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PLATEAU PALEOKARST OF THE WESTERN CARPATHIANS

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Abstract: Plateau paleokarst is a typical feature of the Mesozoic carbonate sequences of the Western Carpathians. A series of paleokarst plateaux are formed, marked by more or less level surfaces. The paleokarst plateaux are divided from each other, by deep canyon like valleys. On the surface of plateaux and underground, a wide range of different karst forms and sediments are present. Typical plateau paleokarst was formed especially on carbonate rocks of the Middle and Upper Triassic ages, most notably on Wetterstein limestones, but also on Gutenstein, Steinalm, Tisovec and Furmanec limestones and dolomites. Plateau paleokarst was formed during the longest and most significant periods of karst formation in the Western Carpathians, which we identify as Paleo-Alpine. Its beginning may be roughly limited by the Lower? Cretaceous, and its end by the Eocene in the north, or the Oligo - Miocene in the south.

Key words: Western Carpathians, Cretaceous, Paleogene, Paleo-Alpine karst period, plateau paleokarst, exhumed and relict forms.

In spite of the fact that plateau paleokarst is a significant feature of the Mesozoic carbonate sequences of the Western Carpathians, appropriate attention has not so far been devoted to this phenomenon, especially in relation to structure, lithology, paleotectonics and paleoclimate. As a result, information about the plateau paleokarst of the Western Carpathians is more than unsatisfactory. The role of this paper is to contribute to increasing knowledge of this phenomenon, partly on the basis of analysis of already existing information, and partly by new views on the problems of plateau paleokarst.

A general outline of plateau paleokarst

Plateau paleokarst is formed on a series of paleokarst plateaux, divided from each other by deep canyon like valleys. Its most significant external feature is more or less level surfaces, which have the character of undulating plains, low hill country, or are more divided. On the surface of paleokarst plateaux, a wide range of karst forms are present, especially different types of grikes and sinkholes, and sometimes valley sinks and inselbergs. Below the surface of plateau paleokarst, various types of cave or chasm are a not uncommon phenomenon.

Typical plateau paleokarst occurs on the carbonate complexes of Middle and Upper Triassic age in the Inner and Central Western Carpathians. It is most notably developed on the Wetterstein limestones, but also formed on the Gutenstein limestones and dolomites, Steinalm, Tisovec and Furmanec limestones.

Typical plateau paleokarst does not occur in the Outer Western Carpathians. Its absence on the surface is a result not only of lithology, a lack of extensive carbonate complexes in comparison with the inner zones of the Western Carpathians, but above all of a diametrical difference in paleogeographical and paleotectonic development, between the Outer Western Carpathians on the one hand, and the inner and central zones on the other.

While the occurrence of plateau paleokarst in various basic zones of the Western Carpathians (Slanicum, Gemericum, Tatricum) is a result of paleotectonic development, the position of paleokarst plateaux at different heights above sea level is a result of neotectonic development.

The most typical and most extensive in area of the paleokarst plateaux occur in the Slovak Karst, on the Muránska Planina, Slovenský Raj Mts., and in Galmus. Plateau forms of paleokarst origin in some of the core mountain ranges are less notable.

The central or inner Carpathian sequences of Middle Triassic age, on which plateau paleokarst developed, were deposited in a relatively monotonous shelf environment. The monotony of this sedimentary environment extending over a huge area, was a result of deep denudation and leveling of relief during a significant period of peneplanization in the final phases of the Variscan tectogenesis.

In contrast to the limestones and dolomites of Middle and Upper Triassic age, Jurassic units occur to a much less extent. They mostly lie discordantly on underlying deposits. They often form the fill of deep hollows in the underlying rocks, or follow the unevenness of the Upper Triassic paleorelief.

It may generally be stated, that sedimentation ended earlier in the southern units of the Western Carpathians, than in those situated further north, in the Meliata unit in the Callovian, in the Silica Nappe in the Tithonian, in Choč Nappe in the Aptian, and in the Krížňa Nappe in the Cenomanian (Rakús et al. 1990). Therefore it may be supposed, that a significant part of the carbonate complexes of Middle and Upper Triassic age were already exposed to subaerial destruction before the chief Middle Cretaceous folding.

We consider the regional extent of the subaerial development of the the Inner and Central Western Carpathians to be a reflection of the Paleo-Alpine collision of the Apulian microcontinent with the margin of the European Platform. The temporary consolidation and origin of the basement of a quasi-platform was a result of this process (Činčura 1988). Not only numerous occurrences of pollen of Upper Cretaceous age washed into younger sequences (Snopková 1990), but also the fresh water limestones

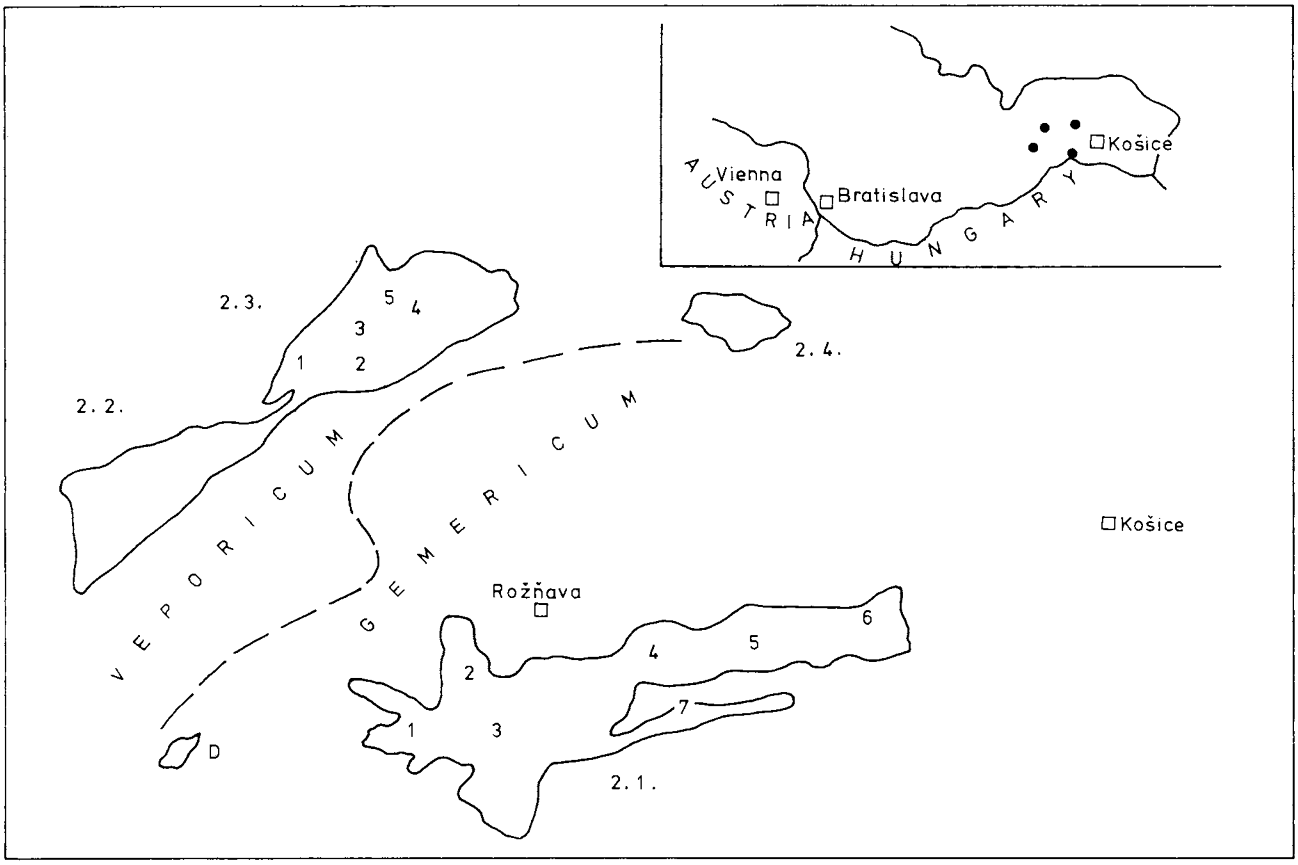

Fig. 1. Areas of plateau paleokarst: *Slovak Karst*: 1 - Koniar, 2 - Plešivec Plateau, 3 - Silica Plateau, 4 - Horný vrch Plateau, 5 - Zádiel Plateau, 6 - Jasov Plateau; *Slovenský Raj Mts.*: 1 - Duča, 2 - Pelc, 3 - Havrania skala, 4 - Geravy, 5 - Glac; *Galmus*, D - Drienčany karst.

of Turonian - Coniacian age known from various localities (Bystrický 1978; Mišík & Sýkora 1980) bear witness to the extent of dry land in the Inner and Central Western Carpathians, especially during the Upper Cretaceous.

The regional extent of plateau paleokarst

We will be concerned above all with further details of the characteristics of the plateau paleokarst in the places of its most typical occurrence, that is in the Slovak Karst, on the Muránska Planina, in Slovenský Raj Mts., and in Galmus.

The Slovak Karst

Extensive level plateaux are a characteristic feature of the Slovak Karst (Silica, Plešivec, Koniar and others, Fig. 1). A general slope towards the south is characteristic, with their surface falling from a height of about 800 m above sea level, to a height of about 400 m. Isolated inselbergs rise from the leveled surface (e.g. Plešivec Plateau, Koniar).

The area of the Slovak Karst, including the Aggtelek Plateau in Hungary is formed by the Silica Nappe. It was above all the limestone-dolomite complex of the Middle and Upper Triassic age which shared in the formation of the Silica Nappe. Wetterstein limestones are most significant, but Gutenstein limestones and dolomites, Steinalm and Tisovec limestones are also present. Jurassic members are only of secondary importance. Limestones and basal breccias of Middle Liassic age form the filling of various hollows in the Upper Triassic paleorelief, or the fill of deeper holes in the underlying rocks. The discordant deposition of the Jurassic members indicates the probable presence of a karst phase in the Slovak Karst, before their deposition, which we identify as Late Cimmerian.

Up to now the oldest example of karst processes in the Slovak Karst, was thought to be the karst pocket in Gombasek quarry, filled with alochthonous sediments (Fig. 2), which contains pollen of Upper Cretaceous age (Mello & Snopková 1973). The end of marine sedimentation in the Silica Nappe, probably during the Tithonian (Rakús et al. 1990), indicates that Paleo-Alpine karst processes could have occurred already during the Middle (Lower?) Cretaceous. Views about the Cretaceous age of the karst in Aggtelek (Jakucs 1977; Bárdossy & Kordos 1989) are in harmony with this idea.

We consider the period of subaerial development, which began in the Silica Nappe after the end of marine sedimentation in the Tithonian, to be very significant from the point of view of the formation of the basic features of the plateau paleokarst in the Slovak Karst. We attribute to this period the origin of the basic features of paleokarst, leveled surfaces and inselbergs, in the carbonate complex of the Silica Nappe.

The occurrence of bauxite iron ore on the surface of the Silica Plateau indicates the relict character of the plateau paleokarst in the Slovak Karst (Borza & Pospíšil 1959). Above all, pizolithic bauxite iron ore forms the fill of cracks in the Wetterstein limestones. Residual iron ores (Kováčik 1955), which have the character of ferricrete formed by haematite and magnetite lying on the surface of the Plešivec Plateau, or form the fill of karst cavities (Fig. 3).

Table 1: Characteristic features of plateau paleokarst.

	altitude	underlying limes./dolom.*	Late Kimmer. karst phase	Denudation remnants					Plateaux type		
				Cretaceous	Paleogene	Oligocene -Miocene	neovolcan.	residual Fe ores	mogotes inselbergs	exhumed	relict
Slovak Karst (Drienčany Karst)	400 - 800	+	+	+		+	+	+	+		+
Muránska Planina	1000	+	+		+		+	+		+	
Slovenský Raj Mts. N	1000	+	+		+					+	
Slovenský Raj Mts. S				+					+		+
Galmus	900	+			+				+	+	

*Middle-Upper Triassic

Subaerial development did not continue uninterrupted on the whole block of the Slovak Karst. Some blocks subsided during the Pyrenean phase, and there was a transgression of the sea onto the subsided blocks, during the Oligocene or Miocene. The paleokarst plateau of the Drienčany Karst represent such a block (Fig. 4). Remnants of shallow sea calcareous silts of Egerian age, and isolated overlapping volcanoclasts of Miocene age lie in the strata overlying the paleokarst (compare Gaál 1982; Vass et al. 1981).

Muránska Planina

Plateau paleokarst occurs only in part of the Muránska Planina. It lies at heights of around 1000 m above sea level. The Muránska Planina is mainly formed by the carbonate sequences of the Muráň Nappe. Wetterstein limestone make up the largest part of these. Upper Triassic sedimentation in the Muráň Nappe occurred in a lagoon environment, with cycles in the Dachstein limestones ending in brief emergences (Borza 1977). Red marly galls in the Dachstein limestones probably represent products of weathering. The Jurassic members, especially dark heavy bedded and platy limestones, which contain a clastic admixture, lie discordantly on the underlying rocks. The facts mentioned indicate, just as in the Slovak Karst, the probable presence of a Late Cimmerian karst phase, in the sequence of strata of the Muráň Nappe.

Fine grained gravels occur in many places on the surface of the paleokarst plateau. Their presence shows, that alochthonous streams of water flowed on the surface of the paleokarst. At that time, the present deep valleys, which divide the karst, still did not exist. In the gravel cover, pieces of vein quartz are most frequent, but metaquartzite is frequent, and iron ore, quartz sandstone, volcanic glass, pyroxenic andesite and paleorhyolite are also present (compare Mitter 1975). The majority of sources of fluvially transported material, can be found in the paleokarst itself, or its immediate surroundings. Vein quartz and metaquartzite may derive from the base of the Struženík unit, the paleorhyolites and their tuffs are found in the shale - sandstones at Malá Stožka (compare Mahel' 1986) in the western part of the Muránska Planina. Neovolcanites also occur in this district, from which the gravels of andesites and the volcanic glass originate. The pieces of quartz sandstone probably belong to the remnants of the basal transgressive lithofacies of Paleogene age, and the gravels of iron ore may represent fluvially worked remnants of fericrust.

Slovenský Raj Mts.

Glac, Geravy, Havrania Skala, Pelc and Duča are the most important paleokarst plateaux of Slovenský Raj (Fig. 1). Their plateau surfaces lie about 1000 m above sea level, and slope towards the north. In places, inselbergs occur above the leveled surface of the plateaux.

The plateau paleokarst of Slovenský Raj developed on a limestone-dolomite complex of Middle and Upper Triassic age, of the Stratenská sequence of the Besnícky Nappe (compare Mahel' 1986). Above all, Wetterstein limestones are present. With the exception of Geravy, Wetterstein limestones form all the plateaux of Slovenský Raj. Steinalm limestones form the sides of the paleokarst plateaux of Pelc and Duča (Tulis & Novotný 1989). The Geravy Plateau is mainly formed by Tisovec and Furmanec limestones of Upper Triassic age.

In the upper parts of Geravy and Lipovec, beds of dark shales and limestones of Liasic age discordantly overlie the limestone-dolomite complex. The presence of detritic quartz and fine organogennic detritus, indicates an interruption of sedimentation, before the deposition of the formation, and indicates the presence of the Late Cimmerian karst phase in Slovenský Raj Mts., just as in the Slovak Karst and Muránska Planina.

The presence of relicts of the basal transgressive lithofacies of Paleogene age on the surface of the paleokarst plateaux, especially in the northern parts of Slovenský Raj (e.g. Glac, Kláštorisko, Fig. 5), indicate that there is exhumed paleokarst from beneath sediments of the Inner Carpathian Paleogene.

Further facts also confirm the exhumation of paleokarst. In the Medvedia Jaskyňa cave system, which lies below the surface of the Glac paleokarst plateau, at the bottom of the Stĺpová passage in a dug hole (Janáčik & Schmidt 1965; Droppa 1977),

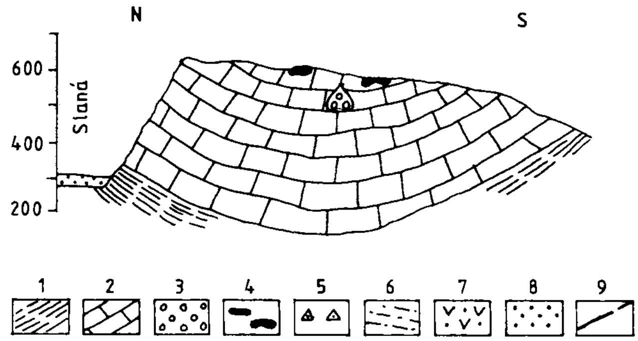

Fig. 2. Schematic profile of the Silica Plateau.

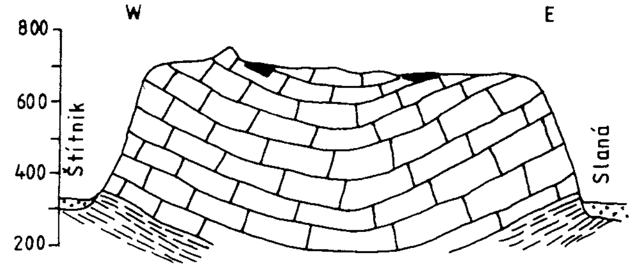

Fig. 3. Schematic profile of the Plešivec Plateau.

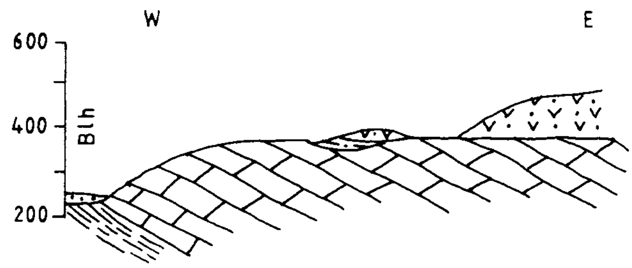

Fig. 4. Schematic profile of the Drienčany karst, (using the work of Gaál 1983).

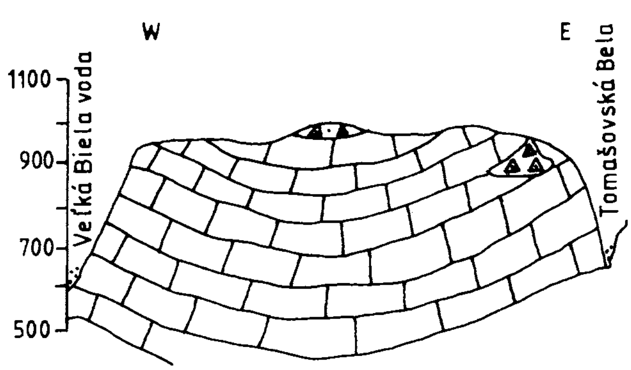

Fig. 5. Schematic profile of the Glac Plateau.

Legend to Figs. 2 - 6.
1 - shale-sandstone formation, Lower Triassic; 2 - limestone -dolomitic complex, mainly Wetterstein, but also Gutenstein, Steinalm, Tisovec and Furmanec limestones and dolomites, Middle and Upper Triassic; 3 - carbonate conglomerate, sandstones, mudstones, or fresh-water limestones, Upper Cretaceous; 4 - iron ores and bauxitic iron ores (?) Middle and Upper Cretaceous; 5 - conglomerates, sandstones, residual gravels, basal trangressive lithofacies, mainly Eocene; 6 - conglomerates, sandstones, clays, schliers, Egerian; 7 - volcanoclastics of andesite, Miocene.; 8 - aluvium, Quaternary; 9 - faults.

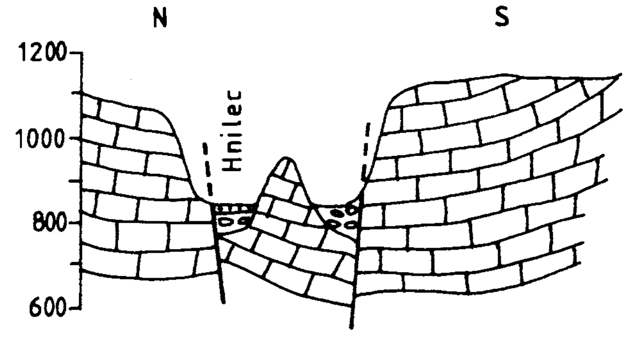

Fig. 6. Schematic profile of the paleokarst depression near the Dobšiná ice cave.

remnants of sediments of the basal transgressive lithofacies of Paleogene age are found. Further evidence of exhumation is the finding of karst hollows with fossil fill near the Novoveská Huta, underlying conglomerates of Paleogene age (compare Novotný 1987).

Galmus

In the northern part of the Slovenské rudohorie Mts., plateau paleokarst occurs in the morphologically individualized block of Galmus. The paleokarst plateau lies about 900 m above sea level. The basic part of the Galmus block is formed by Wetterstein limestones. The occurrence of conglomerates of the basal transgressive lithofacies of Paleogene age in the western part of the paleokarst plateau, overlying the Wetterstein limestones, indicates that it was a paleokarst plateau, which was exhumed from beneath Paleogene sediments.

The age of plateau paleokarst

Up to now, the paleokarst plateaux have been ascribed to the Pannonian (Slovak Karst: Mazúr et al. 1971; Jakál 1983, on Muránska Planina: Mitter 1975; Jakál 1983, in Slovenský Raj: Jakál 1983), or the Upper Pannonian - Pontian age (in Slovenský Raj: Tulis & Novotný 1989). Therefore it may be stated, that the above mentioned works consider paleokarst plateaux to be the products of Upper Miocene karst processes.

In attempts to determine the age of paleorelief is about the limitation of the time period, during which relief gained its basic features. Two limits, lower and upper, exist in the age of paleorelief, since there are usually various long periods of time, which may represent in length of duration, a stage in chronostratigraphic understanding, or even more than one stage. The lower means the beginning of subaerial formation of relief, and the upper, the end of subaerial modelling of relief. Basically the lower limit is most frequently identified with regression of the sea, and the upper limit is connected with a transgression.

Therefore the criterion of superposition may be considered a generally valid and reliable criterion for determining the upper age limit for the age of paleorelief. In cases where we are dealing with buried paleorelief, the upper age limit is determined by the age of the overlying formation, which discordantly overlies the paleorelief. This principle obviously does not lose its validity even in cases, where the relief has been exhumed from beneath its sedimentary cover. For example, relicts of an overlying formation, may be regarded as direct evidence of exhumation.

It results from the above mentioned, that for determining the upper age limit of plateau paleokarst in the Western Carpathians, we will be concerned first of all with the problem of a transgression, which penetrated from the north. The transgression of the Inner Carpathian development of the Paleogene, which penetrated to the Central and Inner Carpathian land from the north, was no synchronous in all places. A relatively unequal advance of the sea is supposed, for example in the Liptov Basin (compare Gross & Köhler et al. 1980). During the Lower Priabonian, the advance of the sea was relatively intensive (5 - 15 km), in the Middle Priabonian, a significant slowing of the transgression occurred (2 - 6 km), and in the Upper Priabonian, the transgression reached only a small area in the eastern part of the basin. At the same time, the northern part of the Central Western Carpathians, that is the northern arc of the core mountains, and the northern part of the Gemericum, were gradually submerged by the transgressing sea during the Eocene (Gross & Köhler et al. 1980).

The occurrence of relicts of sediments of the basal transgressive lithofacies of the Inner Carpathian Paleogene, especially conglomerates and sandstones, or sometimes only residual pebbles originating from basal conglomerates, overlying plateau paleokarst, give evidence of the exhumation of paleorelief in many places. This occurs especially on the more northern lying plateaux of Slovenský Raj Mts., Galmus and Muránska Planina. On parts of the plateaux, which the transgression of the Inner Carpathian Paleogene did not reach, subaerial development also continued during the Eocene.

The transgression of the Buda development of the Paleogene penetrated to the Inner Western Carpathians from the south. Its relicts are more rarely preserved in the plateau paleokarst. They are known for example, from the fallen block of the Drienčanský Karst (Fig. 4), where they are of Oligocene age (compare Vass et al. 1989). As with the transgression of the Inner Carpathian Paleogene development, the transgression of the Buda development did not submerge the paleokarst without traces.

The relicts of the Inner Carpathian, or Buda development Paleogene are not known for example from the more southerly situated paleokarst plateaux (Geravy, Pelc, Duča) of Slovenský Raj Mts. The fact that paleokarst also developed in the southern parts of Slovenský Raj, in places where relicts of Paleogene sediments are not known, is evidence of the existence of an extensive karst depression near the Dobšiná ice cave (Fig. 6). From the bottom of this occurs the mogot of Ostrá Skala hill (970 m), which is surrounded by fill of the depression, conglomerates of continental origin and fresh water limestones of Upper Cretaceous age (compare Bystrický 1978; Mišík & Sýkora 1980; Tulis & Novotný 1989). The facts mentioned are evidence that paleokarst of Cretaceous age also exists in the southern part of the Slovenský Raj Mts.

With the exception of the fallen block of the Drienčany Karst, there are not also known relicts of sediments of Paleogene age, from the surface of the plateau paleokarst in the Slovak Karst. However the Cretaceous age of karst is shown here, by the occurrence of of Upper Cretaceous sediments in the karst pocket in Gombasek quarry (Fig. 3). The above mentioned occurrences of residual iron ore and pizolithic bauxitic iron ore, which we consider to be the fossilized remnants of an originally more extensive latosol cover, bear witness to the relict character of the paleokarst.

The facts mentioned about the absence of relicts of Paleogene marine sediments, in the southern part of the paleokarst of Slovenský Raj Mts., and in the paleokarst of the Slovak Karst, shows the possible existence of dry land during the whole of the

Fig 7. The mogot of Ostrá skala near the Dobšiná ice cave.

Paleogene. This dry land was situated between areas submerged from the north by the Inner Carpathian and from the south by the Buda facies of the Paleogene, even during the maximum extent of the transgression. Other authors also mention, in other contexts, the existence of dry land during the Paleogene (Andrusov & Köhler 1963; Gross 1978; Gross & Köhler et al. 1980; Fusán et al. 1987).

It is necessary to seek the causes of the nonsubmergence of parts of the Inner and Central Carpathians, by the transgression of the Inner Carpathian or Buda facies, in paleotectonic development. The results of F-T ages of apatite from granites of the Veporicum, indicate uplift during the Upper Cretaceous, (Slovenský Raj Mts. is situated on Veporic underlying rocks), and the uplift of the Low Tatra district is thought to have occurred before the Eocene (Král 1977). The gradual origin of a barrier, with a roughly east-west course, allows us to explain the unbroken subaerial development, in parts of the present day plateau paleokarst, also in the period of the maximum extent of the Inner Carpathian or Buda facies transgression of the Paleogene.

Information about the lower limit for the age of the paleokarst, that is about the beginning of subaerial development, is made available to us, by the above mentioned ending of marine sedimentation in various tectonic units.

So we come to the age limitation of a significant stage of subaerial development, which we also consider to be the most significant paleokarst period of the Alpine stage. The length of its duration, as well as optimum climatic conditions for the origin of karst (Činčura 1988) laid the basic outlines of Paleo-Alpine karst in the Western Carpathians. The bases of plateau paleokarst probably began to develop in the Lower (?) Cretaceous period in the Silica Nappe, in the units further north, in the Middle Cretaceous. Its development ended with the transgression of the Inner Carpathian facies during individual stages of the Eocene, or the Buda facies during the Oligo - Miocene. On the dry land, separating both Paleogene facies, subaerial development continued without interuption.

Younger phases of subaerial development contributed to the exhumation of plateau paleokarst in the uplifted blocks. During the climatically more varied and tectonically active Neo-Alpine stage, after the exhumation, the more homogeneous units were divided into individual plateaux, and their surfaces were dismembered. A series of the younger karst formed on the plateau paleokarst, caused partialy remodelling. However younger karst processes did not remove the basic features of the plateau paleokarst, which was formed in the most significant paleokarst period of the Alpine stage, the Paleo-Alpine karst period.

Summary

The plateau paleokarst of the Western Carpathians is marked by various common features, among which we consider the following to be most significant:

1 - The nappe character of the carbonate complexes on which the paleokarst formed.

2 - The synclinal structure of the carbonate complexes, whereby synclines are marked by relatively moderately inclined beds of Middle and Upper Triassic limestones and dolomites.

3 - Heavy bedded Wetterstein limestones take the most significant part in forming plateau paleokarst (Muránska Planina, Slovenský Raj Mts., Galmus and the Slovak Karst).

4 - Before the origin of plateau paleokarst, the effects of the Late Cimmerian collision led to emergence, which is expressed by karst activity. We consider this to be the oldest karst period of the Alpine stage, known so far, and we call it the Late Cimmerian phase of karst activity.

5 - The plateau paleokarst formed during the longest and most significant period of karst activity in the Western Carpathians, which we call Paleo-Alpine. The beginning the Paleo-Alpine karst period may be roughly limited by the Lower? Cretaceous and its end by the Eocene or Oligocene.

6 - Part of the Paleo-Alpine paleokarst may be classified as exhumed from beneath sediments of the Inner Carpathian or Buda facies of the Paleogene, and part as relict.

7 - As a result of the significant quantity of common facial features of Wetterstein limestones of the Alpine and Carpathian regions, we also suppose a definite analogy in the development of plateau paleokarst in the Western Carpathians and Northern Calcareous Alps.

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