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Paleokarsts and long-term karst evolution of the Buda Mountains, Hungary

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Abstract

The Triassic and Eocene carbonates which build up the central massif of the Buda Mts form a joined karst system with 6 stages of karstification.

Depositional paleokarsts formed in the Triassic Dachstein limestone were controlled by depositional facies patterns and lithologies.

From Late Cretaceous to Early Eocene, the area was uplifted and exhumed. Triassic dolomites and limestones were karstified and the dissolution of the oldest caves can be dated back to this period.

During the Middle-Late Eocene transgression, shallow marine limestones and maris were deposited on the former paleokarst surface. Small cavities in the Upper Eocene limestone were formed by dissolving local carbonates during sea-level low stands; they were filled with fine-grained calcarenite in the subsequent high stand periods.

During the Early Oligocene denudation, die former conduits became active again, partly rejuvenating die paleokarst system which later, as a consequence of Late Oligocene clay deposition, was buried. At the same time, nearby andesite volcanic activity initiated the first thermal stage; volatile components were added to the fossil meteoric water and produced controlled currents, material transport and hot water activity.

Another area uplifting occurred in the Early Miocene and the clay began to be eroded. By the end of Late Pliocene, ascending thermal waters from the uncovered karst mixed with cold karstic waters; this had a strong corrosive and solving effect on the karstic networks.

Résumé

Les roches carbonatées triasiques et éocènes qui constituent le massif central des collines de Buda forment un système karstique unifié où six stades de karstification ont été identifiés.

Les paléokarsts de dépôt du calcaire triasique du Dachstein avaient des caractères dépendant des modes de dépôt et de la lithologie.

Du Crétacé terminal au début de l'Eocène, la région fut soulevée et exhumée. Les dolomies et les calcaires triasiques furent karstifiés; les plus anciennes grottes remontent à cette période.

Pendant la transgression de la deuxième partie de l'Eocène, des calcaires et des marnes se déposèrent à faible profondeur dans la mer, sur la surface du paléokarst antérieur. La dissolution fit apparaître des cavités dans le calcaire fini-éocène, quand le niveau de la mer était bas; ces creux se remplirent au contraire de calcarénite à grain fin quand le niveau remonta ensuite.

Au début de l'Oligocène, les conduits redevinrent actifs, ce qui rajeunit le système karstique, qui fut de nouveau enfoui suite aux dépôts argileux de la fin de l'Oligocène. A cette même époque, le volcanisme voisin provoqua le premier stade thermal; des constituants volatils s'ajoutèrent aux eaux météoriques fossiles et il s'ensuivit des courants, du transport et une activité de l'eau chaude.

Au début du Miocène, la région subit un nouveau soulèvement et l'argile commença à être érodée. Tout à la fin du Pliocène, des courants ascendants d'eau thermale, provenant du karst découvert, se mêlèrent avec de l'eau karstique froide; le mélange plus corrosif élargit les réseaux karstiques.

I. INTRODUCTION

Paleokarsts are now widely recognized in ancient carbonate séquences. Most of the published papers, however, focus on only one phase, though the multiple conformities of complex karstification create combined porosity patterns in an individual area.

The Buda Mts provide a good example of long-term karst evolution over a period of 200 million years (Fig. 1). Paleokarsts, related both to high frequency sea-level changes and to major sequence boundaries, can be found in successive positions exhibiting late thermal overprints. Although the overall geological history is clear, the main phase of solutional cave origin contains a major controversy, which is discussed below at greater length.

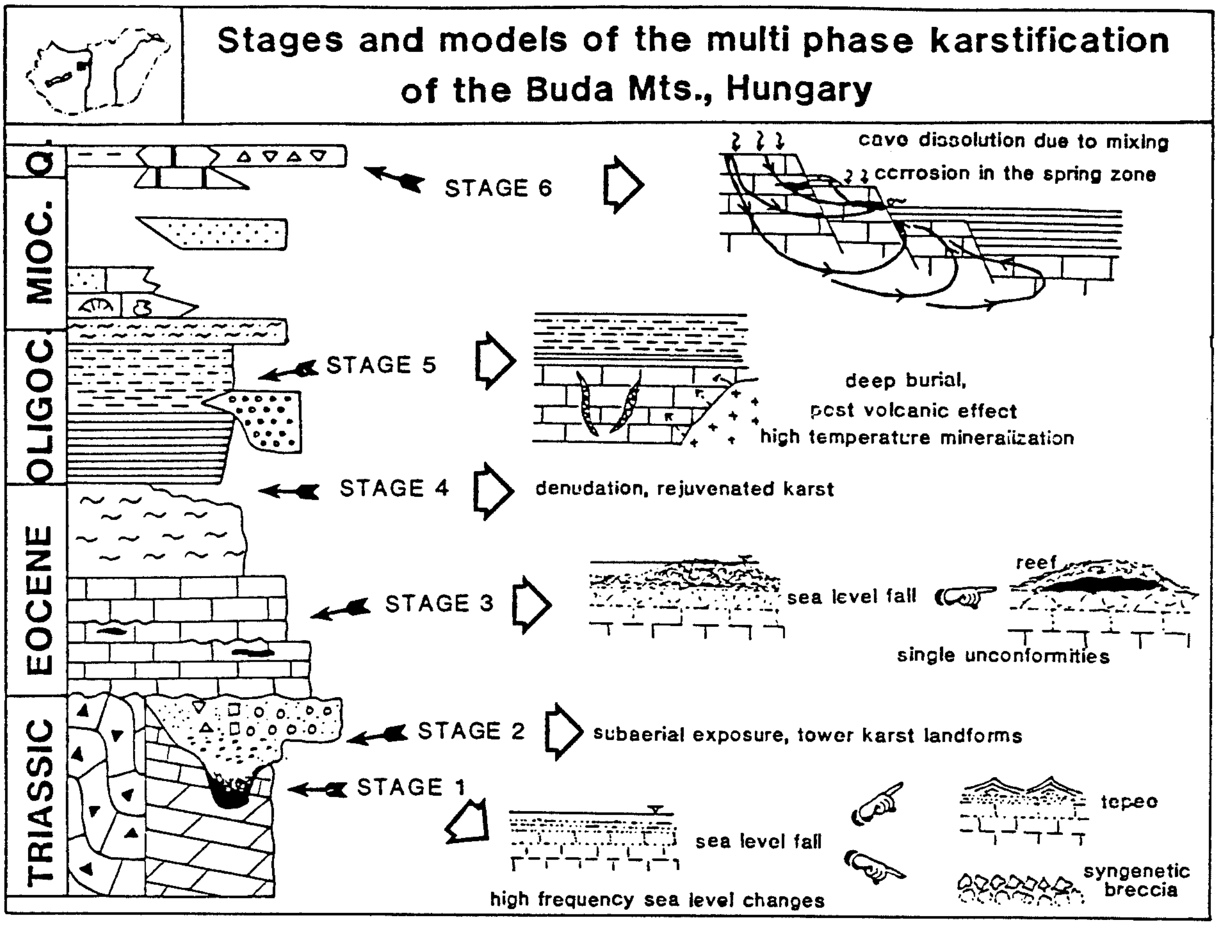

Figure 1 : Interpretation of the stages and models of polyphase karstification in the Buda Mountains.

II. MULTIPHASE KARST EVOLUTION OF THE BUDA MOUNTAINS

A. Stage 1 : Early Diagenesis of the Dachstein Limestone

Depositional paleokarsts, formed by an early stage of subaerial exposure in the peritidal Dachstein Limestone, were controlled by depositional facies patterns and lithologies. The tepees, discontinuities capping shoaling upward cycles, syngenetic breccias and the thin corrosional fissures within the parasequence boundaries were all formed as a result of high-frequency sea-level changes in the Late Triassic (NÁDOR *et al.,* in press).

Strictly speaking these features in the immature carbonate sediment cannot be considered as "real karsts", sine the pore/conduit diameter did not exceed 5-10 mm, thereby allowing flow to change from laminar to turbulent and creating more rapid dissolution.

B. Stage 2 : Late Cretaceous-Early Eocene Paleokarst

The Late Cretaceous-Early Eocene paleokarst is related to composite unconformities, which developed on the Triassic dolomites and limestones after the Austrian orogeny (NÁDOR, 1991), when the area was uplifted. The Jurassic and Cretaceous pelagic sediments were eroded during this long subaerial period and exposed the underlying Triassic carbonates to the circulating fresh water, which was guided through the secondary fractures. The extensive tower karst landforms indicate subtropical climate at that time, and the dissolved caves are the oldest ones of the Buda Mts.

C. Stage 3 : Late Eocene Burial and Related Events

During the Middle-Late Eocene transgression, shallow marine limestones and marls were deposited on the paleokarst surface of the Triassic carbonates, intimately connecting the Triassic and Eocene karst systems. The basal beds of the Upper Eocene carbonates filled the depressions and paleo-caves formed during Stage 2., preserving the Late Cretaceous-Early Eocene paleokarst horizon.

Small cavities observed within the Upper Eocene limestone were formed by dissolving local carbonate buildups (e.g. reefs) during sea-level lowstands and were filled in the subsequent high-stand periods with fine-grained, thin bedded calcarenite (NÁDOR *et al.,* in press). Other syntectonic and erosional discontinuities within the Upper Eocene sequence also show clear evidence of karstification at single unconformities.

D. Stage 4 : Local Uplift and Early Oligocene Denudation

During the Infra-Oligocene denudation a local uplift resulted in the erosion of the Upper Eocene carbonate rocks in some parts of the Buda Mts. The Late Cretaceous-Early Eocene paleokarst system was partly rejuvenated with the exposure of the underlying karstified Triassic carbonates (NÁDOR, 1991). Due to the circulation of the solutionally aggressive waters, the former conduits became active again. The Early Oligocene Harshegy Sandstone was deposited on the rejuvenated karst of the Triassic rocks, filling some fissures and minor cavities within.

E. Stage 5 : Deep Burial of the Late Triassic Cretaceous-Early Eocene and Late Eocene Paleokarsts and Related Events

As a consequence of deposition of the Kiscell Clay in the Late Oligocene, the whole karst-system, built up of Triassic and Eocene carbonates, was buried.

The first phase of thermal water activity was initiated in the Late Oligocene (BÁLDI & NAGYMAROSY, 1976 ; NÁDOR, 1991), as a result of the influence of nearby andesite volcanic activity. This added volatile components to the heated fossil meteoric water, and produced controlled currents, material transport and thermal water activity in the deep buried karst (KOVÁCS & MÜLLER, 1980). Minerais, characterizing high temperature deposition in open fissures, were precipitated in the following order : calcite-1, pyrite, barite-1, silicication of the host rock, calcite-2, cinnabarite-metacinnabarite, barite-2, calcite-3, limonite (NÁDOR & SÁSDI, in press).

Fluid inclusions of calcite-1 were most probably trapped at a temperature of 55-60°C (DUBLYANSKI, 1991), though previous works (GATTER, 1984) assume temperatures as high as 160-200°C. However, the 180 stable isotope values (-14 to 12 % PDB) of calcite-1 also support its precipitation at about 60°C. Cryometric data ail show alkali-alkali earth metal bicarbonate, or alkali-alkali earth metal chloride composition of the captured fluids, with relatively high salinity, and variable amount and distribution of CO, content. Although this pattern can also be related to brins of sedimentary basins, the relative enrichment of Cd, Co, Cr, Cu, Ga, Mo, Ni, Ti and V in calcite-1 suggests post-volcanic effects.

The similar fluid-inclusion composition of barite-2 (GATTER & MOLNÁR, in press), the chemical trends within the silicication zones, the precipitation of cinnabarite and metacinnabarite, and the remarkable Ag and REE content of the limonite ail support the hydrothermal origin of this minerai paragenesis, triggered by volcanism.

F. Stage 6 : Uplift of the Buda Mts and Origin of the Caves

In the Early Miocene with the area uplifted, the Oligocene clay which was covering the karst system began to erode, and exposed the Triassic and Eocene carbonates in the area of the highest peaks.

By the end of the Late Miocene and in the Pliocene, a convention current of thermal water developed (KOVÁCS & MÜLLER, 1980). This current was produced by descending meteoric waters, recharging the uncovered Triassic and Eocene karst, which were forced to penetrate to greater depths. Due to the above-average geothermal gradient in the basin area, after a regional circulation, they ascended as thermal waters. Below the tapping points then they mixed with cold karstic water, causing a strong corrosive effect. This resulted in the broadening by solution of the karstic networks (MÜLLER, 1974), possibly utilising the pre-existing conduits.

At the tapping points, thermal springs deposited dissolved material as freshwater limestones, which now are found in eight main levels at different heights, due to the gradual uplift of the area.

The oldest thermal water caves, at the same height as the Late Miocene freshwater limestones (450 m as!), were probably dissolved at that time (NÁDOR & SÁSDI, in press).

After Late Miocene and Pliocene periods the karst hydrodynamic system began to change, so by the Early Pleistocene a dispersed spring system developed (SCHEUER & SCHWEITZER, 1988). With graduai Pleistocene uplift, caves were formed in two main levels (240 and 22 m asl) in the Upper Eocene limestone and marl, while some lower cave passages extend downdip to the Middle Triassic cherry limestone.

Although the present caves intersect several former paleokarsts, there is no direct evidence that they are exhumed and enlarged paleo-cavities. Yet some outlines of the caves might have been determined long before (NÁDOR, 1991).

The solutional forms and mineral precipitations of these multi-storey 3D maze caves vary in the two cave levels, as a result of different water movement patterns. The solutional walls of tight passages contain upward orientated scallops in the Ferenchegyi cave at 240 m, indicating quick moving rising water. The cave-forming water was rather slow moving in the caves of the 220 m level, as suggested by the big solutional forms and by the almost total lack of flow markings (NÁDOR & SÁSDI, in press).

Most of the solutional forms (e.g. solutional pockets, rising tubes, ceiling canals) were not produced by normal corrosive activity, but by the movement of rising corrosive gas bubbles within the warm water (TAKÁCSNÉ, 1989 ; NÁDOR & SÁSDI, in press).

The mineral precipitations show a great morphological variety in different caves. The most widespread speleothems are the popcorns, which are generally made up of nonluminescent blade calcites with thin micritic encrustations, though bunches of aragonite needles may also occur. Micritic internal sediments in the intercrystalline pores, or in thin layers on redissolved crystal surfaces generally show dull or bright orange luminescence. In some cases a bright orange luminescent late cement of small calcite crystals encrusts the micritic internal sediments, or fills the rest of the intercrystalline pores.

The ^{18}O stable isotope composition of the speleothems ranges between -15,57 and -12,54 % PDB (FORD, 1984). The values leading us to conclusions concerning the temperature of the precipitating fluids, which could have been as much as 55-70°C. The ^{13}C composition ranges between 4,54 and -1,22 % PDB (FORD, 1984), which suggests an increased degree of rock-water interaction, and shows no evidence of the presence of groundwaters charged with soil-derived CO_2.

The ^{18}O composition of the bedrock samples of the caves ranges between -8,94 and -5,12 % PDB, while the ^{13}C ranges between -1,44 and 1,05 % PDB (FORD, 1984). This indicates a strong alteration trend, as a conséquence of hydrothermal action.

The U-series dating (FORD, 1984) showed that most of the spelaean carbonates in Palvolgyi cave are older then 350 ky, and probably younger than 1500 ky.

The Buda Mts were not exposed to glaciation during the Pleistocene, but the close proximity of the continental ice sheets to the north caused considerable fluctuations in climate. The restricted recharge in glacial maxima resulted in local precipitation due to evaporation in the caves from the stagnant waters, while in the wetter interglacial times increased stream flow caused re-dissolution (KRAUS, 1982).

Gravel and sand have been temporarily carried into the caves during floods, showing an obvious relation to the former sinking streams (NÁDOR, 1991).

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