradually diminished.

Human activity had in the course of time a different impact on the relief. For instance, on the lefthandside of the Cibin Valley there are plantations, terracing (between Veștem and Tălmăciu, Cristian and Orlat), more precisely in the hills closing in the Sibiu Depression in the NW and W), sewerage and embankments (between Șura Mare and Șura Mică, at Șelimbăr, etc.) have all contributed to slowing down erosion.

In the depressionary areas the instability of slopes was augmented by quarries being opened at Gușterița, Bungard, Veștem (Sibiu Depression), Dobârca, Gârbova and Călnic (Apold Depression) or by the exploitation of riverbed gravels and sands. These brought changes in the morphology of channels (e.g. the ballast exploitations in the Cibin Valley, downstream of Orlat, and at Veștem).

Modelling processes and ensuing landforms

In the current evolution of the relief, landslides associated with gullying are the main processes on slope, strongly influencing all the other landscape components. The intensity, rate and diversity of these processes is different in the basins of the Cibin, Săliște and the Secașul Mare, without, however, reaching the dimensions and frequency of those in the limitrophe Secașe and Hârțibaciu plateaus.

Saying precisely which of these processes played a major role in triggering events is impossible, but there are some areas in which mass movements are obviously mainly involved.

Pluvial denudation and sheet wash phenomena are obvious on steep slopes (over 10°), terrace surfaces or interflaves. Their intensity depends on declivity, vegetation cover, type of soil and man-changed uses. On low sloping grounds (1°-2°) - the floodplains and terraces of the Cibin, Săliște and Secașul Mare, used largely as arable land, pluvial denudation disperses the soil particles. In severely

degraded areas (Gușterița and Coșcani Hills, the right valley-side slope of Dobârca and Gârbova) rain drop splash removes and transports the soil particles towards the lower section of slopes, over distances that depend on the intensity and duration of the rainfall.

In the southern hills sheet wash is usually weak-to-moderate, moreover so on forest-protected slopes (e.g. between the Sibiel and Pârâul Vale valleys between the Cerna Vodă and the Mag brooks, and between the Chipeșii and the Călnic valleys) and severer where the vegetation is missing (Căplan, Carpeni, Coșcani hills, etc.) These are lands where effective protection against erosion calls for the management of slopes.

Gullying processes

In general, deep erosion has produced a wide range of forms, and all of them are present in the studied area, from incipient to more evolved ones - rills, ditches, gullies, ravenes and torrential organisms in various stages of evolution.

In the Apold Depression, gullying processes are particularly severe on slopes underlain by sands and loose sandstones (Fig. 3). However, they also affect areas subjected to landslides. Covering by far smaller surfaces, gullying is present in the depressions of Sibiu and Săliște as well. Ravenes are usually 5-10 m deep, appearing in the source area in the form of discontinuous small fixed valleys due to piping and down-sagging. Backward erosion of sources and sideway withdrawal of slopes associated with landslides and rock-and-soil falls enlarge the degraded surfaces.



Fig. 3. Righthandside slope of the Călnic Valley subjected to intense gullying (Apold Depression)

Landslides

They are decisively involved in the modelling of slopes in the Sibiu-Apold passageway. Slides may

be superficial (sheet slides) or deep-seated, dislodging materials of 1-2 m or over 2m-thick respectively.

Sheet slides affect much of the area on slopes steeper than 10° (Apold Depression) dominated by marl-clay rocks and a hilly relief. On older, massive fixed slides (steps and monticles - glimee), revealing an older generation, reactivated nuclei appear usually in the median or lower slope section, due to the excess of moisture in the deposits. Attaining a stability threshold takes 1-3 years. In the Apold Depression, such slides are frequently occurring in the basins of the Aciliu, Valea Podului (a righthandside tributary of the Apold Brook), on the righthandside of the Dobârca, Gârbova, Pustia, Călnic, and Răhău valleys and the Secaşul Mare cuesta. The dislodged material often takes the form of small steps or "pseudo-pipings" in some places. They occur either alone or in association.

In general, sheet slides develop in the course of 1-2 months, subsequently their morphology is influenced by other slope modelling processes. The material may travel along one single slide track. Sheet slides may be scores of meters long (80-90 m), 10 m wide and 0.80 - 2.0 m thick. Most scarps have a semicircular or rectilinear form, and are 1.30-2.0 m high.

In the lower section of slopes, they regress backwards, towards the upper slope sector. They are a rich supply source of sediment to the channel. Generally, in the depressions of Sibiu and Sălişte slopes are quite stable. Those affected by sheet slides have varied uses; grazes, arable lands, orchards, and built-in areas. On the righthandside of the Poplaca, Orlat, Cisnădie valleys and in the hydrographic basins of the Afunde and Fileru (righthandside tributaries of the Cisnădioara) these types of slope have been mapped.

Deep-seated slides (old and recent) affect small areas in the three depressions, usually slopes developed on marl-clays with intercalations of sands and sand-clays. Sliding occurs both through translation and rotation, dislodging a quantity of 2-5 m-thick materials (over 5 m in some places), 200-350 m long; the well-outlined scarp is 3-10 m-high.

From a morphogenetical viewpoint, slopes are marked by steps, sliding deluvia and monticles (glimee). In the Apold Depression, the best-known glimee-type slides lie NE of Apoldu de Sus settlement in the Potca and Coşcani hills and in the middle sector of the Aciliu and Amnaş basins. In the Sibiu Depression, deep-seated active slides are seen only in the north-eastern part of Sibiu City, more precisely on the SW slope of the Guşterişa Hill.

Investigations conducted so far in various relief units of Romania have shown that Quaternary landslides had played a major role in the modelling of slopes. In the Transylvanian Tableland, pollen

analyses indicate massive sliding during the Boreal, in the Würm or even Subatlantic interphases, the last one being in the very wet Postglacial phase (Morariu et al., 1964). In the Făgăraş Depression, pollen analyses of the peat from the Avrig swamps occurring between the slided heaps on the upper piedmont glacis scarp (Popescu, 1990), date them to the Pleistocene glaciation (Tardyclacial).

Landslides in the studied area fall into two categories: some are old, presumably of an Upper Pleistocene-Holocene age, others belong to the present-day, recent and contemporary periods.

Deep-seated slides represent basic processes in the evolution of the sub-montane hills from the southern flank and the marginal hills from the eastern and northern flanks closing the depressions in. These slides are preserved in the morphology of slopes in the form of steps, sliding deluvia and occasionally monticles (glimee). In general, they have reached an advanced stage of stability and are functionally integrated with the slopes. A second category are the present-day slides, developed in recent history. They represent reactivations of old slides, permanently in a state of imbalance due to heavy precipitation and human activity (Fig. 4).

Geomorphological risk

Geomorphological risk is defined as a probability for the occurrence of some phenomena liable to changing the dynamic balance of slopes, hence with visible effects on the environment. Like changes can be influenced or unleashed by climatic and anthropic factors. The map of geomorphological risk (grounded on present-day geomorphic processes) has a complex character. It makes a synthesis based on repeated investigations of a set of geomorphic factors, highlighting the dynamics of the Sibiu-Apold depressionary passageway relief. The maps used to bring it as close to reality as possible were: map of morphostructure and morpholithology; map of land use, map of slopes, and map of slope aspect. This map of geomorphological risk is an important achievement, because: 1. It shows the degradation of unstable or fragile environments; 2. It facilitates the zonation of areas fit for construction works; 3. It defines and assesses the constraints or limitations posed by natural landforms. The categories of geomorphological risk in the Sibiu-Apold depressionary passageway are grouped by degree of stability and dynamics of moving material, intensity and frequency of landslides associated with gullyng and human impact. The five categories of geomorphological risk have been listed under three classes: high, moderate and low (Fig. 5).

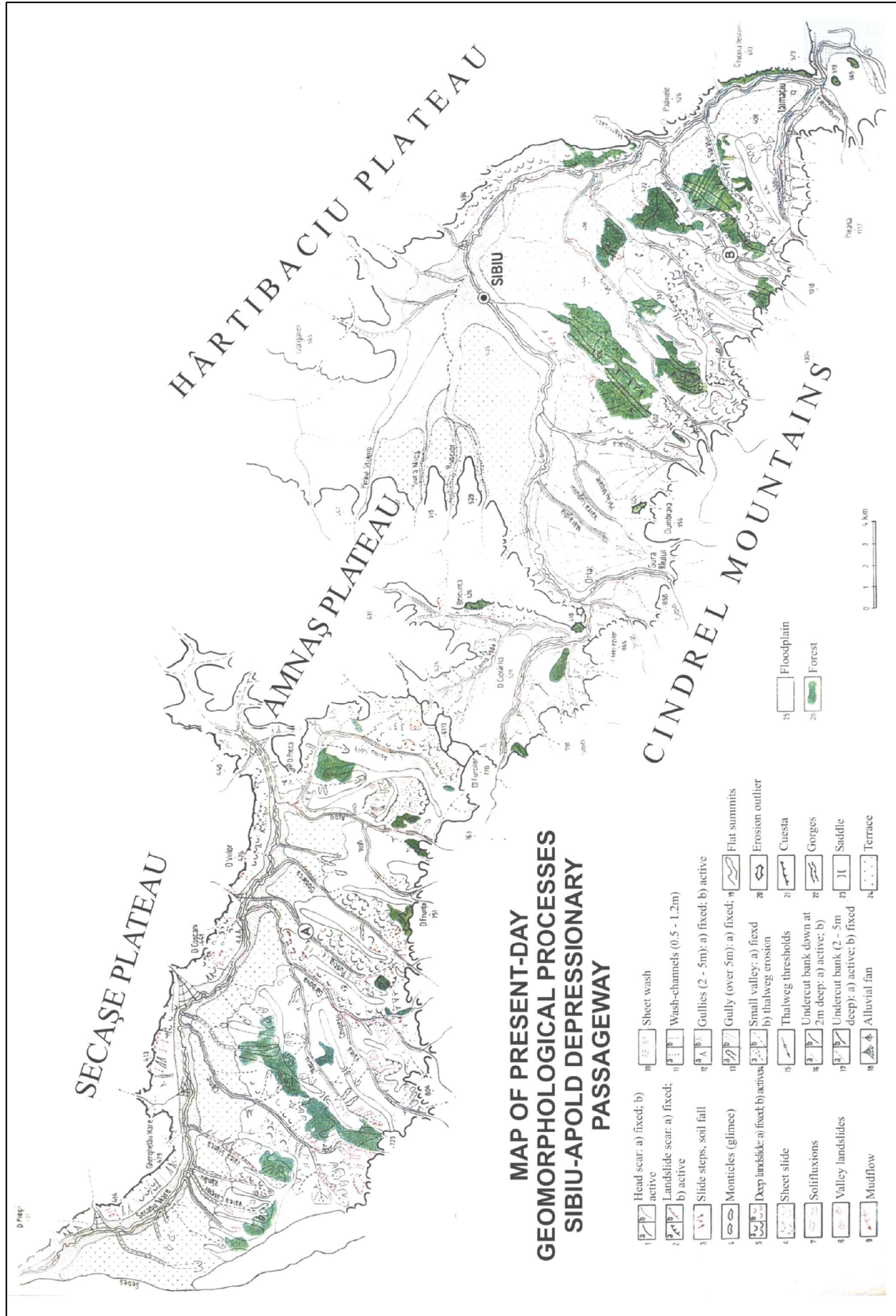


Fig. 4. Map of present-day geomorphological processes. Sibiu-Apold depressionary passageway

High geomorphological risk

Slopes at high geomorphological risk have a big morphodynamic potential, 25-35° declivity, 80-150 relief energy, dominantly south and east aspect and a frequency of 22-30 watercourses/sqkm. In general, these slopes are covered with vulnerable unproductive soils and erosion-control works are suggested. High risk areas represent 17.4% in the Apold Depression, 3.5% in the Sibiu Depression being totally absent in the Săliște Depression. This risk category includes two situations;

- *slopes of high risk from deep-seated slides often associated with gulying*. In the Apold Depression: the Aciliu Basin, the western scarp of Amnaș Plateau, Dobârca and Gârbova hills, Viilor and Coșcani hills (Secașul Mare cuesta). The intensity and frequency of landslides and the backwards regression of the Aciliu and the Amnaș sources maintain a permanent imbalance on slope, being a threat to the railway and the national highway between Aciliu-Apoldu de Sus settlements, corresponding to the unstable sector of the Mureș-Olt watershed.

Despite marked slope instability, works of consolidation, draining, etc. proved to be efficient. In the Sibiu Depression: the Gușterița Hill (NE of Sibiu City).

- *slopes at high risk from gulying associated with severe sheet wash* are found in the Gârbova Hill, the lefthandside slope of the Reciu and the Călnic valleys (Apold Depression) and the righthandside slope of the Orlat Valley, as well as in the Fântânele Basin, east of Rășinari locality.

Moderate geomorphological risk

The slopes in this category have 15-20° declivity, eastern and southern aspect, 50-80 m relief energy, frequency of watercourses 15-20 sqkm. Stability is reduced due sheet and deep-seated slides. This category of slopes represents 20% in the Apold Depression, 22.5% in the Săliște Depression and 16.6% in the Sibiu Depression. Two situations occur in terms of the frequency and intensity of each process:

- *slopes at moderate risk due to sheet slides associated with gulying* in the Apold Depression: the righthandside slope of the Amnaș Valley, the upper Pustia Basin and the Călnic Hill; the Săliște Depression: the lefthandside slope of the Cerna Vodă and the Mag valleys; the Sibiu Depression: part of the western scarp of the Hărtibaciu Plateau (closing in the depression to the east, between Bungard settlement and the Hărtibaciu Valley);

- slopes at moderate risk due to gulying and periodical reactivation of sliding occur in the Ghergheleu and Călnic hills and on the lefthandside slope of the Reciu Valley (Apold Depression), a smaller area on the righthandside slope of the Călnic Valley, and the middle basin of the Sărata (Sibiu Depression).

Low geomorphological risk

This category of slopes has the lowest morphodynamic potential; 2-15° declivity, frequency of watercourses 8-10 sqkm. Sheet wash is weak and reactivation of some gully and ravine sources is ephemeral. These slopes represent 23% in the Apold Depression, 53.7% in the Săliște Depression and 26.4% in the Sibiu Depression. Landforms are in an advanced stage of evolution due to mass movements and gulying. Most of them are fixed by vegetation.

Slopes falling into this category are: both sides of the Tocilelor Brook, the righthandside of the Sadul and of the Sibiel (Sibiu Depression); small areas on the lefthandside of the Dobârca, Gârbova and Reciu valleys downstream of the homonymous settlements, and Răhău (Apold Depression).

Much of the Sibiu-Apold depressionary passageway is *risk-free* in the lower parts of the depressions: floodplains and terraces with stable grounds, declivity around 2° (excepting the fixed terrace scarps: 5-15°), relief energy 5-10 m. Risk-free areas cover 39.6% in the Apold Depression, 23.8% in the Săliște Depression and 53.3% in the Sibiu Depression. The map of geomorphological risk also presents channels at moderate risk of overflowing during floodwaves: the Secașul Mare and its lefthandside tributaries - the Aciliu, Apold, Dobârca and Călnic (Apold Depression); the Săliște and its tributaries - the Sibiel, Pârâul Vale and Cerna Vodă (Săliște Depression); the Seviș, Cisnădie and Sadu (Sibiu Depression) (Fig. 5).

At moderate risk from overflowing is the Cibin between Veștem and Tălmăciu settlements. An important role in preventing and diminishing floodwaves on the Cibin has Gura Râului reservoir (on the river) commissioned in 1980, as well as the draining system that covers 2,300 hectares between the settlements of Șura Mare and Ruscior. It would be advisable to have a similar draining system in the Secașul Mare floodplain (Cunța-Cut segment) where the underground water sheet lies close to the surface (-0.4-0.5 m) and the thin stratum of clay favours water stagnation. Draining would also eliminate gleization of the soil.

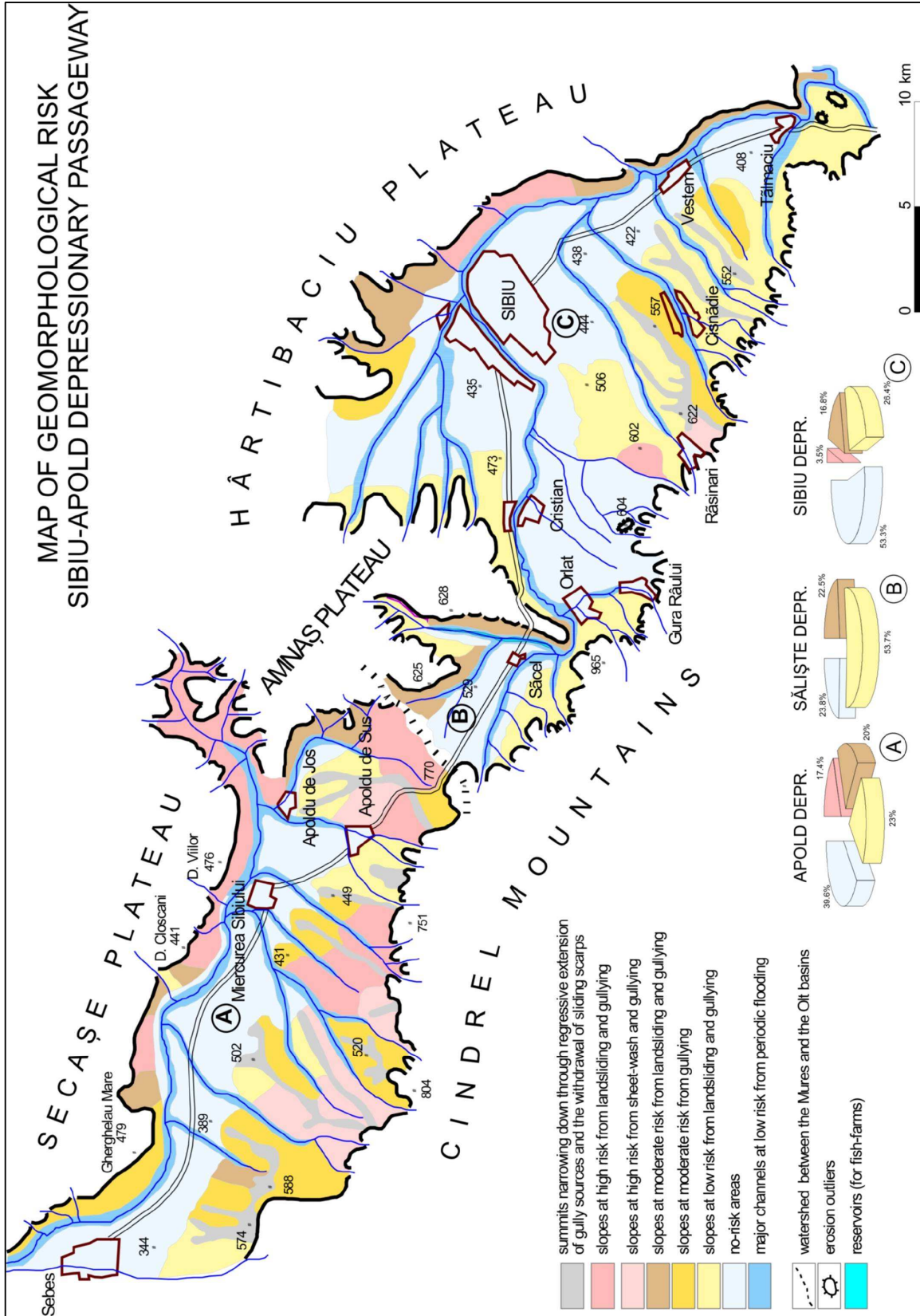


Fig. 5. Map of geomorphological risk. Sibiu-Apold depressionary passageway

Conclusions

The present-day modelling of the study area is a complex process begun in the Pleistocene and continued through the Quaternary to the present. Modelling processes are not isolated, they are associated with similar or different categories of processes. Slopes, for example, undergo several types of mass movements and erosion processes, differing in space or time. It is fairly difficult to say precisely which of these processes have been fundamentally involved in the modelling of slopes. However, in the present stage of relief evolution landslides associated with gullying are the main processes that maintain a permanent state of

imbalance on slope. In general, they are triggered by extreme precipitation and human activity.

Given the specific morphodynamic evolution, as well as the intensity and extension of imbalanced areas, a map of geomorphological risk, based on some characteristic parameters, has been drawn up, with highlight on high, moderate and low risk zones. They relate to the graded complexity of the slope processes studied and the affected area (together with its structure-controlled substrate).

Taking effective measures for a more appropriate use of the land (by observing its characteristic features), simultaneously with improving and protecting the environment, means conducting further investigations by methods and techniques which, so far, are not available to us.

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