HUNGARIAN TRAVERTINES

Ferenc SCHWEITZER - Gyula SCHEUER

ABSTRACT

The travertine levels, which overlie each in a step-like fashion can be divided into two groups (the horizons of travertines were numbered from the lowest point (Budapest, Rómaifürdő, 107 m a.s.l.) up to the highest (Buda Mountains, Szabadsághegy-Normafa, 493 m a.s.l.), so their symbols are T_1 — T_{12}. First are the members of the lower series deposited close to each other on the valley-side terrace between 107 and 240 m a.s.l. (horizons T_1 — T_7). Second are the members of the higher series deposited on older geomorphological levels (T_8 — T_{12}) which succeed each other with considerable local height difference and are lithologically different from the lower series.

Correlations between the lower travertine series and the terraces of the Danube and its tributaries.

Travertine T_1 can be associated with the first flood-free (II/a) terrace, travertine T_2 with the second flood-free terrace (II/b), and so on up to horizon T_5, which is deposited directly on the terrace No. V. north of Budapest. The travertine horizons T_5, T_6 and T_7 are best represented in the Gerecse Mountains, where they lie on terraces V, VI, VII of the Danube and occasionally on those of its tributaries.

The absolute age of selected travertines deposited on the terraces was determined by means of the Th/U method (PÉCSI, — OSMOND, J.K. 1973), and gave ages of 70 000 years for travertine T_2 (Óbuda terrace II/b), 190 000 years for travertine T_3 (Kiscell Plateau) and more than 350 000 years for the travertine T_4 (Vértesszőlős — Buda Castle Hill).

According to the palaeomagnetic data from the loess strata intercalated in the travertine T_4, is younger less than 700 000 years of normal, while the T_5 horizon is older than 700 000 years of reversed magnetic polarity.

The fauna found in the travertines of the Buda Castle Hill (T_4) and at Üröm-hill (T_5) can be referred to the Middle Pleistocene and Upper phases of the Lower Pleistocene (JÁNOSSY, D. et al. 1976; KROLOPP, A. 1966).

In the Gerecse Mountains travertines T_6 — T_7 proved to be of Upper Villányium — Lower Pleistocene (Kislángium age) based on microfauna collected by SCHWEITZER, F. and determined by JÁNOSSY, D. (1978).

Travertines T_9 and T_8 are deposited on the lower (270-250 m) and higher (360-300 m) pediments abutting the valley sides of Szabadság and Széchenyi Hills. Preceding their formation, the Buda Mountains rose considerably at the beginning of the Upper Pliocene, causing a lowering of the karst water table and the generation of new karst springs along the bank line of the lower pediment.

The oldest travertines of the Buda Mountains (T_9 — T_{12}) are deposited on sands and gravels of Upper Pannonian age, the T_{10} is a greyish lacustrine-marshy formation, whose micro- and macrofauna as well as position suggest it to belong to the "Sümegium" of the Upper Pannonian. Travertine T_{11} is deposited on the highest Pannonian marine terrace at a height of 440-450 m above sea level. It is suggested that at the time of the formation of travertines T_{11} and T_{12} the Buda Mountains had risen somewhat above the level of the Pannonian inland sea and that the marine terrace may be associated with karstic springs action.

In the Buda Mountains the travertines suggest the existence of 12 geomorphological surfaces, which are indicative of the degree of tectonic uplift that has taken place since the Upper

Pannonian. Based on the position of the various travertines, we would estimate 70 to 80 m of uplift took place during the Upper Pannonian, 80 to 100 m during the Upper Pliocene and 130 to 140 m during the Quaternary, within which 6 to 8 m can be assigned to the recent (Fig. 1).

INTRODUCTION

In Hungary travertines are quite common; they are in an overwhelming part associated with karst mountains or portions of mountains. Their cadastral survey contains more than 500 independent occurrences. In some mountains their significance is great from the viewpoints of archeology, faunistics and geomorphology. By origin they are deposits of karst and karstic thermal springs (*Fig. 1*).

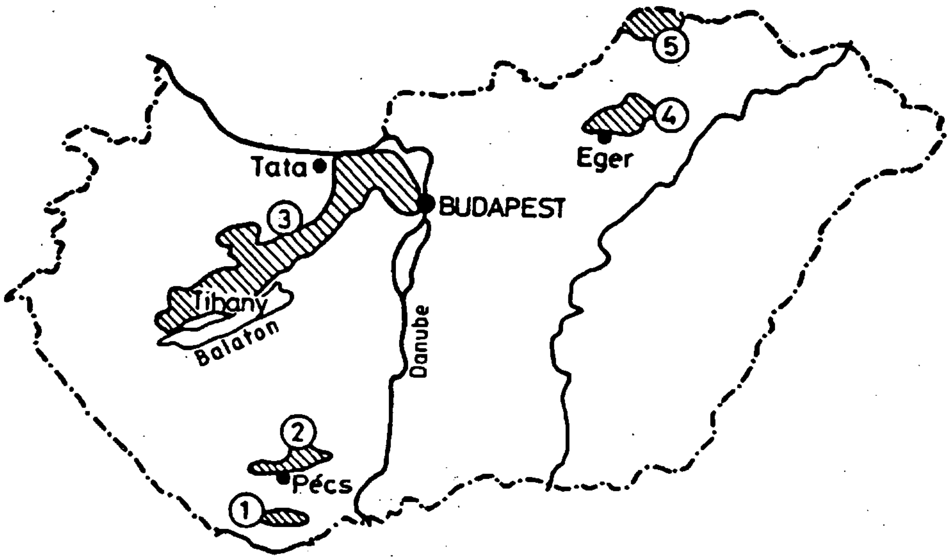


Figure 1 *Layout of the investigated area 1 = Villány Mt; 2 = Mecsek Mt; 3 = Transdanubian Mt; 4 = Bükk Mt; 5 = Aggtelek Mt*

Travertines are also common in the neighbouring countries, moreover, all over the world. In Czecho-Slovakia, for instance, the number of independent occurrences exceeds one thousand (KOVANDA, J. 1971). Several recent travertine occurrences are world-famous natural rarities (Yellowstone Park in the United States, Plitvice in Yugoslavia, and Pamukkale in Turkey).

The study of travertines in Hungary revealed the various types and a kind of diversity not experienced at other groups of rock. Travertines may be hard, compact, unstratified, unconsolidated stratified, or have interbeddings. It is related to the origin of springs depositing them and also to the chemical composition of spring water, particularly its dissolved calcium content, the geomorphological position of springs and their environs.

To interpret and explain the phenomena of travertines of extremely diverse expression and age, the recent travertine occurrences in Hungary and the neighbouring countries, we must directly observe and interpret the intricate forms and the factors inducing them. Moreover, relationships were sought between lime accumulation (carbonate dynamics) and the physical-chemical properties, as well as between lime accumulation and the activity of springs and climatic conditions.

MAIN HYDROGEOLOGICAL AND GEOMORPHOLOGICAL STATEMENTS CONCERNING TRAVERTINE FORMATION

1. The concept of springs of travertine deposition cannot be narrowed down to karst and karstic thermal springs, as had been believed by some experts, since travertine may deposit from any type of water (regardless of origin and temperature) which contains more or less dissolved calcium hydrogen carbonate.

Role of Travertines

The springs and waters of travertine deposition can be referred to five major classes:

a. Cold karst springs and karst water streams (below 14 °C).

b. Lukewarm and warm karst springs and their waters (stream, swamp).

c. Soil, layer and crack springs.

d. Postvolcanic warm or hot springs and waters.

e. Mixed or heterogeneous springs and waters (e.g., gas is postvolcanic [CO_2] and water is ground or karst water).

2. This is the first paper to classify and tabulate springs of travertine deposition from the hydrogeological and water chemical aspect. The tables provide a quick overview and basic information for researchers.

3. Travertine occurrences also exist, the origin of which *cannot be connected with the very frequent karst waters*. They are mainly attributed to springs of postvolcanic activity. Moreover, in restricted areal distribution travertine is observed in the vicinity of certain free and confined groundwater springs too. Its significance, however, is not considerable. Especially important are the travertines accumulated by CO_2 and mineral springs originating from postvolcanic activity.

4. The abundant material for comparison suggests that travertine occurrences of postvolcanic origin are frequent on a global scale. In Hungary, for instance, the origin from thermal water adds special features to the travertines of the Transdanubian Mountains.

5. Travertines of major areal extension are usually found around *springs of great discharge*. In addition to discharge, the time factor plays a remarkable role, as well as the geological stability of springs, i.e. their issuing in approximately the same spot.
In the case of numerous karstic thermal springs travertine deposition was not observed. This can be explained by the unfavourable environmental conditions — primarily the geomorphological position of issue — for accumulation.

6. The *deposition* of travertine series is a joint result of complex processes. The ratios between the most diverse geomorphic factors, environmental conditions, the time factor, and the interactions between the properties of the depositing spring jointly form and influence the origin and development of travertines.

7. From the *bedding conditions* and relative positions of travertines formed from the Lower Pannonian to the Holocene, conspicous features can be found which root in the character of the karst hydrodynamic system of the Transdanubian Mountains, its paleogeomorphology and structure. These features, among others, include:

a. karst springs generally issue from the deepest lying karstic rocks of the topography;

b. contemporaneous springs issue approximately at the same elevation (15 m);

c. accordingly, in an areal unit, limestones of similar age may have been formed at similar altitudes with minor differences, with the exception of travertine formations of tetarata type;

d. in most cases travertines form sequentially in a step-like fashion in certain valley cross-sections and are associated with characteristic geomorphological surfaces.
The hydrogeological and geomorphological positions of travertines show that springs depositing travertines issue, in most cases, from the lowest-lying karstic blocks of free surface. Elsewhere karst springs are absent since the permeable karstic rocks are buried under impermeable formations of great thickness, or karstic rocks have such great elevations which rise above the karst water table governed by the hydrodynamic balance of the karst system.

The formation of the step-like travertine horizons can also be explained by the denudation increased by the uplift of permeable layers inhibiting the issue of water from the permeable karstic horsts. Issuing water found its way along the structural faults typical of the two mountains.

8. The *typology* of travertine series — according to the topographic location of their origin, lithological properties and the analyzed karst hydrological processes — enabled, for the first time in the international literature, judgement of the chronological significance of travertines and their role in the reconstruction of geomorphic evolution.

The possibilities for the deposition of travertines and for the issuing of the karst springs depositing them are associated with four typical geomorphological karst hydrological situations. Several of the four basic types differentiated can combine to form a fifth type.

8.1. *Lacustrine-paludal type travertine series deposited on alluvial surfaces*. They deposited at the base level where on the adjacent terrains of flood-plains enough water was present creating even lakes and swamps. Travertine precipitated and accumulated from springs cutting through fluvial deposits. In many of the cases karst springs were fed by buried horsts covered by flood-plains deposits of moderate depth. In some instances, however, the springs depositing travertine issued immediately from the sides of outcropping karstic horsts on the flood-plain margin. The model outlined here of travertine formation, according to our observation, is not so general or exclusive in the Hungarian Mountains as was represented in earlier interpretation (*Figs. 2 and 3; Pict. 1*).

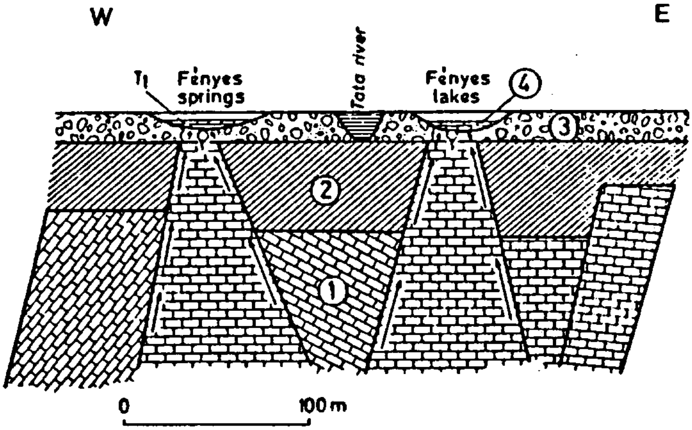


Figure 2 *Flood-plain-lacustrine-marshy travertine formation associated with spring issuing from covered horst through fluviatile sediments.* 1 = permeable Triassic sediments; 2 = impermeable Tertiary sediments; 3 = recent sediments of the Általér; 4 = travertine.

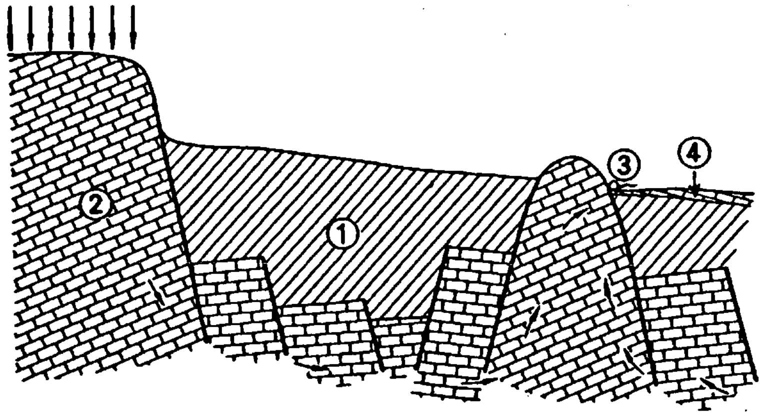
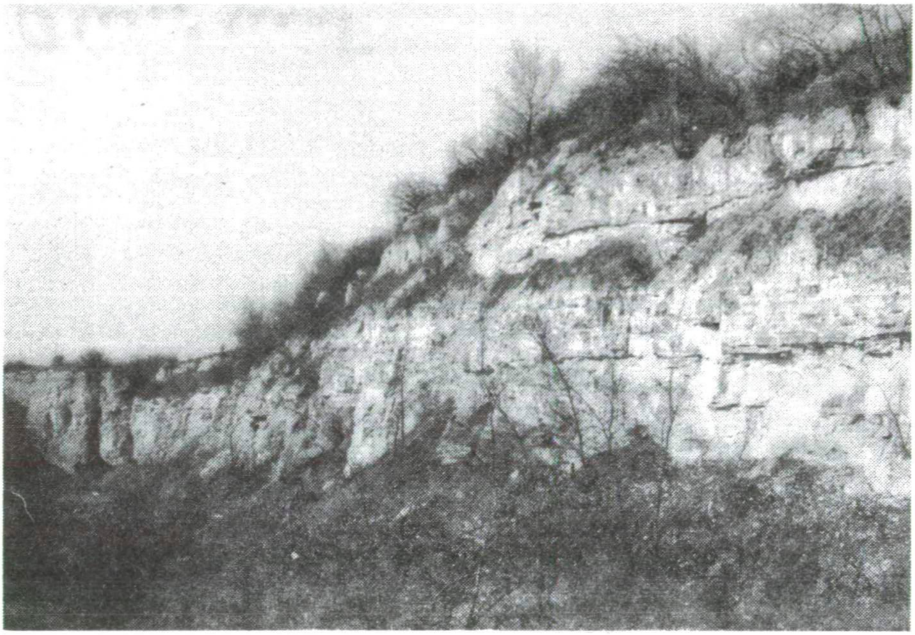


Figure 3 *Travertine associated with springs issuing from horst side onto flood-plain.* 1 = impermeable Tertiary sediments; 2 = permeable Triassic sediments; 3 = karst spring; 4 = travertine.



Picture 1 *The Lower Biharian lacustrine-paludal travertine T_6 (at 220 m a.s.l.), Pilis Mts. Hungary.*

8.2. *The travertine series of spring cone type.* In a geomorphological position similar to the previous, but on a lower terrace, surfaces this type of formation. In the case of this type spring water has a high mineral salt content and travertine precipitation is so intensive even at the spot of issue that a spring vent forms which rises into a cone, while on the slopes of the spring cone travertine accumulates in inclined layers. As a matter of fact, the spring cone can be destroyed or opened by outward effects. The spring issues on the cone top as long as it is made possible by hydrogeological conditions. Subsequent to hydrogeological change the development of the spring cone stops and on a lower surface — e.g. a terrace — the accumulation of a new spring cone may begin (*Fig. 4; Pict. 2*).

8.3. In the case of *travertine formation on valley sides* karstic rocks are buried under impermeable layers on the lower section of the valley side, therefore the spring can issue only above the base level, on the slope. Under such geomorphological or hydrogeological conditions the travertine precipitating from the karst spring accumulates on the slope, incidentally covering one or two surfaces. Here it is possible that during a longer period of travertine deposition two geomorphological surfaces of various age are buried under identical travertine mantles (*Fig. 5; Pict. 3*).

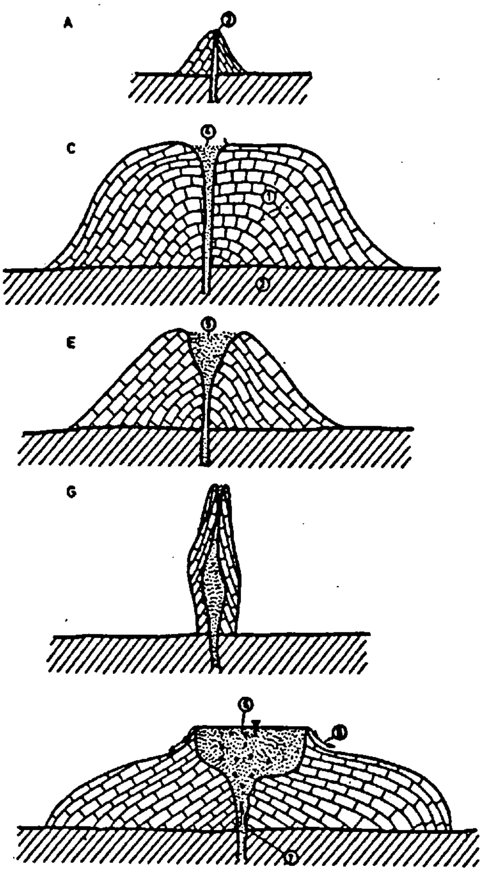


Figure 4 *Main morphological type of travertine cones.*
A = Regular small spring cone, B = Distorted small spring cone C = Elongate cone, D = Coalesced spring-cones aligned, E = Regular spring-cone, F = Spring-cone with parasitic cone, G = Spring-cone of small basal area with steep sides, H = Steppes spring-cone "Tetarata", I = Cone with spring-lake, J = Flat spring-cone of low height.
1 = Freshwater limestone, 2 = Country rock, 3 = Spring vent, 4 = Spring funnel, 5 = Spring-neck, 6 = Spring-lake, 7 = Upwelling waterflow, 8 = Overflowing springwater

8.4. The type of *tetarata barrier travertines* is genetically similar to the travertine type on hillslopes only with different geomorphological conditions, and the surfaces where travertine is precipitated are larger. In their origin flat surfaces above the level of the

Picture 2 *Impressive travertine accumulation precipitated from spring waters flowing down valley walls, Hamman Meskoutine, Algeria*

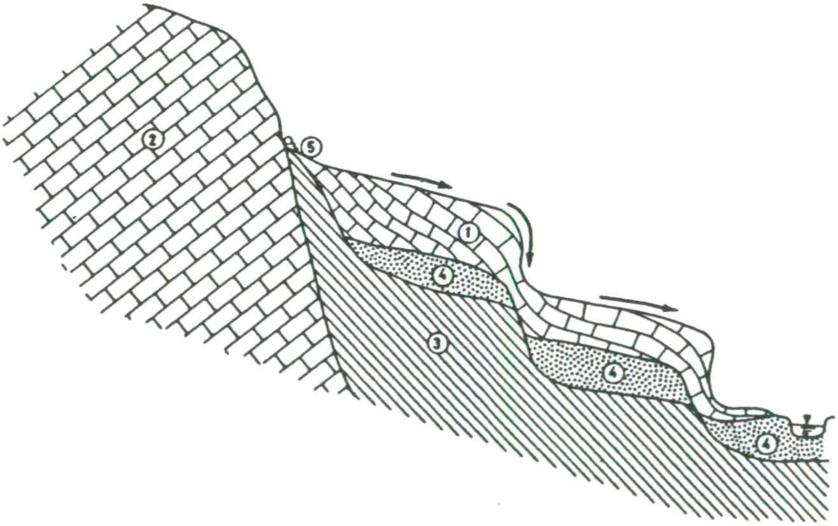


Figure 5 *Travertine of valley-side type.*
1 = travertine; 2 = water-holding limestone or dolomite; 3 = impermeable rock; fluviatile sediments, occasionally slope deposits; karst spring

Picture 3 *The valley-wall type travertine of the Pamukkale thermal spring in Turkey.*

flood-plain (broad terraces, pediments, raised beaches) can be postulated and hydrologically springs of abundant discharge can be taken into account. The karst water under considerable hydrostatic pressure mostly issues from springs in karstic horsts covered by unconsolidated deposits or directly in karst outcrops, or perhaps from springs of abundant water along faults where spring lakes form. Spring water builds a tetarata barrier on the lake margin. The spring water which issues on a higher surface flows over lower geomorphological surfaces, too, giving rise to lake basins. From the downflowing spring water tetarata barriers result in the accumulation of thick travertine series in the lake behind the barriers (*Fig. 6*).

8.5. *Travertine of mixed type.* The last described types can often intermix with each other with the changing geomorphological and hydrogeographical conditions, and one type may survive another. Thus rather diverse travertine series of mixed local properties come about.

Of all travertine types this group has the most intricate structure. This group is also considered an indicator of geomorphological surfaces.

9. The above outlined classification and the new interpretation of spring dynamics enabled, among others, *the recognition of travertine bodies formed in spring funnels and behind tetarata barriers, the correct explanation of the site of origin of travertine series of 30 to 40 m thickness and the interbedded terrestrial deposits and the better understanding of their chronological role.*

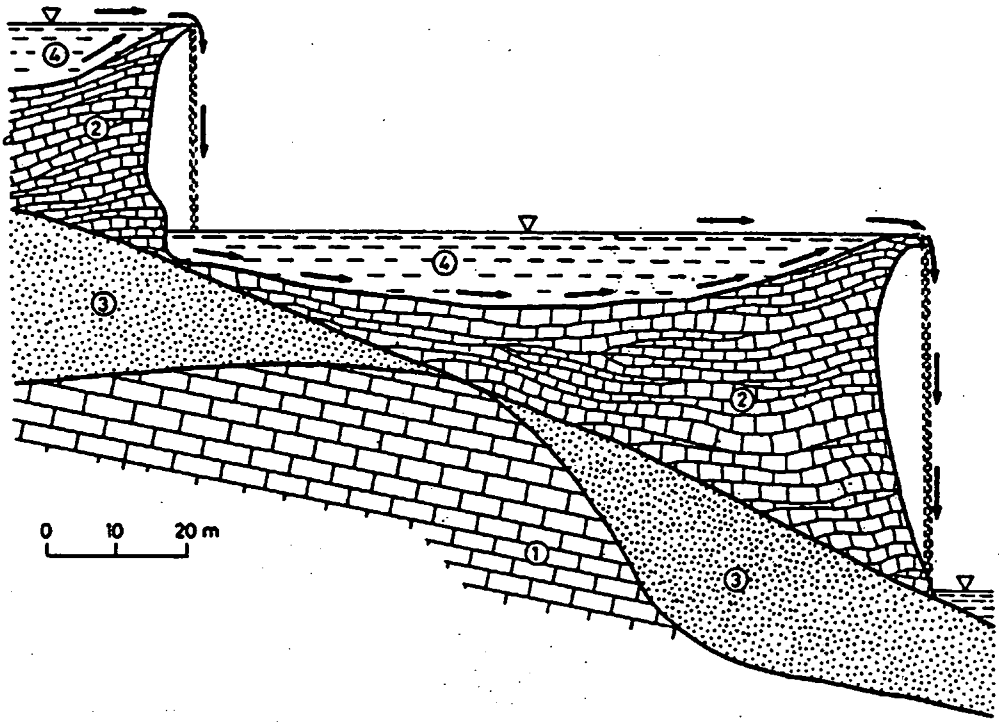


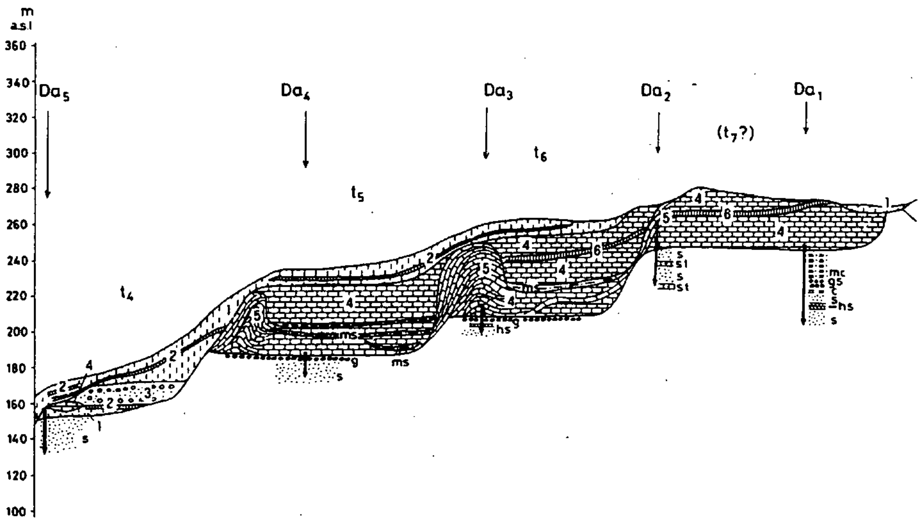
Figure 6 *Formation of tetarata basins of terraced slopes*
1 = travertine; 2 = tetarata dam; 3 = floor; 4 = tetarata lakes

The significance of travertine horizons is underlined by the fact that in the Buda and Gerecse Mountains, and generally in mountains of Mesozoic rocks, distinct geomorphological surfaces (raised beaches, pediments, terraces, etc.) are less frequent than travertine horizons on valley hillslopes. In our experience the higher terraces of valley sides (if uncovered by travertine) may be eroded or buried under slope deposits. In the mountain fore lands of unconsolidated sediments pedimentation continued in certain periods of the Pleistocene, while in the more humid interglacials intensive dissection erased even the last traces of older geomorphological surfaces, the steps of terraces.

10. Since the possibility of karst water activity resulting in travertine accumulation can be associated with as much as four or five geomorphological-karst hydrological situations, the *correlation between travertine occurrences and geomorphological surfaces* also became more intricate.

In most of the cases travertine accumulates on the basic level. The travertine formed there always *preserves a certain geomorphological surface and pointed to its evolution.*

It occurred, however, that travertine series deposited on surfaces above the base level or on hillslopes in some special situations. Some karst springs may have been active in identical topographical positions for longer periods, while in the near neighbourhood there was a remarkable change in the relative elevation of the base level (due to valley cutting or terrace formation on a lower level, etc.). The change (subsidence) of base level did not involve the sinking of the level of karst springs in each of the cases and always in a short time (*Fig. 7*).



1 = loess, slope loess; 2 = fossil soils in loess; 3 = terrace gravel; 4 = travertine; 5 = tetarata dams; 6 = fossil soil in travertine;
D_{a1}-Da5 = borehole locations; t_1-t_7 = terraces; c = clay; mc = muddy clay; ms = muddy sand; s = sand; gs = gravelly sand; hs = hydromorphous soil; st = sandstone; g = gravel.

Figure 7 *Profile of Danube terraces V-VII and the overlying travertine sequences based on superficial exposures and boreholes* (after Pécsi, Scheuer and Schweitzer, 1980).

11. On the basis of *the relationship between the base level and the displacement of springs* three cases are frequent for the travertine formation.

In the *first* possible case, the lowering of the base level is followed by the springs. The springs above the local base level cease to be active in a very short time, and thus become travertine series distinct in both age and geomorphological form. This type is mostly characteristic of the valley floor lacustrine-paludal type of travertines.

In the *second* case springs always follow the subsidence of the base level of erosion, but springs on higher levels keep up their activity or slowly run dry with gradually decreasing discharge.

Here the old spring on higher level keeps on depositing travertine, but in a reduced rate according to the decreasing discharge. The new spring issuing on the lower level begins to accumulate travertine in its environs, too. If the distance between the two springs is not so large as to allow independent lime accumulation, the processes are connected and complex intertwining travertine results. In these cases detailed investigations are necessary to establish the correct sequence of layers.

If the karst springs on the lower and higher terrain are distinct from each other spatially, independent travertine formation begins on the lower level, too.

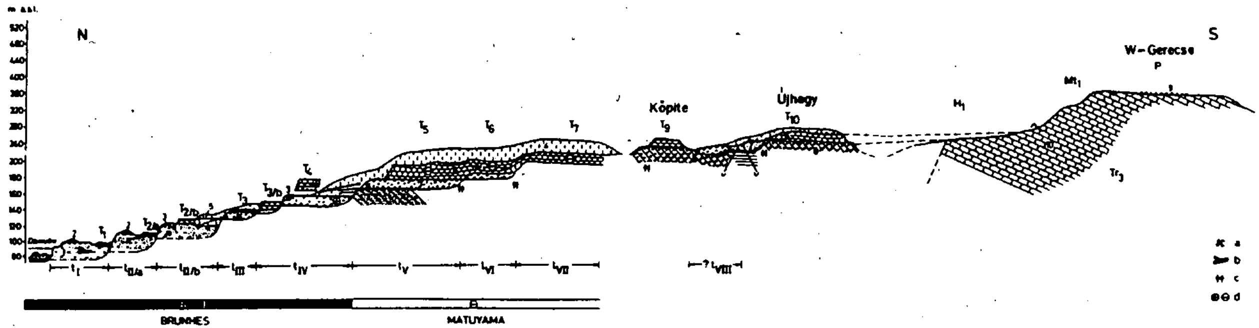
In the *third* possible case springs follow the subsidence of the local base level with a delay, or do not follow it at all. As a result on the terraced valley sides formed in several stages, mainly valley-side and mixed type travertine series formed in an intricate tetarata fashion.

12. Spring discharge and consequently assumed *travertine deposition had optimal* conditions if precipitation was abundant all through the year, and annual peaks of precipitation occurred in spring, autumn, and winter. Travertine accumulation of lesser intensity or of a temporary nature is probable if there is a more humid spell within a drier climatic period, or due to lesser evaporation and sparser vegetation the conditions for the recharge of water are less favourable under the conditions of lower values of annual precipitation.

13. The reevaluated previous and recent results in the investigations of flora, molluscs, and vertebrate fauna within the periods of the Pleistocene considered up to now homogeneous, several distinct climatic stages followed each other. The flora and mollusc investigations prove that travertines may form in any period when the necessary conditions exist (precipitation, vegetation) and therefore *their origin, contrary to the general opinion, cannot be restricted to the interglacials or interstadials*. The rate of travertine accumulation and the intervals indicate the time of the given climatic change. Thus *travertine series also reflect the climatic stages of the period of their origin*. In these investigations much help is given by the so far neglected unconsolidated sedimentaries of various types and age which reflect different climates, and are interbedded in the travertine series (such as loess, sandy loess, sand, fossil soils, deluvia, etc.).

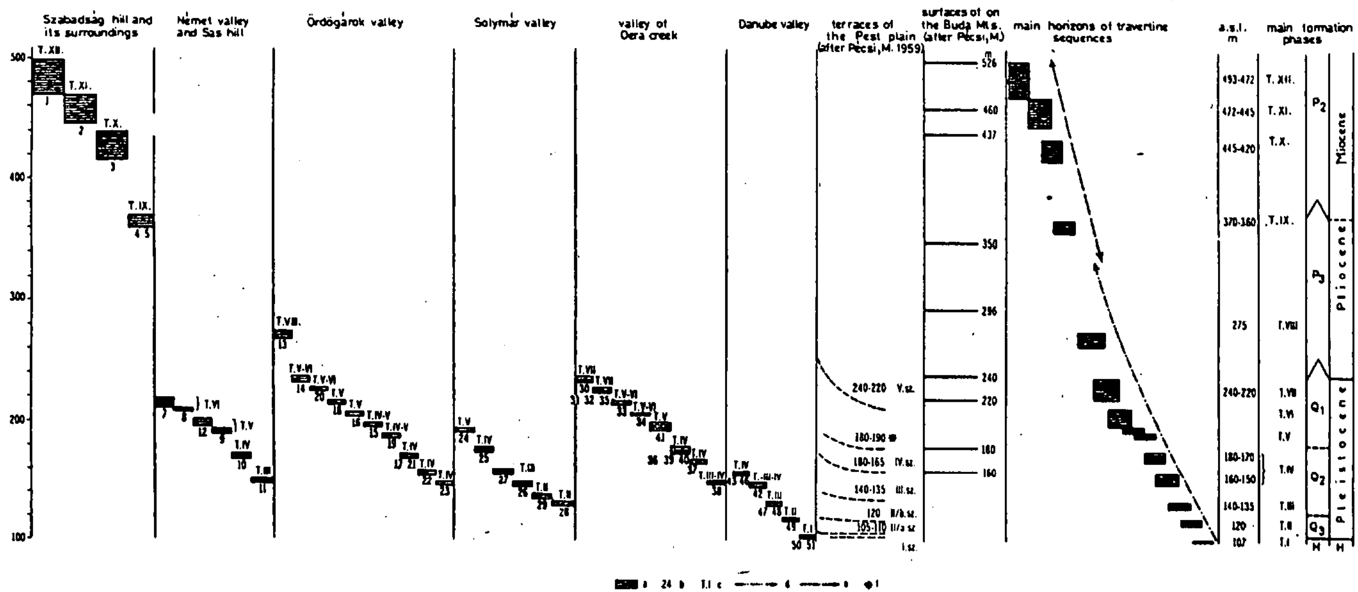
Role of Travertines

14. A peculiar geomorphological feature of the Hungarian Mountains is the frequent accentuation of the Neogene and the younger Quaternary geomorphological surfaces by occurrences of travertine overlying them. The investigations allow the conclusion that travertine series appear on at least ten geomorphological surfaces of the Gerecse Mountains, and on twelve surfaces into the Buda Mountains. Although in some groups of the Gerecse and the Buda Mountains *travertines occur in different positions, their positions also indicate a chronological sequence* (*Figs. 8, 9*).



1 = Fluviatile terrace gravel and sand; t_I-t_{VII} = terraces, Terrace gravel t_{VIII} is presumed to overlie the Upper Pannonian delta gravels by an erosional unconformity, destroying the uppermost Pannonian cross-bedded sands; 2 = blown sand; 3 = remnants of Pleistocene cryoturbation; 4 = loess, slope loess; 5 = fossil soils in loess; 6 = travertine horizons; T_1-T_{10} = travertine horizons of different age; 7 = Upper Pannonian cross-bedded sands and gravel with rounded travertine blocks in lower parts; 7a = Upper Pannonian cross-bedded sand (?) Bélbaltavárium?; 8 = Upper Pannonian clays; 9 = Miocene (?) terrestrial gravels; 10 = Upper Triassic limestone; H_1 = Upper Pliocene pediment remnant with Upper Pannonian wave-cut platform No. 2 preserved on its margin; M_{t1} = Upper Pannonian marine terrace; P = pre-Tertiary — Tertiary planation surface with Miocene terrestrial gravel occurrences; a = fauna location; b = fossilized tree trunk; c = traces of hot spring tunnels in travertines and gravel; d = palaeomagnetic polarity.

Figure 8 *Geomorphological horizons of the Western Gerecse Mountains* (after Pécsi, Scheuer, Schweitzer and Pevzner).



a = travertine horizons; b = locations of occurrences; c = T_I-T_{XII} = main travertine formation phases; d = travertine horizons associated with Danube-valley occurring on the eastern margin of the Buda Mountains and formed during the development of valley systems; e = travertine horizons associated with tectonic movements (mainly uplifted) and related valley formations in the János and Szabadság-hill region; f = local terrace occurs in Pest-plain between alluvial fan terraces IV and V.

Figure 9 *Travertine horizons and main formation phases in the valleys of the Buda Mts.* (after Scheuer and Schweitzer, 1973).

Undoubtedly the oldest travertines in the Carpathian basin are related to the raised beaches of the Pannonian inland sea or to gravelly deltaic deposits, or overlie them and are also situated on Pliocene pediments.

Certain geomorphological surfaces are mostly preserved by travertines to this day.

15. It was found that most of the travertine horizons formed (on the actual base level on Pannonian raised beaches, pediments, fluvial terraces and lacustrine raised beaches) and the travertine series accumulated in this position always preserve a certain geomorphological surface and reflects its evolution.

Consequently, the places of issue of Pliocene and Quaternary karst springs regionally also followed the evolution relief of the periodical subsidence of base level from the Middle Pliocene, both on mountain margins and in the valleys. The *cessation of activity of springs* issuing on the geomorphological surfaces *were caused by* changes in the karst hydrological system (*subsidence, uplift*) which can be followed not only vertically but also horizontally (*Fig. 10*).

16. In the Carpathian basin the travertine horizons are *associated with* characteristic *geomorphological surfaces*: the horizons were formed them:

a. Pannonian (Upper Miocene) raised beaches;

b. Pliocene pediments;

c. Pleistocene terraces nos. II/a to VII;

d. Holocene surfaces.

Day spring caves can be associated with Pannonian or Pliocene erosion surfaces: they only serve to supplement correlation which represents some stages of valley development.

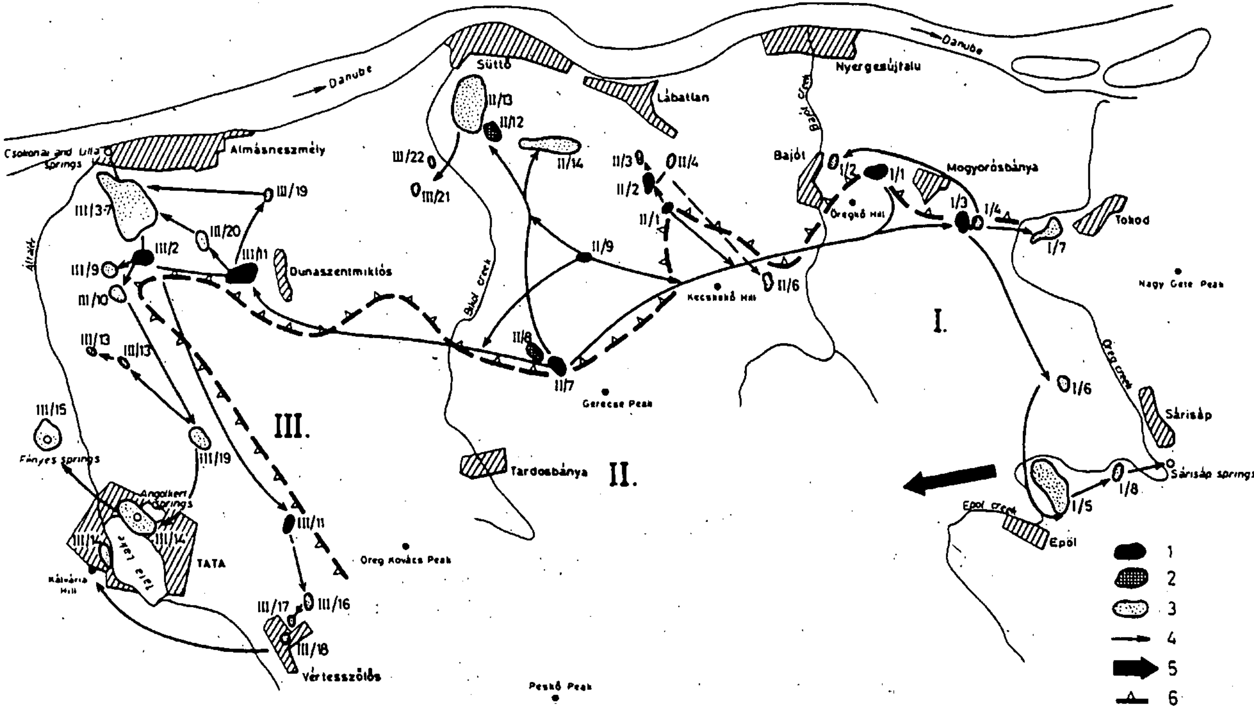
For the alteration of base levels for springs it can be hypothesized that they reflect Pliocene and Quaternary tectonic stages.

In the Buda and Gerecse Mountains travertine occurrences indicate ten to twelve geomorphological surfaces (after some simplifications) which show the degree and stages of tectonic uplift continued in cycles from the Upper Miocene (Lower Pannonian) to the Holocene. The rate of uplift — by the positions of travertine horizons — may have been 70 to 80 m in the Upper Miocene, 80 to 100 m in the Pliocene, 130 to 140 m in the Quaternary and within that value 6 to 8 m in the Holocene.

DATING OF TRAVERTINES BY GEOMORPHOLOGICAL, BIOSTRATIGRAPHICAL, PALAEOMAGNETIC, AND ABSOLUTE CHRONOLOGICAL (C^{14}, Th/U and ESR) METHODS

17. Previously by geological, geomorphological, paleontological and archaeological data and finds only classic relative dating could be used.

In the last two decades some new chronological methods evolved which enabled us to date the absolute age of travertines overlying certain terraces. In the early 1970s a team was established, led by M. KRETZOI and M. PÉCSI, to continue the geochronological evaluation of geomorphological surfaces with biostratigraphic finds. This work still goes on (HENNING, G.I. — GRÜN et al. 1983; SCHWARZ, H.P. — SKOFLEK, I. 1982).



1 = Upper Pannonian springs and travertines; 2 = Upper Pliocene springs and travertines; 3 = Quaternary springs and travertines; 4 = direction of spring displacement; 5 = direction of Late Pleistocene spring displacement; 6 = <R>presumed Upper Pannonian shoreline; I = Eastern Gerecse; II = Central Gerecse; III = Western Gerecse.

Figure 10 *Principal travertine occurrences in the Gerecse Mountains* (after Scheuer and Schweitzer)

To establish age units of travertines and *to place* their geomorphological positions *on a time scale* the Upper Cenozoic stratigraphic-morphogenetic-climatic and biological evolution synthesis, the Pliocene-Quaternary chronostratigraphic system by M. Kretzoi (1969), D. Jánossy (1978), M. Pécsi (1970), and M. Kretzoi and M. Pécsi (1979) was used as a basis (*Tables 1-2*).

18. On the fluvial terraces, pediments and raised beaches on the margins of the Gerecse and Buda Mountains ten or twelve travertine horizons of various ages are located in a step-like fashion. They help to reconstruct a splendid series of events, *stages of tectonic movements* during the Pliocene and Quaternary relief evolution.

19. *Ordinals* were placed to the travertine occurrences from the lowest-lying one (at 107-100 m a.s.l.) to the highest one (in the Buda Mountains at 493 m a.s.l., in the Gerecse Mountains at 350 m a.s.l.) and they were given *signs from* T_1 to T_{12}. Two groups can be differentiated for the travertine horizons arranged in a step-like fashion.

a. The members of the *lower series* — deposited on terraces on the valley sides — come close above each other between 107 and 250 m a.s.l. (horizons T_1 to T_7).

b. The members of the *higher series* (T_8 to T_{12}) — deposited on older geomorphological surfaces — follow each other with considerable intervals of height and, compared to the lower ones, they manifest distinct lithological differences, too.

20. In the *Gerecse Mountains* the members of the lower series can be correlated to the Danubian terraces (*Fig. 8*).

20.1. *Travertine* T_1 was deposited on the high flood-plain (*Terrace I/b*). The age of the tree trunk find of the terrace gravel was found 11,830 ± 10000 years old, i.e., early Holocene, by C^{14} examination.

20.2. *Travertine* T_2 covers the second flood-free terrace (*no. II/b*). At Tata the age of the lower part of the travertine deposited on the terrace II/b of the Általér stream, and including the paleolith settlement, is 101,000 ± 10,000 years, and the age of the upper part is 98,000 ± 8,000 years. In the Vértesszőlős section its Th/U age is 135,000 ± 11,000 years. The travertine can be dated in the last interglacial (Pict. 4).

20.3. *Travertine* T_3 overlies the Áltálér terrace III. At Vértesszőlős it is 248,000 ± 67,000 years old. The ESR age of this latter is 202,000 ± 20,000 years. The travertine belongs to *the middle part of Solymár period.*

20.4. *Travertine* T_4 overlies terrace IV. Its ESR age at Dunaalmás is 360,000 ± 36,000 years and in the Vértesszőlős section the one containing the paleolith settlement is more than 350,000 Th/U years. *According to the faunistic finds it can be referred to the Tarkő period of the Upper Biharian.*

20.5. *Travertine* T_5 is paleomagnetically of reverse polarity, i.e. older than 700,000 years. In the new interpretation of the Archidiskodon meridionalis (planifrons) FALC, Megaloceros sp. and accompanying faunas (KRETZOI, M. 1954, 1979; JÁNOSSY, D. 1979) Lower Pleistocene—Lower Biharian age is postulated.

20.6. *Travertine* T_6 also shows reverse polarity and was formed in the Matuyama palaeomagnetic era reaching back to 2.4 million years. By the rich microfauna of the red brown paleosol interbedded into travertine layers it can be referred to the *Kisláng horizon of the Upper Villányium* (JÁNOSSY, D. 1979).

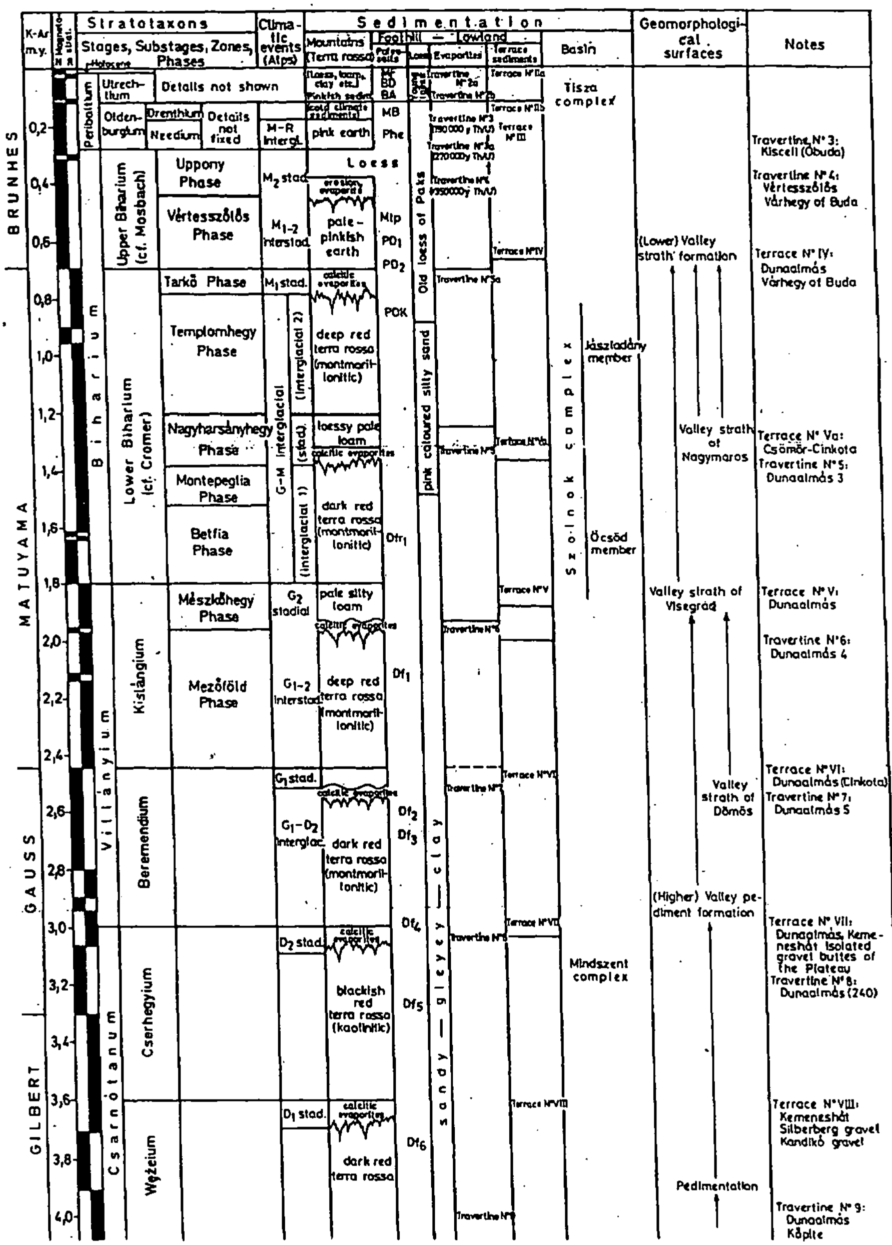


Table 1. *Correlation of the Terrestrial, Biostratigraphical and Geomorphological History of the Pliocene and Quaternary in the Carpathian Basin* (Kretzoi and Pécsi).

m.y.	Stratotaxons: Stages	Stratotaxons: Substages, Zones		Sedimentation: Travertines	Sedimentation: Terraces	Sedimentation: Basin sediments	Tectonics	Geomorphological surfaces	Notes
	Peribaltium	Utrechtium, Oldenburgium	—	For details see Table 2					
	Biharium	Uppony, Vértesszőlős		Travertine N°4, Travertine N°5a	Terrace N°IV	↑			
1		Lower Biharium (cf. Cromerium): Tarkő, Templomhegy, Nagyharsányhegy, Montepeglia, Betfia	OM.1	Travertine N°5	Terrace N°Va		Bakinian (2-300 m upheaval)		
2	Villányium	Kislángium	NM.17	Travertine N°6	Terrace N°V				
		Beremendium	NM.16	Travertine N°7	Terrace N°VI		Villányian		
3	Csarnótanum	Cserhegyium	NM.15	Travertine N°8	Terrace N°VII		Basalt tuff? ?New Roumanian	↑ Pediment surfaces N° 2a	Basalt tuff: Magyargencs
4		Wężelum			Terrace N°VIII			↑	
	Ruscinium		NM.14	Travertine N°9	Old gravel sheet		? Roumanian	Pediment surface N°1	Kandikó, Silberberg (Ezüst-hegy)
5								↑	
6		Estramontium				Terrestrial sedimentation			
	Baltavárium	Bérbaltavárium	NM.13	Travertine N°10a	Beginning of river system forming	Cross-bedded fluviolacustrine sand group	Rhodanian	Beginning of the main period of pedimentation	T.N°10a. Gerecse: Mogyorós-bánya; Kőhegy; Várpalota
7		Hatvanium				↑	Basalt N°3	↑	Basalt N°3 Pula; Gérce
8		Sümegium	NM.12	Travertine N°10	Marine terrace N°1		Basalt N°2		T.N° 10. Várpalota; Nagyvázsony; Széchenyi-hegy; Gerecse: Új-hegy (320);
9									
10		Csákvárium	NM.11	Travertine N°11	Marine terrace N°2a	Late Pannonian sand-silt-clay group	Basalt N°1, Attican II		Mt.N°2a. Gerecse: Margithegy; Vértes: Haraszthegy; K.Bakony: Várpalota. T.N°11. Szabadsághegy (499–472); D.Bakony: Kapolcs
11		Rhenohassium	NM.10		Marine terrace N°2 Delta gravel formation	↑			Mt.N°2. Bakony: Bakonynána; Vértes: Murva-domb; Gerecse: Dunaszentmiklós (delta gravel)
12	Eppelsheimium	Bodvalum	NM.9						
13		Monacium	NM.8		Marine terrace N°3	Early Pannonian shale group; Glass sand; Ground gravel group			Mt.N°3. Budai-h.: Diósd-Sóskút; Balatonfelvidék: Balatonfüred

Table 2. *Correlation of the Terrestrial, Biostratigraphical and Geomorphological History of the Upper Pliocene and Quaternary in the Carpathian Basin* (Kretzoi and Pécsi).

Picture 4 *Travertine cone with spring funnel. In the background a small parasitic cone is seen. Vysny Sl.ac, Slovakia*

20.7. *Travertine T_7* shows red clay accumulations in its karstic depressions. At Süttő the Tapirus sp. find found in the Harasztihegy travertine and the archaic shape of the Archidiskodok meridionalis (JÁNOSSY, D. 1979) indicate upper *Csarnotanum, Cserhegyium*.

20.8. *Travertine T_8* can be referred to the upper horizon of the Upper Pannonian (Bélbaltavár period) identified by the enclosed mollusc fauna, and by the Unio wetzleri horizon.

20.9. *Travertine T_9* and T_{10} are the highest occurrences in the Gerecse Mountains (300 to 340 m a.s.l.). They are deposited on Upper Pannonian sandy-gravelly delta sediments and raised beaches. Their date of origin can only be estimated in lack of direct information. In the travertine T_9 — deposited at 300 m a.s.l. — Rozlozsnik (1919) recognized Upper Pannonian Dreissena sp. This is one of the most important evidences that the geomorphological surfaces mantled by travertine horizons at 300-340 m a.s.l. belong to the Upper Pannonian. By the position of travertines, they belong to the terrestrial *Upper Pannonian Sümegium* or to the *lower Upper Pannonian*.

21. *In the Buda Mountains* — similar to the travertine horizons in the Gerecse Mountains — the members of the lower seies (T_1-T_7) could be corresponded to the terraces of the Danube and its tributaries (*Fig. 9*).

21.1. *Travertine T_1* is deposited on the high flood-plain (on terrace I/b) at 105-108 m a.s.l. The radiocarbon analysis of the paleosol dividing the blown-sand series covering the terrace II/a of the Pest Plain is of Early Holocene age (9,500 years).

21.2. *Travertine T_2* covers terrace II/b (120 m a.s.l.). Its Th/U age is 70,000 years.

21.3. *Travertine T_3* accumulated on the Danube terrace III (150 m a.s.l.). By Th/U analyses it is dated at 175,000 years and can be corresponded to the middle part of the *Solymár period*.

21.4. *Travertine T_4* is deposited at 170 to 180 m a.s.l. and adjusts to the Danubian terrace IV. According to palaeomagnetic analysis it has normal polarity. The Th/U age of the travertine overlying terrace IV is 358,000 years. Faunistic finds also give evidence to the Tarkő period of the Upper Biharian (JÁNOSSY, D. 1979).

21.5. *Travertines T_5* - T_6 lie at 220 to 200 m a.s.l. They have reverse polarity, i.e. they may be older than 700,000 years. The enclosed fauna remnants — Archidiskodon "Trogontherii Cromerensis Depéret et Majet", Mimomys savini Hinton, Hippopotamus antiquus Desmarest etc. — indicate Lower Biharian (JÁNOSSY, D. 1978; Pict. 1).

21.6. *Travertines T_7*—T_8 are deposited on pediments of the Szabadsághegy — the higher at 360 to 370 m a.s.l. and the lower at 270 to 250 m a.s.l. Chronologicallly significant fauna have been revealed from them.

21.7. *The older travertine horizons (T_9*—T_{12}) are deposited on Upper Pannonian sandy-gravelly deltaic deposits and on raised beaches. Their dating had been uncertain until recent years. They were generally considered Levantan or Lower Pleistocene. The most recent geomorphological and paleontological investigations help divide the travertine series regarded homogeneous up to now.

The *oldest travertine T_{12}* (472-499 m a.s.l.) overlies the *Eppelsheimian (Lower Pannonian)* raised beach by its geomorphological position.

The lower-lying T_{11} travertine horizon M (472-445 m a.s.l.) is underlain by Lower Pannonian according to M. Kretzoi (1981) judged from the collected Aceratherium incisivum KAUP, sp. fauna. Thus the age of the distinct travertine horizon at 472-499 m a.s.l. one level higher, is either Csákvárium or the older *upper part of the Lower Pannonian*, the *Rhenohassium*.

Travertine T_{10} also overlies the raised beach of the Széchenyi-hegy. The fauna identified by M. Kretzoi (1978) from the travertine at 420 m proves *Sümegian age*. This travertine is distinct in position and lies about 80 m lower than T_{12}—T_{11} horizons on the Szabadság-hegy. According to M. Kretzoi its Parapodemus, Gerbillida and Ochatonida sp. exclude the possibility of Lower Pannonian (Eppelsheimian) age and the small Giroffida and Tapiriscus give testimony against Upper Pannoniaum (Hatvanium or Unio wetzleri).

POSSIBLE INDUSTRIAL USE OF TRAVERTINE SERIES WITH SPECIAL REGARD TO RESEARCH IN TO ORNAMENTAL STONES

22. The extended *application* of travertines *in building industry* is common and popular. Therefore, the quantitative and qualitative cadastral survey and reserves calculations for the building-industrial use of travertines has begun.

In Hungary, the rapid and dynamic urban development of the last decades increased the demand for building raw materials, and it motivates and necessitates the survey of the available reserves in order to promote their rational exploitation and utilization.

REFERENCES

Allen, E.T. and Day, A.L., Hot springs of the Yellowstone National Park, Carnegie Institution of Washington Publication 446, 525 p. (1935)

American Geological Institute, Dictionary of geological terms, Olphin Reference Book, p. 360. (1962)

Burnes, Iván and O'Neill, J.R., Calcium-magnesium carbonate solid solutions from Holocene conglomerate cements and travertines in the Coast Range of California, Geochimica et Cosmochimica Acta, V. 35, pp. 699-718. (1971)

Baszkov, E.A. and Szuzikov, Sz.N., Gidrotermál Tyihookeanszkogo szegmenta zjemli, Moscow, p. 171. (1975)

Bögli, A., Karsthydrographie und physische Speläologie, Springer Verlag, Berlin-New York, pp. 1-137. (1978)

Evans, P., The Present Status of the Determination in the Quaternary (with Special Reference to the Period between 70,000 and 1,000,000 Years ago), 24th IGS, Section 12, Quaternary Geology, Montreal, pp. 16-21. (1972)

Feth, J.H. and Barnes, I., Springs Deposited Travertine in eleven Western States, U.S. Department of the Interior Geological Survey, pp. 1-68. (1979)

Frechen, J. and Lippolt, H.J., Kalium-Argon-Daten zum Alter des Laacher Vulkanismus, Eiszeitalter und Gegenwart, 10., pp. 5-30. (1965)

Geurts, M.A., Genese et Stratigraphie des Travertins de Fond de Valléc en Belgique, Acta Geographica-Lovaniensie, 16, pp. 1-66. (1976)

Hennig, G.J., Grün, R., Pécsi, M. and Brunnacker, K., Th-230/U-234 — sowie ESR-Altersbestimmungen einiger Travertine in Ungarn, Eiszeitalter und Gegenwart, 33, pp. 9-19. (1983)

Jánossy, D., A magyarországi pleisztocén tagolása gerinces faunák alapján (Classification of the Hungarian Pleistocene based on vertebrate fauna), Bp. Akad. K., 206 p. (1979)

Jakucs, L. Aggtelek és környéke (az észak-borsodi karsztvidék) útikalauza. Bp. Sport. 358 p. (1961.)

Jakucs, L. A karsztok morfogenetikája. A karsztfejlődés varianciája. Bp. Akad. K. 310 p. (Földrajzi Monográfiák 8.) (1971.)

Jakučs, L. Szerelmetes barlagjaim Bp. Akad. K. 315p. (1993.)
Lozek, V., Travertines, INQUA, Warszawa, pp. 1-19. (1961)
Messini, M. and di Lollo, E.C., Acque minerali del mondo, Roma, 417 p. (1957)
Pécsi, M., Hegylábi (pediment) felszínek a magyarországi középhegységekben (Pediment surface in the Hungarian Middle Mountains), Földr. Közlem. 11, 3, pp. 195-212. (1963)
Pécsi, M., Development of the Hungarian section of the Danube valley, Geoforum, 6, pp. 21-32. (1971)
Pécsi, M., Geomorphological position and absolute age of the lower Paleolithic site at Vértesszőlős, Hungary, Földr. Közlem. 21, 2, pp. 109-119. (1973)
Pécsi, M. and Osmond, J.K., Geomorphological position and absolute age of the settlement at Vértesszőlős of the lower Paleolithic prehistoric man in Hungary, Ninth Congress Internat. Union Quaternary Research, Christchurch (N.Z.), 2-10 Dec. 1973, Abstracts, pp. 283-284. (1973)
Pécsi, M., Scheuer, Gy. and Schweitzer, F., Die plio-pleistozänen tektonischen Bewegungsphasen im Budaer Gebirge, DEUQUA-Tagung, 3-5 Sept. 1978, Wiener Becken — Mittleres Burgenland — Transdanubien: Excursionsführer, Helga Schneiderbauer, Budapest-Wien, pp. 45-49. (1978)
Scheuer, Gy. and Schweitzer, F., Új szempontok az édesvízi mészkőösszletek képződéséhez (New aspects on the formation of travertine sequences), Földr. Ért. 19, 1, pp. 381-392. (1970)
Scheuer, Gy. and Schweitzer, F., New aspects on the formation of the freshwater limestone series in the environs of the Buda Mountains, Földr. Ért. 33, 2, pp. 113-135. (1974)
Scheuer, Gy. and Schweitzer, F., The development of the Hungarian travertine sequence during the Quaternary, Földr. Közlem. 21, 2, pp. 133-141. (1974)
Scheuer, Gy. and Schweitzer, F., A budai hévízforrások fejlődéstörténete a felsőpannontól napjainkig (Entwicklungsgeschichte der Budaer Thermalquellen vom oberen Pannon bis zu unseren Tagen), Hidrológiai Közl. 11, pp. 492-501. (1980)
Scheuer, Gy. and Schweitzer, F., A Gerecse-hegység paleokarszthidrológiai viszonyainak rekonstrukciója a felsőpannontól napjainkig (Rekonstruktion der paläokarsthydrologischen Verhältnisse des Gerecse-Gebirge vom oberen Pannon bis zu unseren Tagen) Hidrológiai Közl. 61, 8, pp. 333-380. (1981)
Scheuer, Gy. and Schweitzer, F., A magyarországi édesvízi mészkőösszletek származása és összehasonlító vizsgálatuk (Origin of Hungarian freshwater limestone sequences and their comparative study), Földtani Közl. 111, pp. 67-97. (1981)
Scheuer, Gy. and Schweitzer, F., A Gerecse és a Budai-hegység édesvízi mészkőösszletei és képződésüknek geomorfológiai és geokronológiai sajátosságai (Travertine sequences in the Gerecse and Buda Mountains: geomorphological and geochronological features of their development). Tézisek 24—25 old. (34, 53, 61, 67. tételek). Hung. Acad. Sci., Budapest, 213 p. (1983)

Scheuer, Gy. and Schweitzer, F., The role of travertines in the geomorphological, paleohydrogeological and geochronological research of the upper Cainozoic. In: Pollution and water resoures. (Columbia University Seminar series XVII—XIX.). New-York. 71—90. (1986)

Scheuer, Gy. and Schweitzer, F., Genetics and occurrence of Holocene travertines in Hungary. In: Geomorphological and geoecological essays. (Studies in geography in Hungary 25.) Bp. Akad. K. 39—48. (1989)

Scheuer, Gy. and Schweitzer, F., Travertine formation of the Gerecse Mountains. In: Vértesszőlős site, man and culture. Bp. Akad. K. 43—62. (1990)

Schréter, A., A Buda és Gerecse hegységperemi édesvizi mészkőelőfordulások (Freshwater limestone occurrences on the margins of the Buda and Gerecse Mountains), MÁFI Évi Jel. 1953-ról, pp. 111-146. (1953)

Schwartz, H.P. and Skoflek, I., New dates for the Tata, Hungary, archaeological site. Nature, 295, pp. 590-591. (1982)

Schweitzer, F. and Scheuer, Gy., Geomorphological position and chronological classification of Hungarian travertines. In: Proceedings of the International Symposium "Geomorphology and Sea" and the Meeting of the Geomorphological Commission of the Carpatho-Balcan Countries Mali Losinj, September 22—26 1992. Zagreb, Dept. of Gejogr. Faculty of Science Univ. of Zagreb. 223—240. (1992)

Schweitzer, F., Angaben zum Trocken-warmen Klima des Ungarischen beckens Aufgrunden des "Wüstenlacks" in Mogyoród. In: Abstracts. Debrecen. Carpatho-Balcan Geomorphological Commission. 21—22. (1994)

Steiner, W., Zur Stratigraphie des Oberen Travertine im Quartär Profil von Ehringsdorf bei Weimar, Zeitschrift für geologische Wissenschaften 1, pp. 515-529. (1973)

Steiner, W., Die Faziesanalyse in der Travertinforschung, Zeitschrift für geologische Wissenschaften 7, o, pp. 443-446. (1979)

Zötl, J.G., Karsthydrogeologie, Springer Verlag, Wien-New York. (1974)

Address of authors:

Ferenc SCHWEITZER - Gyula SCHEUER
Geographical Research Institute,
Hungarian Academy of Sciences,
H-1388 Budapest, Andrássy út 62, HUNGARY