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RELIEF DEVELOPMENT OF THE SLOVAK WESTERN CARPATHIANS IN SPACE AND TIME

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The Western Carpathians formed as a result of a collision of the NW projection of the Apulian microcontinent with the margin of the European platform. This collision took place during several stages which can be distinguished in the sedimentary record as well as in the erosional history. As a result of the collisional development an important continental period started during the Cretaceous in the Western Carpathians. The collisional development during the Neogene caused not only horizontal and vertical movements, but also rotation of blocks. The maxima of sedimentation rate in molasse basins migrated not only in time but also in space. The formation of extensive synchronal levelled surfaces in source areas of the outer, inner and back molasse appears to be in contradiction to the conception of dynamic evolution in the Western Carpathians.

Key words: Western Carpathians, relief development, Mesozoic, Kenozoic, paleoclimate

1 INTRODUCTION

The Western Carpathians are an important element of the Alpine-Himalayan mountain systen of Central Europe. They begin at the Rába tectonic line, on the right bank of the river Danube in Austria. Their elliptical arch, representing a continuation of the Northern Calcareous Alps, extends eastwards across the territory of Slovakia,

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where their core is situated and further to Moravia, Poland and Hungary. In the East the Western Carpathians end in the valley of the river Uh (cf. Maheľ 1986).

The division into lower taxonomic units used at present is either twofold (older) - Outer and Inner Western Carpathians, or threefold (newer) - Outer, Central and Inner Western Carpathians. The Outer (northern) Western Carpathians are called Polonides, Central (middle) Slovakides and Inner Pannonides (Maheľ 1986, p. 32). The differences between the Polonides, Slovakides and Pannonides and their reliefs, are mainly the result of their different paleotectonic and paleogeomorphologic development (Fig. 1).

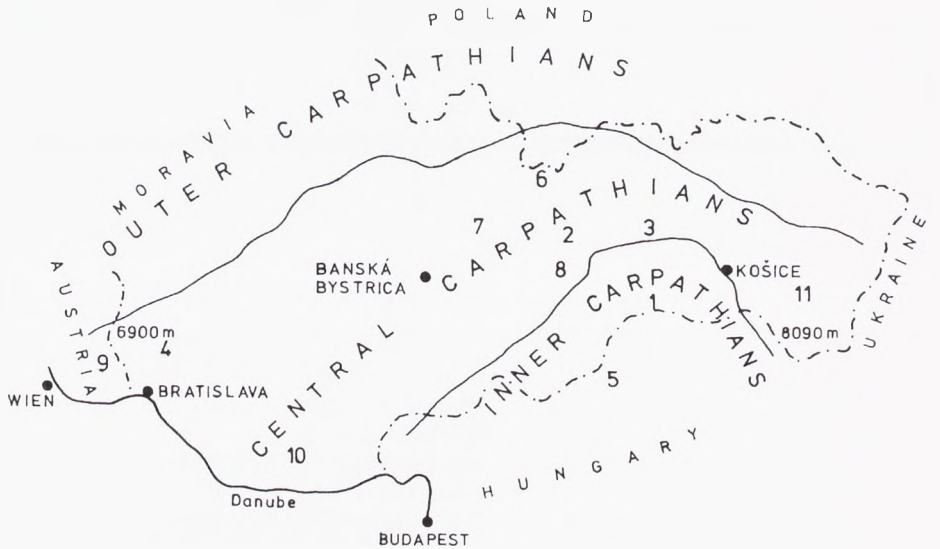

Fig. 1. The Outer, Central and Inner Western Carpathians and location of the mentioned units. 1 - Slovak Karst, 2 - Muráň Plateau, 3 - Slovenský Raj plateaux, 4 - Malé Karpaty Mts., 5 - Bükk Mts., 6 - Vysoké Tatry Mts., 7 - Nízke Tatry Mts., 8 - Slovenské rudohorie Mts., 9 - Vienna Basin, 10 - Danube Basin, 6900 m, 8090 m - thickness of molasse sediments.

2 SPATIAL AND TEMPORAL ASPECTS OF THE RELIEF EVOLUTION

Paleogeographical and tectonic syntheses about the European Alpides - and within them also about the Western Carpathians - accept important horizontal movements of lithospherical plates or microcontinents (Maheľ 1978, Roth 1980, Michalík and Kováč 1982). The Western Carpathians formed as a result of a collision between the NW margin of the Apulian microcontinent, the Alpine-Carpathian shelf fragment and the European platform margin (Michalík and Kováč 1982, Michalík and Činčura 1991). It is assumed that spatial changes, caused by horizontal movement of the European Alpides - and together with them also the Western Carpathians - affected the evolution and changes of the paleoclimate during the Alpine stage (Činčura 1987, 1988). This is so, especially because during a considerable part of the Alpine stage,

the horizontal movement took place in a meridional direction. The generally accepted northward trend of movement of the Western Carpathian space, beginning approximately in the Middle Cretaceous, was the result of pressures due to the above mentioned convergence of the Apulian microcontinent and the European platform.

There are several opinions concerning the width of the Western Carpathian space especially in the period preceding the Middle Cretaceous. Maheľ (1979) assumes a width of 500 km, Krs and Roth (1979), on the basis of paleomagnetic data, estimated the total width of the Western Carpathian space at 1200-1300 km.

The collision of the Apulian microcontinent and the European platform occurred in several phases. The main phases of the collision were, from the geomorphological viewpoint, very important periods, since they represented significant periods of continental evolution, or geocratic periods, in contrast to thalassocratic periods, when marine sedimentation prevailed in the Western Carpathian space.

The most important phases of the collision of the approx. 250 Ma long Alpine stage were:

1. The Early Kimmerian stage which began approx. 200 Ma ago, on the boundary between the Upper Triassic and Lower Jurassic;

2. The Paleoalpine stage, which began approx. 100 Ma ago, roughly during the Middle Cretaceous;

3. The Savian-Styrian, or early Lower Miocene stage, which began approx. 20 Ma ago.

3 THE OLDEST WESTERN CARPATHIAN PALEORELIEFS OF THE ALPINE STAGE

The oldest Western Carpathian paleoreliefs of the Alpine stage are older than the oldest - Early Kimmerian stage of collision. They are not present in the recent Western Carpathian relief, however, they can be reconstructed from the sedimentary record. We shall briefly mention two of them.

1. Lower Triassic quartzites (approx. 240 Ma) are characterized by unrounded grains and unsorted material, indicating short transport. At present, they are interpreted as deposits of ephemeral streams of a piedmont lowland (Mišík 1978). The sedimentation took place in a braided aluvial system. Coarser material probably has its origin in redeposited debris. Well-rounded grains occur sporadically as well, probably representing the remnants of eolian sands of the piedmont lowland. Sedimentation of the Lower Triassic quartzites took place under semiarid climatic condnitions.

2. The Central and Inner Carpathian carbonate complexes of Middle and Upper Triassic were sedimented in a relatively monotonous shelf environment, extending over a large area (Michalík 1993). The Middle Triassic Gutenstein limestones and dolomites also represent a relief type which has been preserved only in the sedimentary record. They are sediments of extensive shallows of the Bahama platform type, with considerable areas exposed at low tide. Hypersaline conditions existed on the surface of more permanently exposed islands. This is documented in the sedimentary record by the occurrence of pseudomorphs after anhydrite or gypsum crystals (Mišík 1978), which can be regarded as indicators of aridity in the environment.

The paleogeomorphological conditions in the period of the formation of the Gutenstein limestones and dolomites were probably analogous to recent conditions in the Carribean, or Persian Gulf regions, where the sebkhas form extensive arid or semiarid coastal plains.

4 EVOLUTION OF RELIEF DURING THE EARLY KIMMERIAN PHASE

The Early Kimmerian emergence and terrestrial development in the Western Carpathian space occurred at the boundary of the Upper Triassic and Lower Jurassic. The duration of this important terrestrial phase can be estimated on the basis of data from various locations at approx. 10-15 Ma. Early Kimmerian morphological forms are not present in recent relief. They can be reconstructed from the sedimentary record.

After sedimentation on carbonate platforms, on which various types of limestones and dolomites sedimented, especially during the Middle and partly during the Upper Triassic, several units of the Western Carpathians emerged and marine sedimentation was interrupted during the Upper Triassic. Terrestrial development also frequently continued during the Lower Jurassic. Younger Jurassic sediments of marine origin are therefore lying unconformably on the underlying beds.

In the Slovak Karst region, limestones and basal breccias of Middle Liassic age form the filling of various irregularities of the Upper Triassic paleorelief, or they fill deeper fissures of the basement.

On the Muráň Plateau, Upper Triassic sedimentation took place in a lagoonal environment. The cycles ended in the Dachstein limestone with short emergences (Borza 1977). Red marly galls in Dachstein limestones are probably products of terrestrial weathering.

In the Slovenský raj region, a formation of slates and limestones of Liassic age lies unconformably above the limestone-dolomite complex. The presence of detrital quartz and fine organic detritus indicates an interruption of the marine sedimentation.

In the Malé Karpaty Mts., it is possible to observe - in an inverted sequence of strata (Plašienka et al. 1991) - how brecciated limestones of Middle Liassic age penetrate deep into underlying Triassic limestones and fill various depressions in them (Fig. 2).

All the above facts indicate that the reaction to the Early Kimmerian collision was uplift of the carbonate platform. The Western Carpathian relief started to develop on the surface of the exposed complexes of limestones and dolomites (Činčura 1992).

We can assume that the climate during the development of the oldest hitherto known karst relief in the Upper Triassic - Lower Liassic was subtropical, with signs of cyclicity (Michalík 1978).

5 EVOLUTION OF THE RELIEF DURING THE PALEOALPINE PHASE

The Paleoalpine emergence as well as the subsequent terrestrial development, were the results of a collision phase during approximately the Middle Cretaceous.

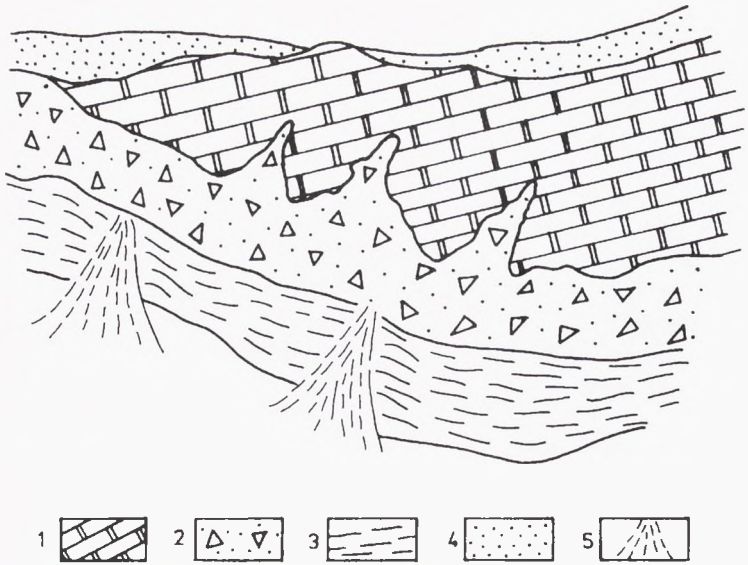

Fig. 2. Schematic picture of the Early Kimmerian karst in an inverted strata sequence, Malé Karpaty Mts. 1 - limestones, dolomites, Middle Triassic, 2 - brecciated limestones, Lower Jurassic, 3 - limestones, shales, Middle Jurassic, 4 sands, sandstones, Miocene, 5 - debris (modified, after Plašienka et al. 1991).

The onset of terrestrial development, however, was not simultaneous in the whole Western Carpathian space. The unequal duration of the Paleoalpine emergence is a result of this. Marine sedimentation in the Bükk Mts. was interrupted in the Berriasian (approx. 140 Ma) and a new transgression took place only during the Priabonian (approx. 40 Ma) (Rakús et al. 1989). The period between the Berriasian and Priabonian belonged in the Bükk Mts. to the Paleoalpine emergence. The maximal length of terrestrial evolution caused by the Paleoalpine collision known up to now varies in the Slovak Western Carpathians by about 110 Ma (Činčura 1993, Činčura and Köhler 1995, Činčura 1998 a, b).

In the Western Carpathian space the Paleoalpine collision led to stabilization, or reconsolidation. The result of these processes was the formation of the basement of the Paleoalpine quasi-platform on the surface of which the Paleoalpine relief developed.

The development of Paleoalpine relief on the basement was controlled by climatic and tectonic factors. At the beginning of the Paleoalpine emergence the Western Carpathian space lay in the subequatorial, or tropical zone (Činčura 1987, 1988). The climate was characterized by high average annual temperatures and only small temperature variations during the year. Summer monsoons brought abundant precipitation not only to the southern margins of the European platform, but also to the Western Carpathian space, represented by the basement, lying in the northern part of the Tethys ocean. Changed pressure during the winter caused dry air masses to flow from the European platform above the basement to the ocean.

In the above mentioned climatic conditions, the surface of the basement was exposed to intensive weathering processes - confirmed by sedimentology and paleontology (Činčura 1987, 1988, Snopková 1990). The weathering products were above all kaolinite and kaolinite-montmorillonite weathering crusts; bauxites or ferricrust formed at several places as well (Činčura 1998a, b).

From a geomorphological viewpoint it is an interesting question, whether a mountain range in the morphological meaning of the word formed on the basement during the Paleoalpine emergence. This would mean a convex unit with mountainous relief, separated from the adjoining lower parts by substantial foothills. This question can be at least partly answered on the basis of an analysis of the Upper Cretaceous sediments of the basement.

The formation of mountainous relief due to uplift of the territory and subsequent division of the mountain range, especially due to the activities of consequent flows, is accompanied by the formation of a large quantity of molasses in the foreland of the forming mountain range. In the Western Carpathian space sedimentation during the Middle Cretaceous - Paleoalpine collision, is characterized predominantly by flysch, molasses are scarce. At the same time, there are early molasses, indicating an extremely low sedimentation rate - 0.14 cm/100 years (Vass and Čech 1983). These are the lowest values of molasse sedimentation in the Western Carpathians, which is obvious from a comparison of the sedimentation rate of early molasse with molasses of the orogenic stage. These facts indicate rather that a mountain range did not form during the Paleoalpine emergence in the Western Carpathian space.

The most widerspread surficial forms, formed during the Paleoalpine period, existing in the present relief are paleokarst plateaux (Činčura 1993). Their surface has the character of an undulating plain or hillyland. A wide range of karst forms occurs on the surface of these paleokarst plateaux, from which some belong to the Paleoalpine period, while others are younger (Fig.3).

The Paleoalpine age of the paleokarst plateaux is shown by relatively frequent remnants of Paleogene sediments on the surface of the plateaux, indicating that these are frequently exhumed forms.

The most important and longest phase of terrestrial evolution of the Alpine stage in the Western Carpathians ended with the transgression of the Paleogene sea, which inundated extensive parts of the basement and thus concluded the Paleoalpine quasi-platform development.

6 EVOLUTION OF RELIEF DURING THE SAVIAN-STYRIAN PHASE

The Savian-Styrian collision phase, the beginning of which is dated to the Lower Miocene (approx. 20 Ma ago), caused gradual emergence of the Western Carpathian space. It brought about the end of the Oligocene-Miocene marine regime. Eggenburgian dry land from the early phases of the emergence was located mostly in the present Vysoké Tatry Mts., Nízke Tatry Mts., Slovenské rudohorie Mts. and Podunajská nížina lowland (Kováč et al. 1989). The later - Karpatian, Badenian and Sarmatian (17.5-11 Ma) - dry land developed progressively. Sedimentation areas with marine or brackish regime remained practically only in the present Podunajská and Východoslovenská nížina lowlands. The sea intruded into the intensively elevating Western Carpathian space only as bays. The predecessors of the present main

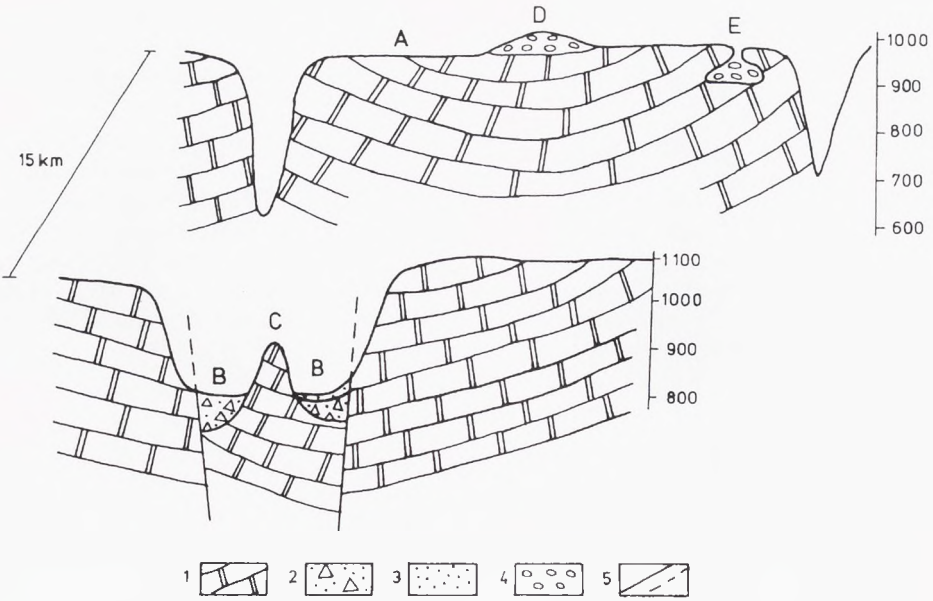

Fig. 3. Paleoalpine karst in Slovenský Raj, schematic profile of two paleokarst plateaux. 1 - limestones, Middle and Upper Triassic, 2 - breccias, Upper Cretaceous, 3 - freshwater limestones, Middle-Upper Cretaceous, 4 - basal transgressive lithofacies, Paleogene, 5 - faults, A - paleokrast plateau, B - ? paleopolje, C - mogote, D - remnants of Paleogene sediments, E - cave.

rivers flowed in to these bays, mostly following subsequent depresions at the beginning of the Savian-Styrian emergence.

As well as vertical movements, forming height unevennesses in the Western Carpathian space, the Savian-Styrian collision also caused horizontal movements and block rotations (Kováč et al. 1989). A reaction of the collision development was intensive molasse sedimentation of the main (Eggenburgian? 22 - Sarmatian 11 Ma) and the late (Pannonian 11 Ma- Quaternary) molasse (Vass 1989). In the Western Carpathians the main molasse is characterized by considerable thicknesses of clastic sediments. The sediments of the main molasse are 6900 m thick in the Vienna Basin and 8090 m thick in the East Slovak Basin (Vass l. c.). Huge masses of clastic sediments indicate mountainous relief in the source areas of the main molasses, as well as considerable erosion effects during the Savian-Styrian emergence phase (Fig. 4).

It can be assumed that in the early phases of the Savian-Styrian emergence, sandstone and claystone formations covering the Paleoalpine basement of the quasi-platform were eroded. The beginnings of the formation of the present epigenetic valleys also belong to this time. The process of exhumation of Paleoalpine relief also continued in many places during the Karpatian (17.5-16.5 Ma), this is shown by basal conglomerates of the Karpatian frequently containing blocks of Paleogene rocks. It was not only exhumation that took place on elevated blocks, but also

rejuvenation of forms, or their destruction. A system of consequent valleys as well as the first signs of antecedence were forming. Gradual erosion led not only to removal of the less resistant beds of Paleogene age, but also to exposure of the granitoid cores of the mountains.

From the geomorphological viewpoint it is important information that the sedimentation rates of the main molasses were not synchronal in the Western Carpathian space. The sedimentation rate culminated in the Vienna Basin in the Karpatian (17.5-16.5 Ma), in the Danube Basin during the Badenian (16.5-13.6 Ma) (Vass 1989). The sedimentation rates of the main molasses not only migrated in the West-East, but also in the South-North direction. These facts indicate that in the source areas of the molasses the relief of the elevating Western Carpathians formed dynamically during the Karpatian to Sarmatian and probably later as well.

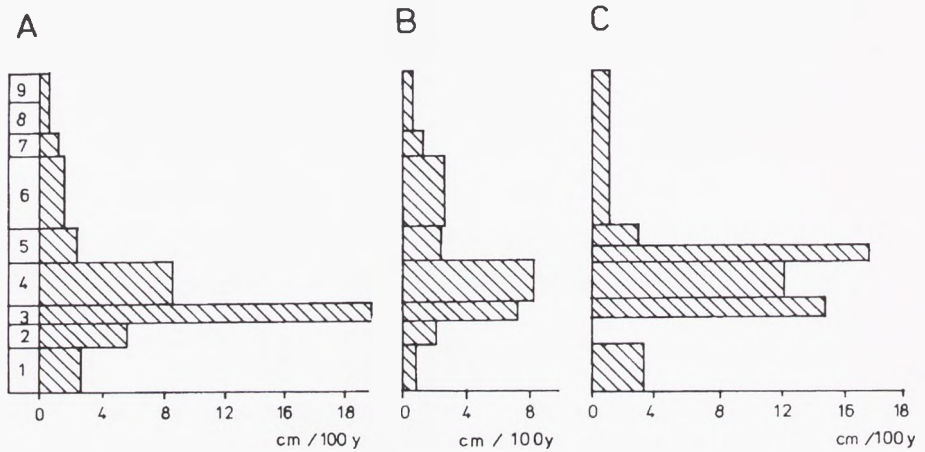

Fig. 4. Sedimentation rate in Neogene basins of the Western Carpathianas (after Vass 1989). 1 - Eggenburgian, 2 - Ottnangian, 3 - Karpatian, 4 - Badenian, 5 - Sarmatian, 6 - Pannonian, 7 - Pontian, 8 - Dacian, 9 - Rumanian. A - Vienna Basin, B - Danube Basin, C - East Slovak Basin.

On the basis of the above facts, it is not very probable that during the period of the main molasses, but to a certain extent also of the late molasses, regionally widerspead levelled surfaces of the same age would have developed on all Western Carpathian territory.

The development of the relief was also affected by the climatic conditions of the Savian-Styrian emergence. Gradual cooling is assumed to have occurred during the Neogene, the climate changing gradually from subtropical Mediterranean to cooler subtropical in the main molasse period, and ultimately cooling to the temperate climate of the late molasse (Planderová 1978). The evaluation on the basis of pollen spectra is not quite consistent with interpretations of climate obtained from sedimentological data (Činčura 1970, Kraus 1989). Besides marked arid variations during the Miocene, indicated by occurrences of salts, gypsum and anhydrite, the character of

weathering during the Pannonian and especially the Pontian, with kaolinite clays of the Poltár Formation (approx. 7-6 Ma), indicates a humid subtropical rather than a temperate climatic zone.

The Savian-Styrian collision is also closely connected with volcanic activity, culminating in the main molasse formation period (Vass 1989). The most marked forms of volcanic relief are desintegrated stratovolcanos, volcanic plains, necks, volcanic bodies and remnants of lava flows.

The interference of climate and tectonics, led to the formation of the glacial relief of the highest mountains during the Pleistocene, as well as river terraces in basins, indicating erosion during this period exceeding 100 m, and in the lowlands above all loess covers and eolic sands accompanied by fluvial forms.

7 CONCLUSION

Significant periods of terrestrial development during the Alpine stage - the Early Kimmerian, Paleoalpine and Savian-Styrian - were connected with the main collision phases of the Apulian microcontinent with the European platform. The oldest reliefs of the Alpine stage - reconstructed from the sedimentary record - are of Triassic age (piedmont lowlands of semiarid zone, coastal plains of the sebkha type of arid zone, karst of semiarid zone).

The oldest morphological forms which can be observed in the present relief developed during the Paleoalpine emergence in the Cretaceous. Since extensive regions were formed by limestones and dolomites, the dominant forms of this period were karst forms, which developed in conditions of subequatorial or monsoonal climate.

The Savian-Styrian emergence was a period of time, during which the Western Carpathian relief acquired features of its present appearance. It is not very probable that during this period regionally widerspread levelled surfaces of the same age would have developed on all Western Carpathian territory. At the same time it is necessary to note that numerous features of the Western Carpathian Paleoalpine relief were not destroyed during this phase.

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Juraj Činčura

VÝVOJ RELIÉFU SLOVENSKÝCH ZÁPADNÝCH KARPÁT V PRIESTORE A ČASE

Paleogeografické a tektonické syntézy o európskych alpidách a v rámci nich aj o Západných Karpatoch, akceptujú významné horizontálne pohyby litosferických mikroplatní, resp. mikrokontinentov. Západné Karpaty sa vytvorili ako dôsledok kolízie medzi SZ okrajom apúlskeho mikrokontinentu a alpsko-karpatského fragmentu šelfu a okrajom európskej platformy. Kolízia sa odohrala počas viacerých fáz, pričom jej hlavné fázy boli z geomorfologického aspektu významnými obdobiami, pretože reprezentovali signifikantné periódy suchozemského, resp. geokratického vývoja, na rozdiel od thalasokratických období, kedy v západokarpatskom priestore prevládala morská sedimentácia.

VÝVOJ RELIÉFU POČAS STAROKIMÉRSKEJ KOLÍZNEJ FÁZY

Trvanie tejto významnej fázy terestrického vývoja možno na základe rôznych údajov odhadnúť na asi 10-15 miliónov rokov. Starokimérske morfologické formy nie sú prítomné v dnešnom reliéfe, dajú sa rekonštruovať zo sedimentárneho záznamu. Po sedimentácii na karbonátových platformách, na ktorých sa usadili rozličné typy vápencov a dolomitov, došlo vo viacerých jednotkách Západných Karpát počas vrchného triasu k vynoreniu a prerušeniu sedimentácie. Suchozemský vývoj pokračoval aj počas spodnej jury. Popri viacerých príkladoch možno v Malých Karpatoch sledovať - v prevrátenom vrstvenom slede - ako brekciovité vápence spodnojurského veku prenikajú hlboko do podložných triasových vápencov a vypĺňajú v nich rozličné depresie. Ide doteraz o najstaršie známe krasové formy alpínskej epochy v Západných Karpatoch.

VÝVOJ RELIÉFU POČAS PALEOALPÍNSKEJ KOLÍZNEJ FÁZY

Paleoalpínske vynorenie, ako aj nasledujúci terestrický vývoj boli výsledkom kolíznej fázy zhruba počas strednej kriedy. Doteraz maximálna dĺžka trvania suchozemského vývoja je asi 110 miliónov rokov. Vývoj paleoalpínskeho reliéfu na fundamente kontrolovali klimatické a tektonické faktory. Západokarpatský priestor sa počas paleoalpínskeho vynorenia nachádzal v subekvatoriálnom, resp. tropickom pásme. Klímu charakterizovali vysoké priemerné ročné teploty a letné monzúny prinášali dostatok vlahy. Na fundamente prebiehalo intenzívne zvetrávanie, jeho produktom boli kaolinické a kaolinicko-montmorilonitické kôry zvetrávania a krasové bauxity. Najrozšírenejšími povrchovými formami v dnešnom reliéfe, ktoré sa začali vytvárať počas paleoalpínskeho obdobia, sú paleokrasové plošiny. Na ich povrchu je prítomná široká škála krasových foriem, z ktorých časť patrí paleoalpínskemu obdobiu a časť je mladšia. Najvýznamnejšiu a najdlhšiu fázu suchozemského vývoja v západokarpatskom priestore ukončila transgresia palaeogénneho mora, ktorá zavŕšila vývoj palaeoalpínskeho reliéfu.

VÝVOJ RELIÉFU POČAS SAVSKO-ŠTAJERSKEJ KOLÍZNEJ FÁZY

Eggenburská súš z počiatočných fáz emerzie sa sústreďovala najmä na dnešnú vysokotatranskú, nízkotatranskú, rudohorskú a podunajskú časť Západných Karpát. Neskôr, počas karpatu, bádenu a

sarmatu, sa progresívne vyvíjala. Odrazom kolízneho vývoja bola intenzívna molasová sedimentácia hlavnej a neskorej molasy. Obrovské nakopenia klastických sedimentov indikujú horský reliéf v zdrojových oblastiach hlavných molás, ako aj značný erózny a denudačný efekt. Z geomorfologického aspektu je dôležitý poznatok, že rýchlosť sedimentácie hlavných molás nebola v západokarpatskom priestore synchrónna. Vo Viedenskej panve kulminovala rýchlosť v karpate, v Podunajskej počas bádenu a na východnom Slovensku v spodnom sarmate. Migrácia rýchlostí neprebiehala iba v západovýchodnom, ale aj v severojužnom smere. Na základe tejto skutočnosti sa ťažko dá očakávať, že počas obdobia formovania hlavných molás, ale do istej miery aj molás neskorých, by sa v celom západokarpatskom priestore vyvíjali regionálne rozšírené povrchy zarovnania rovnakého veku.

Významné obdobia suchozemského vývoja počas alpínskej epochy zanechali nielen v sedimentárnom zázname, ale aj v dnešnom reliéfe výrazné stopy. Savsko-štajerská emerzia bola obdobím, počas ktorého západokarpatský reliéf nadobudol súčasné rysy. Zároveň však treba konštatovať, že počas tohto obdobia sa nezotreli početné črty paleoalpínskeho reliéfu.

Obr. 1. Vonkajšie, centrálne a vnútorné Západné Karpaty a lokalizácia jednotlivých celkov. 1 - Slovenský kras, 2 - Muránska planina, 3 - Slovenský raj, 4 - Malé Karpaty, 5 - Bükk, 6 - Vysoké Tatry, 7 - Nízke Tatry, 8 - Slovenské rudohorie, 9 - Viedenská panva, 10 - Podunajská panva, 11 - Východoslovenská panva, 6 900 m, 8 090 m - hrúbka molasových sedimentov.

Obr. 2. Ranokimerský kras v prevrátenom vrstevnom slede, Malé Karpaty. 1 - vápence, dolomity, stredný trias, 2 - brekciovité vápence, spodná jura, 3 - vápence, bridlice, stredná jura, 4 - piesky, pieskovce, miocén, 5 - sutina.

Obr. 3. Paleoalpínsky kras v Slovenskom raji, schematický profil dvoma paleokrasovými plošinami, 1 - vápence, stredný a vrchný trias, 2 - suchozemské brekcie, vrchná krieda, 3 - sladkovodné vápence, vrchná krieda, 4 - bazálna transgresívna litofácia, paleogén, 5 - zlomy, A - paleokrasová plošina, B - ? palaepolje, C - mogot, D - zvyšky paleogénnych sedimentov, E - jaskyňa.

Obr. 4. Rýchlosť sedimentácie v neogénnych panvách Západných Karpát (podľa Vassa 1989). 1 - egenburg, 2 - otnang, 3 - karpat, 4 - báden, 5 - sarmat, 6 - panón, 7 - pont, 8 - dák, 9 - ruman. A - Viedenská panva, 2 - Podunajská panva, 3 - Východoslovenská panva.