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GEOLOGICAL MODEL OF PALEOKARST SYSTEMS: THEORY AND APPLICATIONS

ABSTRACT: KORPÁS L., *Geological model of paleokarst systems: theory and applications*. (IT ISSN 0391-9838, 1998).

In the course of the last two decades the new diagenetic school of paleokarst has been established after Esteban & Klappa (1983). In contrast with the classical geographical and geomorphological approach the new concept of investigations, the sedimentological and diagenetic study of karst systems has been introduced. The most important considerations and conclusions are summarised in the following:
- The evolution of the paleokarst systems is related to the cyclic development of carbonate platforms. Diagenetic paleokarst cycles are subsequent and phase retarded in time;
- The paleokarst horizons have formed in well defined sections of the carbonate platform, reflecting clear regularities in their distribution;
- The formation and evolution of paleokarst systems is controlled by global eustatic sea level fluctuations, governed by climatic changes;
- The main conduit zones are the cave horizons, parallel to the bedding, consequently they can be detected and delineated by simple geological and geophysical methods.

The introduction and application of this model, as resulted in genetic reconstruction of short term and long term multiphase paleokarst evolution, is demonstrated by some examples from Hungary and from different areas of the world.

KEY WORDS: Paleokarst, Diagenesis, Carbonate platforms.

RIASSUNTO: KORPÁS L., *Un modello geologico dei sistemi paleocarsici: teoria e applicazioni*. (IT ISSN 0391-9838, 1998).

Nel corso degli ultimi due decenni si è affermata, dopo i lavori di Esteban & Klapka (1993), una nuova scuola di pensiero sul paleocarso. In contrasto con la classica scuola geografica e geomorfologica la nuova concezione introduce gli studi sedimentologici e diagenetici. I punti più importanti sono i seguenti:
- L'evoluzione dei sistemi paleocarsici è correlata ai cicli di sviluppo delle piattaforme carbonatiche e i livelli paleocarsici si sono formati in ben definite sezioni delle piattaforme, mostrando una chiara regolarità nella loro distribuzione;
- La formazione e l'evoluzione dei sistemi paleocarsici è controllata dalle variazioni eustatiche del livello del mare, governate dai cambiamenti climatici; i cicli diagenetici paleocarsici sono successivi e in fase ritardata rispetto ad essi;
- Le zone dei principali condotti sono degli orizzonti paralleli alla stratificazione, per cui essi possano essere individuati e studiati con semplici metodologie geologiche.

L'introduzione e l'applicazione di questo modello, quale è risultato dalla ricostruzione genetica dell'evoluzione multifase a breve e lungo termine del paleocarso, è mostrato con alcuni esempi tratti dalla casistica ungherese e di altre zone del mondo.

TERMINI CHIAVE: Paleocarsismo, Diagenesi, Piattaforme carbonatiche.

INTRODUCTION

One of the today's largest provocations for the Society is its supply of healthy potable water. Just this controversional phrase itself, used frequently in politics, reflects very well the day by day and more and more limited satisfaction of this promordial human right. It seems to be non-causal, that the possession in potable water of this potential has become one of the strategic tasks in many places of the world. The potable water is nowadays in the focus of many national and international conflicts and it will become even more so in the future.

Hungary, because of its geological setting and of favourable geographic and climatic conditions, is in the possession of the largest subsurface water resources in the region. The natural equilibrium of these resources with quality of potable water, has gradually broken up because of the effects of the exaggerated exploitation and of the industrial pollution of this potential. Therefore the welfare of the future generations requieres to stop this process, already irreversible in human life-scale in order to satisfy their potable water need.

The surface and subsurface paleokarst systems in Hungary are representing an unestimable great value for the population. They give about 10% of the subsurface, partly thermal water resources, approximately 30% of the petroleum reserves, the whole bauxite, limestone and dolomite resources and a significant part of manganese ores.

The caves have extraordinary values in themselves, with their minerals, fossile and living flora and fauna. The surfa-

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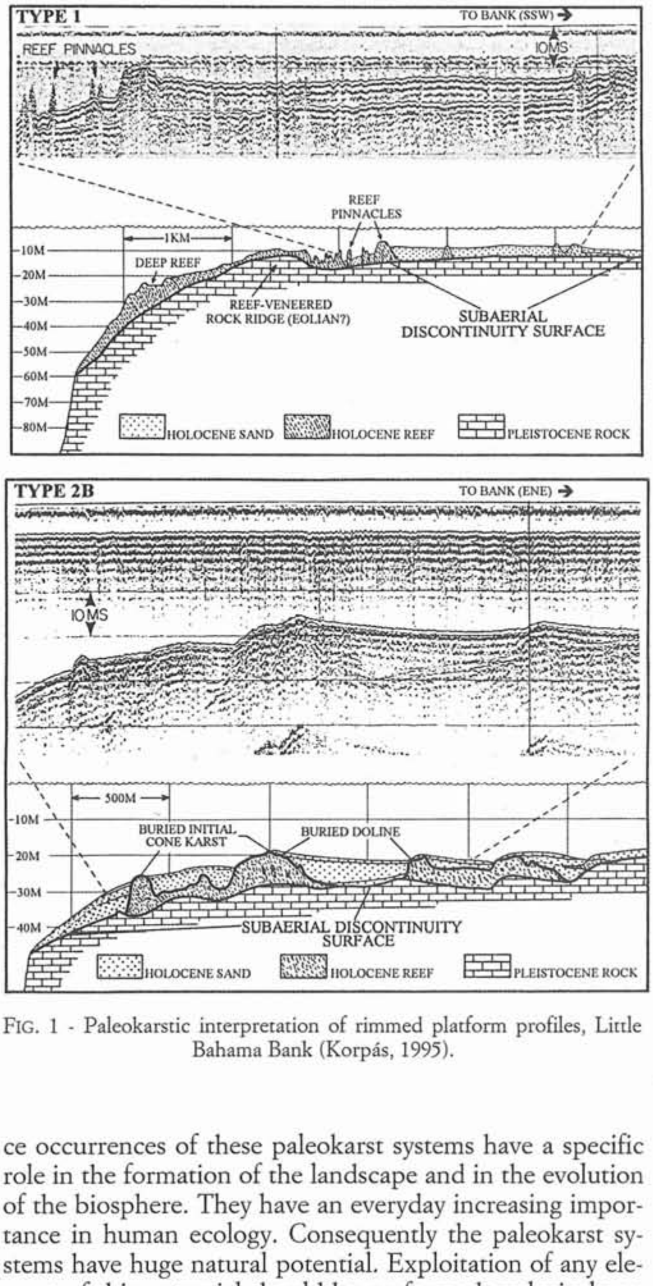

FIG. 1 - Paleokarstic interpretation of rimmed platform profiles, Little Bahama Bank (Korpás, 1995).

ce occurrences of these paleokarst systems have a specific role in the formation of the landscape and in the evolution of the biosphere. They have an everyday increasing importance in human ecology. Consequently the paleokarst systems have huge natural potential. Exploitation of any element of this potential should be performed exclusively on the account of the other ones and could result in the break up of its equilibrium. This process of deterioration was generated by the effects of mining activity, of the industrialization and urbanization already some ten years ago, which resulted in the acceleration of considerable drop of the karst watertable, influenced by climatic changes too and in increasing, sometimes critical pollution of the paleokarst systems. Among the elements of the systems the environmental factors, the quantity, and the state of the karst waters have become decisive.

The investigation of paleokarsts has become worldwide an outstanding area of research as proved by the wide range and of the related natural and mineral resources potential (oil, bauxite, Pb-Zn ores, uran ores, manganese ores, phosphates, nitrates, karstwater and thermalwater, see tab. 1). The actuality and significance of paleokarst studies is enhanced by the fact that 35% of oil, 15% of bauxite 10% of Pb-Zn and 10% of water reserves of the world are located in paleokarst areas.

Since a considerable part of natural potential and mineral resources of Hungary is connected with paleokarst, in 1989 the Geological Institute of Hungary began a systematic research of the paleokarst systems in Hungary. The research aims at the clarification of the following points: time and environmental conditions necessary for the formation of paleokarst, the criteria for recognition of paleokarst, the role of paleokarst in carbonate diagenesis, the role and significance of paleokarst horizons in local and regional stratigraphic correlation as well in geodynamic reconstruction, genetic-paragenetic relations between paleokarsts and related natural potential, 3D models of paleokarst systems.

The solution of the above mentioned problems is expected to provide up-to-date explanation of the genetics of paleokarst on one hand and the conceptual renewal of the research and exploration strategies of the natural potential related to paleokarst on the other.

Defining paleokarsts we used the definition of Wright (1982), Esteban & Klappa (1983), Choquette &. James (1988), Kahle (1988), Meyers (1988), Vera & *alii* (1988), according to which paleokarst was formed over geological time. The statesment is evident in case of karsts filled with younger sediments (covered karst), whereas with uncovered, relict or exhumed karsts it can be applied only occasionally. From among the general (morphological, hydrodinamic, hydrochemiacl, biochemical, lithologic, climatic

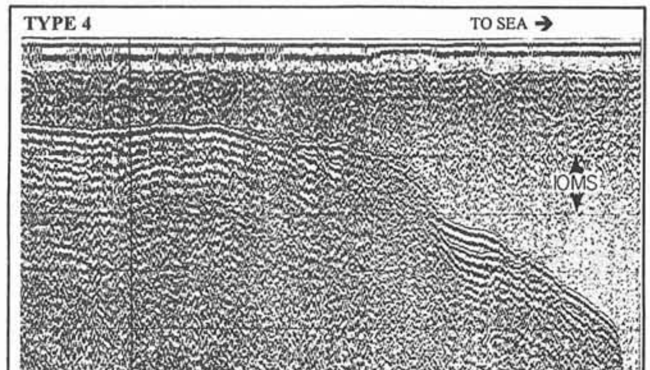

FIG. 2 - Paleokarstic interpretation of rimmed platform profiles, Little Bahama Bank (Korpás, 1995).

TABLE 1 - Examples of some raw material-occurrences related to paleokarst (Korpás & Juhász, 1993)

EXAMPLES OF SOME RAW MATERIAL-OCCURRENCES RELATED TO PALEOKARST						
RAW MATERIAL TYPE	PALEOKARSTIC RESERVOIR FORMATION				OCCURRENCES	
	NAME	LITHOLOGY	AGE	COVER	PLACE	REFERENCES
PETROLEUM	San Andrea	Dolomite	Late Permian	Late Permian	USA/W-Texas Yates field	D.H. Craig (1988)
	Hauptdolomit	Dolomite	Late Triassic	Late Cretaceous	Hungary/	Gy. Bárdossy-
	Dachstein limestone	Limestone			Nagylengyel	L. Kordos (1989)
	Ugod Limestone	Limestone	Late Cretaceous	Eocene		
	El Abra	Limestone, dolomite	Middle Cretaceous	Late Cretaceous	Mexixo/Tampico	C.J. Minero (1989)
BAUXITE	Szársomlyó Limestone	Limestone	Late Jurassic	Early Cretaceous	Hungary/Nagyharsány	Gy. Bárdossy-L. Kordos (1989)
	Dachstein Limestone	Limestone	Late Triassic	Middle Cretaceous	Hungary/Alsópere	
	Guajaibon	Limestone, Dolomite	Middle Cretaceous	Middle Cretaceous	Cuba, Pan de Guajaibon	L. Korpás (1988)
	Hauptdolomite	Dolomite, Limestone	Late Triassic	Late Cretaceous	Hungary/Halimba	Gy. Bárdossy-L. Kordos (1989)
	Kössen F., Dachstein Limestone					
	Ugod Limestone	Limestone	Late Cretaceous	Middle Eocene	Hungary/Csabpuszta	
MN-ORE DEPOSITS	Csárdahery	Limestone	Early Jurassic	Middle Eocene	Hungary/Úrkút	Gy. Bárdossy-L. Kordos (1989)
PB-ZN ORE DEPOSITS	Knox Carbonates	Limestone	Ordovician	Ordovician	USA/E-Tennessee	W.J. Mussaman & *alii* (1988)
	Madison Limestone	Limestone	Early-Late	Early-Late	USA/Wyoming	W.J. Sando (1988)
	Leadville F.	Dolomite Limestone	Carboniferous	Carboniferous	USA/Colorado	R.H. De Voto (1988)
	Muschelkalk	Dolomite	Early-Middle Triassic	Middle Triassic	Krakow/Poland	K. Bogacz & *alii* (1970)
U-ORE DEPOSITS	Madison Limestone	Limestone	Early Carboniferous	Pliocene-Pleistocene	USA/Pryor-Bighorn	W.J. Sando (1988)
WATER	Paget F.	Limestone	Late Pleistocene	Holocene	Bermudas	H.L. Vacher (1978)

and tectonic) conditions of paleokarstification also specified by the above authors we could emphasize the statement by Esteban & Klappa (1983) who point to proper «diagenetic facies» as a distinct marker.

TABLE 2 - The stratigraphic position of some paleokarst horizons (Korpás & Juhász, 1993)

THE STRATIGRAPHIC POSITION OF SOME PALEOKARST HORIZONS		
Stratigraphic position	Occurrences	References
Holocene/Pleistocene	Bahamas	Rasmussen & Neumann (1988)
Late Pleistocene	Bermudas	Bretz (1960)
	Florida	Dodd & Siemens (1971)
Pleistocene	Hungary	Bárdossy & Kordos (1989)
Pliocene/Pleistocene	Bahamas	Beach & Ginsburg (1980)
Neogene/Oligocene	Hungary	Bárdossy & Kordos (1989)
Late Eocene	Hungary	Kraus (1989)
Paleocene-Early Eocene	Hungary	Bárdossy & Kordos (1989)
Late Cretaceous		
	Mexico	Minero & *alii* (1988)
Middle Cretaceous	Cuba	Korpás (1988)
	Hungary	Bárdossy & Kordos (1989)
Early Cretaceous	Hungary	Bárdossy & Kordos (1989)
Early-Middle Jurassic	Spain	Vera & *alii* (1988)
Late Triassic	Sicily	Catalano & *alii* (1974)
Early-Middle Triassic (?)	Poland	Bogacz & *alii* (1970)
Late Permian	W-Texas/USA	Craig (1988)
Early/late Carboniferous	New Mexico/USA	Meyers (1988)
Early Carboniferous	Colorado/USA	De Voto (1988)
	South Wales (England)	Wright (1982, 1988)
Silurian	W-Ohio/USA	Kahle (1988)
	Sweden	Cherns (1982)
Ordovician/silurian	Ontario/Canada	Kobluk (1984)
Ordovician	Quebec/Canada	Desrochers & James (1988)
	Appalache/USA	Mussman & *alii* (1988)

The cited examples (tab. 2) suggest, that the paleokarstification, completed in a short time by geological standards, involved shallow marine, often peritidal platform carbonates (mainly limestones, and frequently also dolomites). Taking this into account along with the considerations of Esteban & Klappa (1983) according to which paleokarstification appears on shallowing upward sequences and divided by discontinuity surfaces of different order, the obvious conclusion to be drawn is that, there must be certain relation, between the original facies of carbonate rocks and the paleokarst facies.

SELECTED EXAMPLES OF THE PALEOKARSTS

Short-term marine paleokarst systems

The paleokarst phenomena are developed without exception in shallowing upward sequences of cyclic peritidal platform carbonates, mainly in limestones, subordinately in dolomites (fig. 5-12).

The correlative infilling sediments of paleokarsts are represented partly by subaerial paleosoils, *terra rossas*, and bauxitic clays (fig. 7), partly by early submarine laminites, practically coeval with the bedrocks (fig. 5, 6, 8, 9, 10, 12).

The paleokarst formed at the sea level should be considered as intraformational and shows a short-term cyclic development (fig. 1, 2, 5, 6, 7, 8, 9, 10, 12).

Morphological features of paleokarst are represented by dissolution enlarged fissures (fig. 5, 6, 8, 9), by sharp elongated caves and cavities parallel to the bedding (fig. 10, 12), by buried paleodolines (fig. 1, 2, 7) and by karst pinnacles and cones (fig. 1, 2).

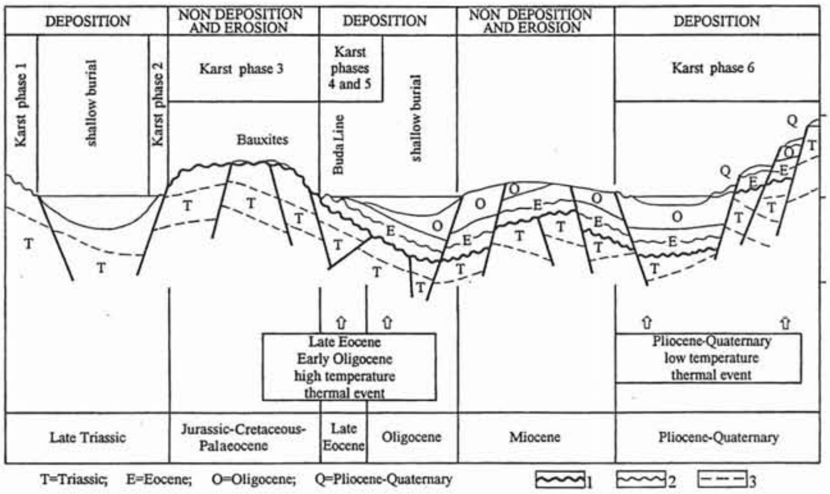

FIG. 3 - Model of paleokarst evolution Buda Hills, Budapest, Hungary (Korpás & *alii*, 1993).

Well developed single and composite cave horizons, parallel to the bedding can be recognized and delineated (fig. 11).

Long term composite paleokarst systems

The majority of the paleokarst systems of Hungary is located in Triassic platform carbonates Middle and Late Triassic in age. They are well developed overall in the mid-mountainous regions, including the Transdanubian Range and Northern Range. Less importance can be attributed to the paleokarst formed in narrow carbonateshelfs of Late Eocene age (fig. 3, 12).

Selected case studies, performed on Middle Triassic dolomite ramps (Korpás & *alii*, 1992; Korpás & Dudko, 1993; Korpás, 1995), on Late Triassic limestones of rimmed platform margin (Juhász & *alii*, 1995; Korpás, 1995), further on Late Triassic platform dolomites and Late Eocene carbonateshelfs (Korpás & *alii*, 1993; Korpás, 1995; Korpás & *alii*, 1996) have resulted in genetic reconstruction of long term composite paleokarst systems. General conclusions of these studies will be summarised in the following.

Disintegration of the Middle Triassic ramp of Megyehegy Dolomite was accompanied by multiphase paleokarst evolution, interrupted by coeval volcanism and shallow burial events at the Litér-Hajmáskér area of the Balaton Higland (fig. 7). The subaerial paleokarst showing paleosoils and traces of bauxites has developed along the wide tidal flat of the Megyehegy Dolomite and has reached its maximum morphological dissection at 235 Ma. The early paleodolines and paleokarstic pockets were buried by pelagic sediments of the subsequent high stand event between 234 and 232 Ma.

Multiphase paleokarst evolution of a Late Triassic rimmed platform, Dachstein Limestone, Naszály Hill, Trans-danubian Range (Juhász & *alii*, 1995) reflects a great diversity of paleokarstic processes, including submarine, subaerial and hydrothermal ones.

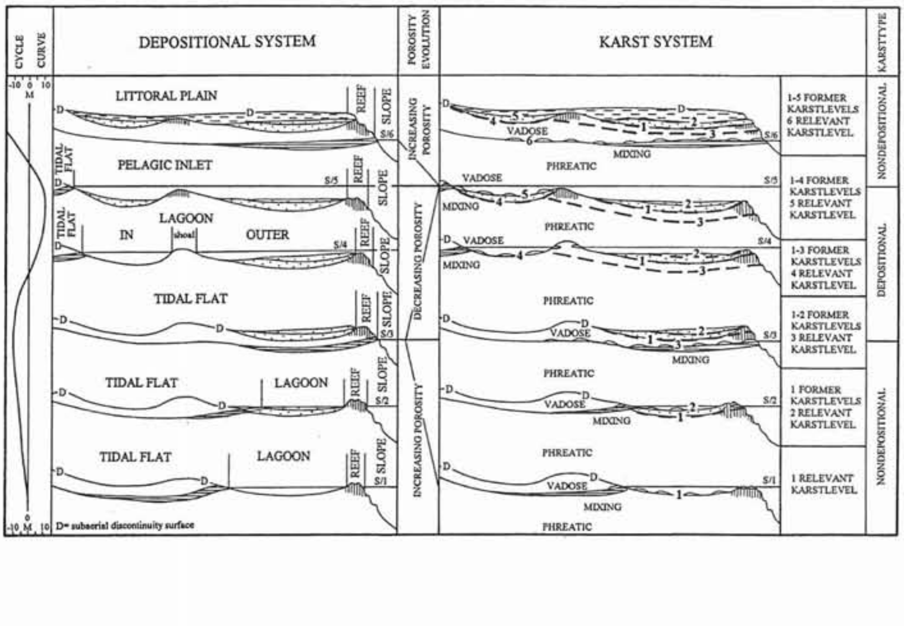

FIG. 4 - Rimmed carbonate platform evolution and related karst development (Korpás, 1995).

FIG. 5 - Unconform early marine infillings of laminites in the cavities of the Polgárdi Limestone, Devonian. Szabadbattyán, Köszár-hegy, Hungary (Korpás, 1995).

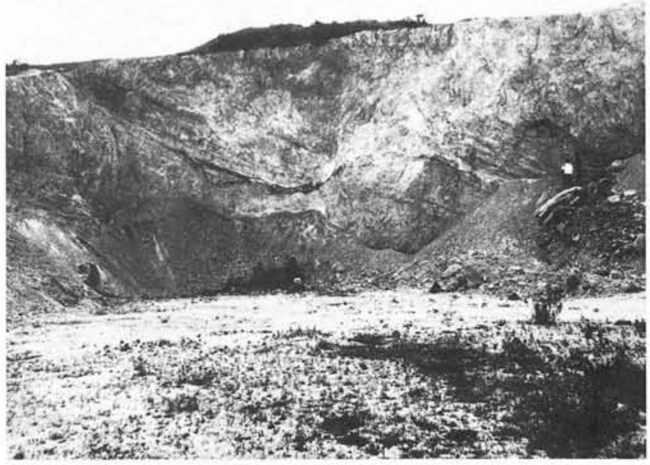

FIG. 7 - Early paleokarstic pocket with traces of bauxite in the Megyehegy Dolomite, Late Anisian. Hajmáskér, Balaton Highland, Hungary (Korpás & Dudko, 1993).

Thick platform carbonates of Dachstein Limestone accumulated in the Late Triassic. Several episodes of subaerial exposure resulted in syndepositional paleokarstification associated with Löfer cycles. At the end of the Triassic, disintegration of the platform comenced due to Tethyan rifting. The Naszály Hill platform segment was gradually uplifted and carbonate deposition ceased, following subaerial exposure and intense meteoric paleokarstification.

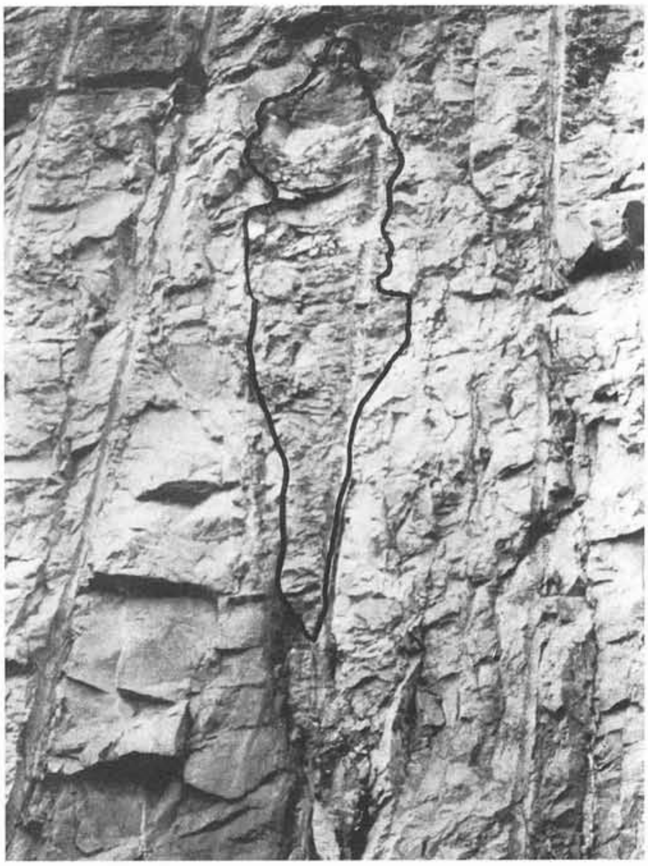

FIG. 6 - Early marine infilling of laminite in the fissure of the Guilly oolite, Lower Carboniferous. Chipping Soudburry, South Wales, England (Korpás, 1995).

Erosion during the pre-Tertiary produced composite unconformities overprinting of earlier paleokarst phases. During this erosional interval the platform was a low-relief area where bauxite accumulated. Subsequent Late Eocene hydrothermal activity was related to local magmatism.

In the Early Oligocene the effects of tectonic uplift were enhanced by a large-scale eustatic sea-level fall, resulting in repeated denudation and paleokarstification producing the new karstgenerations. At the beginning of the Rupelian

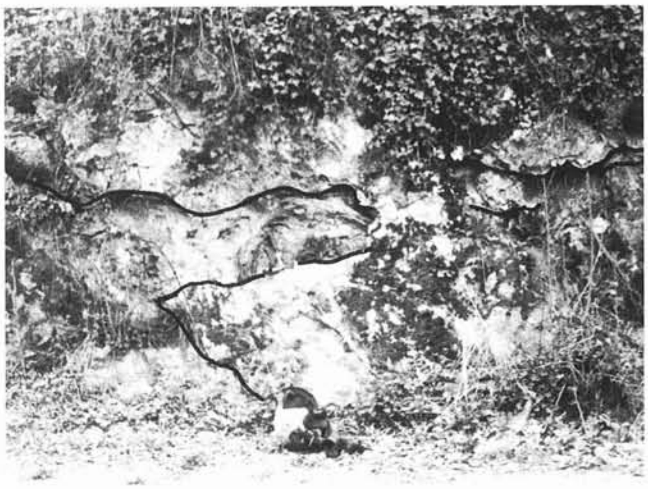

FIG. 8 - Overturned early paleokarst fissure with infilling of unconform marine laminites in Fehérkő Limestone, Middle Triassic, Lillafüred, Bükk Mountains, Hungary (Korpás, 1995).

FIG. 9 - Radiolaria bearing early marine laminites in the cavities of Hierlatz Limestone, Toarcian. Úrkút, Csárda-hegy, Transdanubian Range, Hungary (Korpás, 1996).

an important depositional phase started, and most of the caves were filled by marine conglomerate, sandstone and fine-grained siliciclastic sediments. Naszály Hill subsided and was covered by at least 350m of sandstone and marl.

In the Late Oligocene and Miocene the area was uplifted again and the second phase of hydrothermal activity occurred. Most of the caprock was eroded and the carbonates repeatedly became subaerially exposed.

The multiphase paleokarst evolution of the Buda Hills (fig. 3, 12) has started in the Late Triassic and resulted in the formation of early syndepositional, mainly marine paleokarsts. These early paleokarst phases were followed by a long term subaerial exposure period, from Early Jurassic till Paleocene in age, producing continental paleokarsts with traces of bauxites. The new syndepositional, dominantly marine paleokarst cycles of Late Eocene age were interrupted by the subsequent high temperature hydrothermal paleokarst event under shallow burial conditions. The gradual uplift of the former and buried composite paleokarst systems started in the Miocene has resulted in their partial exhumation with vadose and low temperature hydrothermal overprints during the Pliocene and Quatarnery.

PALEOKARST AND CARBONATE PLATFORMS

The fundaments of the model

The examples cited above have illustrated what kind of genetic relations should be proven between the evolution of the carbonate platforms and of the related paleokarst systems. Among the discussed examples both recent or very young and old or fossil occurrences can be found. But their scales in time and in space are very different and the intensity of the karstification differs too. Their single common pattern is the Caribbean type of karstification. This marine, phreatic karstification of the cited examples is proven partly by early marine infilling generations and cements, partly by the shallow marine sediments both in the hanging wall and in the footwall of the buried paleokarst horizon. The shown examples are also illustrating, that time has no significant role in the formation and in the evolution of morphologically perfect karst systems. It means, that the formation of a complete paleokarst level requieres no more than a few 1000 years. At the same time, in the case of the composite and multiphase paleokarst systems, bounded frequently to the 1-2 order unconformities only the timespan some million of years of the subaerial gap can be fixed. But it does not necessarry follow that this is the time, needed for karstification.

Consequently the new and basic element of the suggested model is the linking up of the evolution of the carbonate platforms with the paleokarst systems belonging to them. As the cyclicity governed by climatic factors play the decisive role in the evolution of both of them, therefore the spatial distribution of the paleokarst horizons inside the carbonate platforms has to reflect the periodicity of the Milankovich (12,000 years), of the precession (19-23,000 years), of the obliquity (41,000 years) and of the composite (100,000, 400,000) cycles.

FIG. 10 - Jurassic early marine radiolarian bearing laminites in the cavity of the Felsőtárkány Limestone, Felsőtárkány, Bükk Mountains, Hungary (Korpás, 1995).

FIG. 11 - Cave horizons parallel to the bedding in Senonian Limestone, Santa Lucia, Oriente, Cuba (Korpás, 1972).

The model

Although among the cited examples both rimmed platform and ramp types occur, the proposed model (fig. 4) was elaborated for the more attractive rimmed platform type. The model itself comprises a complete Milankovich cycle, starting at the relative sea-level «0m» (s_1), with the correspondent depositional environments and karst in the mixing and in the phreatic zones.

During the first sea-level fall of 5m (s_2) the subaerial tidal flat areas and the related discontinuity surface (D) are increasing and the area of the lagoon is decreasing. The relevant karst level (Nr. 2) is coming over to the former one and the karstification in the mixing zone is stepping gradually seaward.

The next sea-level drop of a new 5m (s_3) has resulted in the further increase of the subaerial tidal flat areas, and the relevant karst level (Nr. 3) has developed below the former ones. So far the process is accompanied by gradual but continuous increase in porosity and correlative sediments are not to be expected in the karst system. Consequently this is a nondepositional karst period with the formation of individual and composite, mainly phreatic karst levels.

In the course of the following sea-level rise (s_4) the former depositional and karst systems fall almost completely below the sea-level. The subaerial tidal flats areas will be significantly reduced, while new inner and outer lagoons, separated by a shoal will be formed. This means, that the former karst levels (Nr. 1-3) will be completely located below the sea-level and the relevant karst level (Nr. 4) will be landwardly situated.

Because of the further sea-level rise (s_5) the former depositional system will be covered by pelagic sediments and the relevant karst level (Nr. 5) will be restricted only on to the even more narrower subaerial tidal flat areas. The former karst levels (Nr. 1-4) will take their place in the shallow marine phreatic zone. These phases, accompanied by sea-level rise result in the decrease of porosity, reflected by the partial infilling of the karst system. That is the depositional period in the evolution of the karst system and the proves for the highstand are given by the shallow marine infillings and cements.

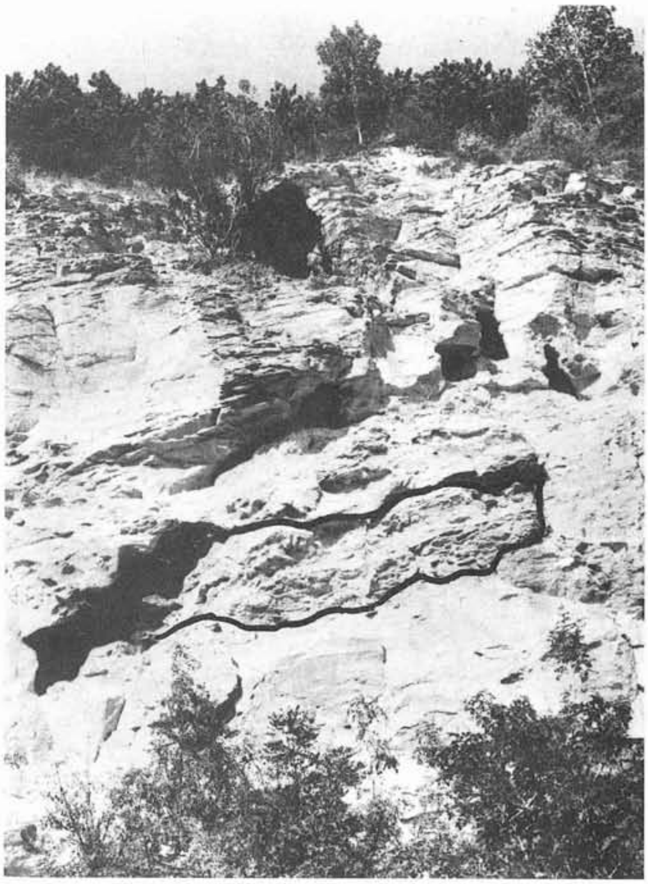

FIG. 12 - Unconform generation of early marine laminites in the cavity of Szépvölgy Limestone, Late Eocene, Mátyás-hegy, Buda Hills, Budapest, Hungary (Korpás, 1995).

Finally the cycle will be closed by the rapid sea-level fall (s_6) and the former depositional system will be completely changed into a subaerial exposure surface resulting in the formation of a littoral karst plain, bordered by terraces. For the evolution of the karst system this is a new, significant phase and the relevant karst level (Nr. 6) will be located below the former ones (1-5). This nondepositional period means again the increase of the porosity with a new, independent karst level and with the overprinting of the former ones.

CONCLUSIONS

According to the explained model the evolution of the paleokarst systems has to be in a strong correlation with the development of the carbonate platforms. The evolution of both is cyclic, but the great difference between them lies in the fact that the depositional cycles are followed by paleokarst cycles retarded in time.

The sea-level falls represent phases of increasing porosity and they are nondepositional karst periods, whereas the sea-level rises represent phases of decreasing porosity and they are depositional karst periods.

The caves, formed in these paleokarst systems are marine phreatic in origin and the bottom surface of the individual caves is paralell to the bedding. In the formation of the paleokarst levels a greater role is attributed to the mechanical corrosion, produced by the submarine earth tidal pump, than to the mixing corrosion.

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