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MÁRTON PÉCSI (*)

EVOLUTION OF SURFACES OF PLANATION: EXAMPLE OF THE TRANSDANUBIAN MOUNTAINS, WESTERN HUNGARY

ABSTRACT: PÉCSI M., *Evolution of surfaces of planation: example of the Transdanubian Mountains, Western Hungary.* (IT ISSN 0391-9838, 1998).

This model claims that the surfaces of planation[1] once produced by some erosional processes, were reshaped in the later geological periods by repeated, alternating erosional and accumulation processes on the morphostructure also repeatedly affected by tectonic uplift, subsidence and horizontal displacement.

According to this model, late Mesozoic tropical etchplanation with paleokarst and bauxite formation did not continue during the Tertiary in the Transdanubian Mountains of Hungary. As a consequence of multiple differential tectonic subsidence, most of the range was buried in various thickness and at various intervals. This burial was followed by complete or partial exhumation on at least three occasions (Paleogene, Neogene and Quaternary). During repeated burial and exhumation the Cretaceous tropical etchplain was affected by further erosion or accumulation through non-tropical processes (such as peripedimentation, marine terrace formation, alluvial fan building and others). In the horst series of the Transdanubian Mountains, divided by graben-like basins, the position and evolution of the geomorphological surfaces allows the identification of some main groups:

1. (semi) exhumed horst of etchplanation in summit position;
2. buried horst of etchplanation in uplifted position;
3. horst of etchplanation in threshold position, buried or exhumed and reshaped, mostly pedimented;
4. buried etchplain in basin position;
5. peripediments, rock pediments, locally buried under detritus.

The model of geomorphic surface evolution through alternating erosion/accumulation does not only apply to the Hungarian medium-height mountains, but also to numerous other geomorphological regions, eg. the Alpine-Carpathian-Dinaric Mountains, several old mountains and massifs of Europe and other continents.

KEY WORDS: Late Mesozoic, Surface of planation, Burial, Exhumation, Polycyclic surfaces.

RIASSUNTO: PÉCSI M., *Evoluzione delle superfici di spianamento: l'esempio delle Montagne Transdanubiane, Ungheria Occidentale.* (IT ISSN 0391-9838, 1998).

Il modello ritiene che le superfici di spianamento, già prodotte da vari processi erosivi, vengano rimodellate in più tardi periodi geologici da ripetuti, alterni processi di erosione ed accumulo su morfostrutture ripetutamente interessate da sollevamenti tettonici, subsidenza e stiramenti orizzontali.

Secondo questo modello, lo spianamento di tipo tropicale (*etchplanation*) del tardo Mesozoico con la formazione di paleocarso e di bauxite non continuò nelle Montagne Transdanubiane. Come conseguenza di una complessa subsidenza tettonica differenziata, la maggior parte dei rilievi fu ricoperta in vari momenti da variamente spesse coltri sedimentarie. Il seppellimento fu però seguito da una totale o parziale esumazione almeno in tre momenti, nel Paleogene, nel Neogene e nel Quaternario. Durante questi avvenimenti la superficie di spianamento di tipo tropicale cretacea fu interessata da erosione o da sedimentazione attraverso processi non tipicamente tropicali (quali la peripedimentazione, la formazione di terrazzi marini, la messa in posto di mantelli alluvionali e altri). Nelle serie degli horst delle Montagne Transdanubiane, separate da bacini tettonici tipo graben, la posizione e l'evoluzione delle superfici consente il riconoscimento di alcuni morfotipi principali:

1. superfici di spianamento (*etchplain*) in posizione sommitale di horst parzialmente esumati.
2. superfici di spianamento (*etchplain*) in posizione tettonicamente sollevata di horst sepolti.
3. superfici di spianamento (*etchplain*) di horst in posizione di soglia tettonica, sepolti o esumati, e rimodellati, frequentemente interessati da processi di pedimentazione.
4. superfici di spianamento (*etchplain*) sepolte in corrispondenza di bacini.
5. peripediment, pediment in roccia, localmente sepolti da copertura detritica.

Il modello dell'evoluzione delle superfici geomorfiche attraverso processi alternati di erosione e sedimentazione può non soltanto essere applicato alle Montagne di media altezza dell'Ungheria, ma anche a molte altre regioni, quali le catene Alpine, Carpatiche e Dinariche, a molte vecchie montagne e massicci dell'Europa e degli altri continenti.

TERMINI CHIAVE: Tardo Mesozoico, Superficie di planazione, Seppellimento, Esumazione, Superfici policicliche.

INTRODUCTION

The term *geomorphological surfaces* denotes plains and gently sloping slopes, which are the products of erosion, of accumulation or of their combination, under the influence of tectonic processes. Their formation may be dated from their correlative sediments or by other methods.

For the timing of successive formation of landforms, i.e. for a reconstruction of the denudational chronology, an

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(*) *Geographical Research Institute, Hungarian Academy of Sciences, P.O.B. 64 H-1388 Budapest, Hungary.*

interpretation of the different geomorphological surfaces is needed. Several models were proposed for the development of erosional surfaces (landforms) on great continental morphostructures. Some of these have become classic (Davis, 1906, 1922; Penck, 1924; King, 1949, 1962; Büdel, 1957 and his followers, Bulla, 1958; Bremer, 1986).

1. According to Davis, the *peneplain* (ultimate peneplain) is the final product of fluvial erosion on different humid regions. The *almost plane surface* is the penultimate phase of the planation at the base level[2].
2. Penck's Primärrumpf (primary peneplain)[3] is a plain surface just emerged above the sea level. *Piedmonttreppen* (piedmont benchlands) are explained by fluvial erosion and retreat of valley sides. Erosional surfaces on slowly but uniformly elevating morphostructures may be explained this way.
3. According to King, pediplanation also takes place by the retreat of slopes on slowly but continuously elevating terrains, especially under semiarid climates, where the rate of the mechanical weathering exceeds that of the chemical one. Retreat of slopes results in a gradual surface lowering and pediplain formation. According to King, pediplanation[4] is the most widespread process reducing relief, this way it replaces Davis' peneplain theory.
4. Büdel proposes that the *double etchplain*[5] (doppelte Einebnungsfläche) is an erosion surface created by intensive lateritic deep weathering and strong washdown (stripping) of the thick weathered rock under a seasonal dry and wet tropical climate.
5. A *pediment* is a gentle erosional foothill slope in front of a steep mountain slope, generally formed of hard rock. *Pedimentation* is admitted to be the most general erosional, planation process. Mcgee, (1897) believes that a river, on leaving a mountain, deposits most of its load, while the rest of the sediment transported causes lateral planation (corrasion). The pediment is covered by a thin layer of sediment, deposited by sheetwash or by small rivers under a semiarid climate.

Several researchers adhere to the above models for the origin of *surfaces of planation*, while others criticise or modify them. In one respect these models are uniform, they suppose that the studied surfaces were formed during *long geological times*, when uplift was slow, continuous or periodical. It is generally admitted that the highest situated geomorphological surfaces are the oldest, the lower ones are ever younger. Such presumptions might only be valid for a part of the cases and for some geological times. Presumably the planation surfaces (models 1 to 5), explained by different processes, might be attributed to effects of as many different geographical environments. If this is true, each of these models and conceptions generally represent genetically and climatologically different morphofacies rather than one single, global type of surface. It must be mentioned that these early models of planation surfaces were based on fixist tectonism.

In this presentation we want to introduce a polygenetic model of geomorphological surface evolution, through processes acting on different morphostructures affected by plate tectonic events, particularly in orogenic belts. The units studied were horizontally displaced over great distances, tectonically dismembered, recurrently uplifted and subsided, thus the planation surface became repeatedly buried, elevated and exhumed again (Pécsi, 1970a,b). Polygenetic morphostructures with planation surfaces, which were shaped under the influence of alternating erosional and depositional processes of long duration, were removed from their original place and carried over long distances, passing under various climatic belts. This way units of most different genesis might have come in each other's proximity.

The tectonic and geomorphic history of the Transdanubian Mountains (Western Hungary) was used as a model for the evolution of such polygenetic planation geomorphological surfaces. Geological and geomorphological studies of the last half century served as a basis of a new geomorphological evolutionary model, differing from the previously mentioned ones (Pécsi, 1968, 1975, 1993; Székely, 1972).

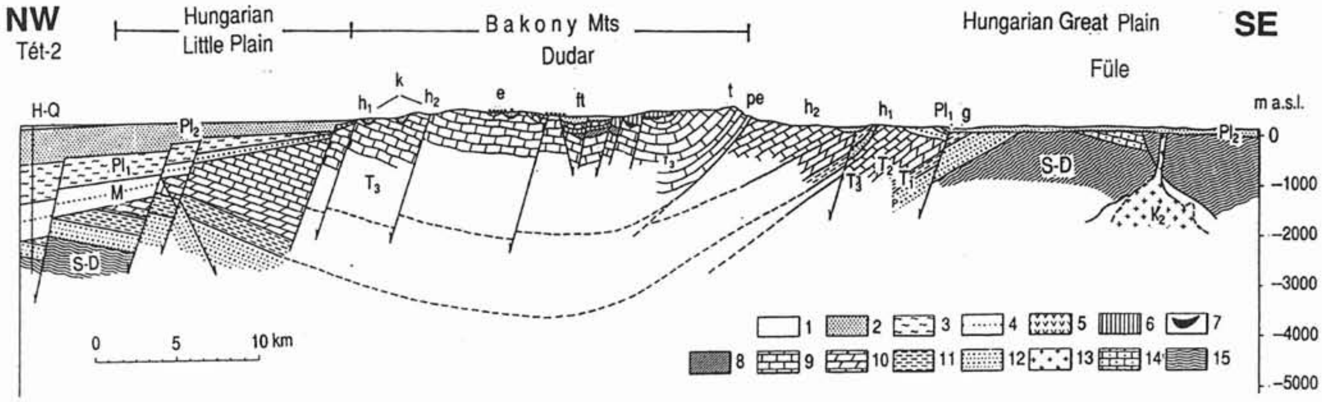

FIG. 1 - Profile across the Bakony Mountains (after Wein & Pécsi). 1) Holocene-Pleistocene fluvial sand and gravel, alluvial plain; 2) Upper Pannonian sand and clay; 3) Lower Pannonian (Miocene) claymarls; 4) Lower Miocene-Upper Oligocene gravel and sand (in the Dudar Basin); 5) Eocene coal seams and carbonate rocks; 6) Lowe Cretaceous (Aptian, Albian and Cenomanian) limestones and calcareous marls; 7) bauxite and related formations; 8) Jurassic limestones; 9) Upper Triassic dolomites and limestones; 10) Middle Triassic limestone; 11) Lower Triassic siltsstone, marl and limestone; 12) Permian sandstones and conglomerates; 13) Upper Carboniferous granite porphyry; 14) Lower Carboniferous conglomerate and shale; 15) Silurian - Devonian phyllite and marble; t) uplifted remnant of tropical etchplain; ft) buried etchplain; e) exhumed etchplain, locally covered with Miocene gravel; pe) mountain margin benchland; h_2) Pannonian marine terrace; h_1) piedmont surface (pediment); g) Pleistocene piedmont surface formed on moderately consolidated sediments (glacis); k) remodelled tropical etchplain in threshold position; Tét-2) prospect drilling; S-D) Silurian-Devonian; T_1, T_2, T_3) Lower, Middle, Upper Triassic; M) Miocene; Pl_1) Lower Pannonian (Upper Miocene); Pl_2) Upper Pannonian (Upper Miocene).

DISCUSSION

The Transdanubian Mountains (TM) is a low range of slightly folded structure, built mainly of Mesozoic and Paleogene carbonates (limestone and dolomite), affected by overthrusts and faults. Horst and graben structures are common, delimited by mainly NE-SW and NW-SE running structural lines. In the southern foreland a thick Paleozoic sequence of south Alpine affinities underlies the similarly thick Mesozoic strata (fig. 1). Comparative structural investigations proved that the TM was a part of the carbonate platform formed at the northern margin of the African plate in the southern Tethys, during the Triassic. During the rifting and subsequent convergence of the Tethys this unit was overthrusted on an oceanic crust fragment, the Penninic unit. The TM, as a part of a microcontinent, was subsequently carried into the southern Alpine area, wherefrom, in late Cretaceous/Paleogene times it was horizontally shifted into the Carpathian basin (Horváth, 1974; Géczy, 1974; Wein, 1977, 1978; Balla, 1988, Hámor, 1989; Fülöp, 1989; Stegena & Horváth, 1978).

During the late Triassic and Early Jurassic the low and extended carbonate platform of the TM was cut into a horst and graben structure. In the grabens the sedimentation went on during the Jurassic and early Cretaceous. On the elevated parts a long lasting continental downwearing went on during the Jurassic and Cretaceous. The upper Triassic carbonates were affected by tropical karstification, accompanied by bauxite formation. Cockpits and tower karst may have been formed under tropical savanna climate with humid and dry seasons, simultaneously with bauxite formation. The initial sediments of the bauxite formation were resedimented from siliciclastic areas by sheet wash and by small rivers. Lateritification was simultaneous with karstic planation. Witnesses of this marked tropical karst planation were buried and preserved by Lower Cretaceous (Albian), upper Cretaceous, and, locally, Paleogene sediments in the TM.

Buried surfaces of karstic planation may be found between horsts, forelands and on horsts, buried with Cretaceous or Tertiary strata (figs. 2 and 3).

The tropical karst planation surface of the TM was slightly remodelled between the Late Cretaceous and Middle Eocene (Laramian tectonic phase?). On horsts summits it was well preserved, but on the margins pediments were formed due to early Eocene subarid coarse clast production. Dolomite karst towers and bauxites, if not buried, were eroded or resedimented.

During Middle and late Eocene the area of the TM became an archipelago. Most of its territory subsided continuously, but not uniformly. The sea inundated the low horsts and intramontane basins. Bauxite bearing karstic surfaces of etchplanation were often buried during the Eocene. Bauxite lenses in sinkholes, capped with Eocene layers, are often interpreted as a result of a continuation of tower-karst plain formation and bauxite genesis in the first part of the Eocene (Bárdossy, 1977; Mindszenty & *alii*, 1984). This would mean that such bauxites are not merely products of Eocene redeposition of earlier deposits. We think, however, that early Eocene conditions characterised by dolomite breccia formation were not favourable for bauxite genesis and tower karst evolution. Under a subaridic climate predominantly coarse clastics were formed and transported by ephemeral water-courses and pedimentation prevailed (Pécsi, 1963, 1970b).

From the Eocene-Oligocene boundary the TM was uplifted and the previously submerged and buried parts were eroded. Some segments or entire horsts were exhumed and

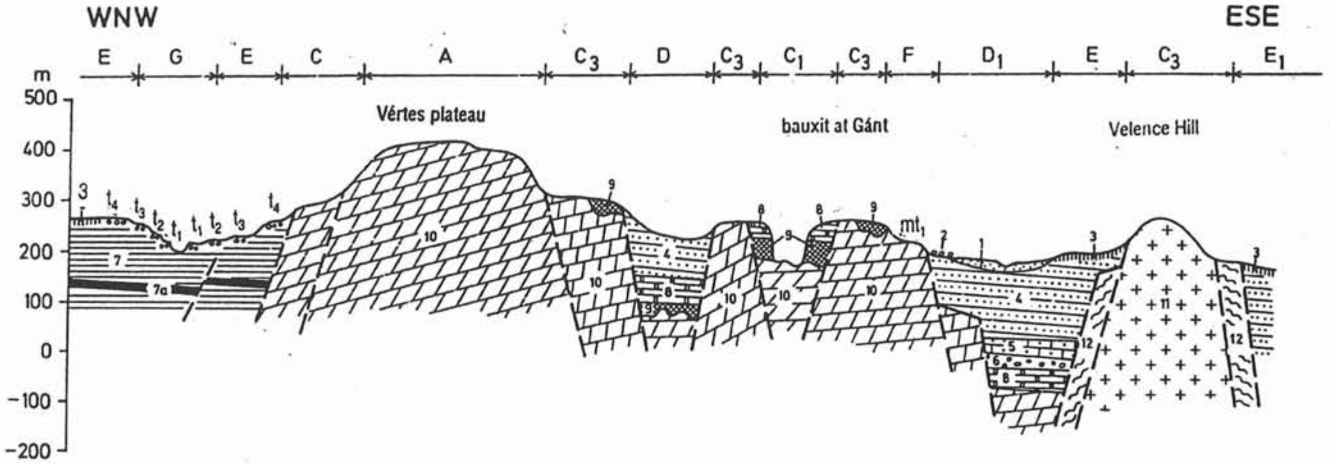

FIG. 2 - Geomorphological surfaces in the Vertes Mountains in Hungary. A) exhumed horst in summit position, a remnant of slightly remodelled Cretaceous etchplain; C) horst in foothill position; C_1) totally buried; C_3) totally exhumed; D) buried surface of etchplain in intermontane graben position; D_1) intermontane graben, filled with molasse and alluvial fans; E) glacis d'erosion with terraces; E_1) rock pediment and glacis d'erosion; F) remnants of marine terrace (Upper Pannonian); G) submontane basin with river and glacis terraces; t_1-t_4) fluvial terraces; mt_1) marine terrace; 1) alluvium and meadow soil; 2) alluvial fan; 3) loess and loess-like sediments; 4) Pannonian sandy and silty formations; 5) Sarmatian formations; 6) Miocene gravel and sand; 7) Oligocene sand and clay formations; 7a) Oligocene lignite; 8) Eocene limestone; 9) Cretaceous bauxite; 10) Triassic dolomite and limestone; 11) granite; 12) Carboniferous metamorphic rocks.

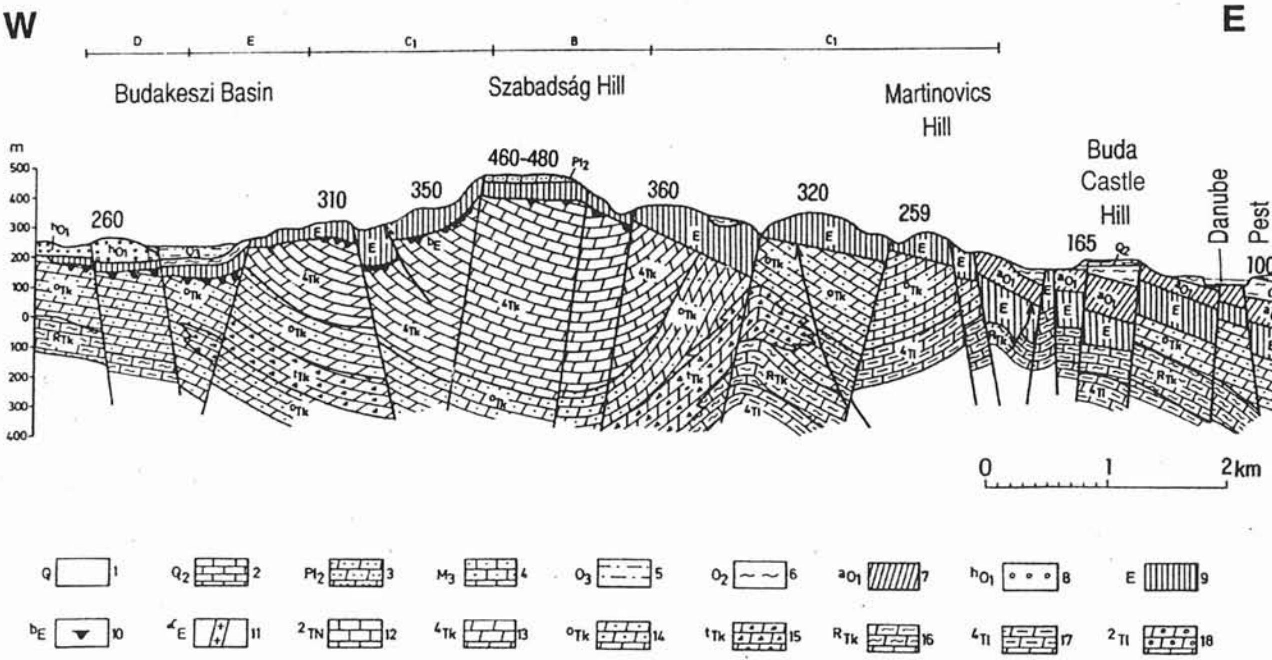

FIG. 3 - Alternating erosional/accumulational planation surfaces of the Buda Highland in Hungary (after Pécsi & Wein). B) buried Cretaceous etchplain in uplifted position; C) surfaces of planation in uplifted position: 1) totally buried, 2) partially exhumed, 3) totally exhumed; D) buried surfaces of planation in graben position; E) glacis d'erosion; 1) Pleistocene loess and wind blown sand; 2) Pleistocene travertine; 3) Pliocene sand, clay, travertine; 4) Sarmatian conglomerate. and limestone; 5) Upper Oligocene sandy clay, silt; 6) Middle Oligocene clay; 7) Lower Oligocene marl; 8) Lower Oligocene sandstone; 9) Eocene formations; 10) Eocene reworked bauxite and conglomerate; 11) Eocene acid dyke; 12) Upper Triassic Dachstein Limestone; 13) Upper Triassic Hauptdolomite; 14) Upper Triassic coarse dolomite; 15) Upper Triassic cherty dolomite; 16) Upper Triassic marl, limestone, dolomite; 17) Middie Triassic pink dolomite; 18) Middie Triassic *Diplopora*-bearing dolomite.

subsequently pedimented. There are several horsts, where bauxite and tropical tower-karstic surfaces were preserved under a thick Eocene limestone cover (fig. 3).

During the second part of the Oligocene the horizontal shift of the TM was going on, its subsidence was highly differentiated. This is supported by the fact that sediments of differing facies (coarse clasts, gravel, sand and clay) were deposited on the surface of the TM, which moved eastward. The sediments originating from some higher, crystalline mountains in the vicinity.

During the Miocene (from 24 to 5.5 Ma) the relief of the TM and its close environs changed repeatedly and fundamentally in consequent tectogenetic phases, horizontal and vertical displacements, subduction, a powerful volcanic activity, partial transgressions and regressions. These processes resulted in a geomorphological inversion at the end of the Miocene. The Mountains was uplifted to a moderate altitude, but definitely over its surroundings, for the first time during the Tertiary. On its sinking north-eastern part andesitic volcanoes erupted during the middle Miocene (15-14 Ma BP). Deposition of terrestrial gravel and other clastics continued on the margins of planation surfaces, with some interruptions.

On some low-lying Mesozoic horsts and in intramountain small basins the remnants of etchplains were newly but incompletely buried during the late Tertiary. On tectonically uplifting horsts the old tropical karsts were exhumed and remodelled.

During the late Miocene by the Sarmatian and Pannonian transgression (ca 13 to 11 Ma BP) the TM subsided again, but adjacent regions to the south and north (Little Plain and Transdanubian Hills) were subsided at higher rate thus the TM remained a mainland or an archipelago (-Jámbor, 1989). Some mountain groups, marginal horsts and intramountain grabens were buried, in fact, for the third or fourth time during the Tertiary, under Pannonian sands and freshwater limestones, at an elevation close to the base level. During the late Miocene the majority of horsts in the TM were at an elevation of 100 to 200 m above the Pannonian lake level. Due to the uplift and climate turning from subhumid to semiarid, pedimentation processes intensified along the margins of horsts for short periods (eg. at the Sarmatian-Pannonian boundary). Morphological evidence of deflation are wind-abraded and polished rocks, sand blankets, iron-varnished pebbles, iron-oxide concretions, meridional valleys and ridges (yardangs), which were formed during the late Miocene.

Horsts uplifted during such periods and especially at the end of the Pannonian were stripped off a cover of Oligocene and Miocene clastic sediments. In some spots marine shelves were formed, preserved by travertine deposits (fig. 4). The horizontal displacement of the TM into its recent structural position lasted from the end of the Oligocene (Báldi, 1982; Hámor 1989) to the middle Miocene (12-10 Ma BP, Balla, 1988, Kázmér, 1984), when the subsidence of the Pannonian basin started. From about this time tectogenetic processes caused repeated subsidence and uplift of the horst groups and grabens of the TM, upward movements dominated. This resulted in formation of marine terraces, deltaic deposits and erosional foothill slopes on marginal parts of the mountains.

At the beginning of the Pliocene (5.4 Ma BP) uplift intensified. From the late Miocene on the climate shifted to a subhumid one. In consequence, a considerable part of the Tertiary siliciclastic, gravel, sand cover of the TM was eroded and redeposited on the forelands. On the unconsolidated molasse like sediments a broad hillfoot surface took shape, while in the forelands wide alluvial fans were deposited. The hot subarid climate was interrupted several times and followed by subhumid warm periods. This increasingly favoured the cyclic development of red and variegated clays.

Neither the considerable time span of variegated and red clay formation nor the cause of the subhumid climate has been investigated in details. The effect of these events on the morphological evolution also needs further studies.

In the Bakony Mts. (western TM) basaltic tuffs and lava were deposited over late Miocene and Pliocene foothill surfaces. The basalt-capped mesas are witnesses of the removal of about 100 to 200 m thick Pannonian sequence.

Neogene and Quaternary geomorphological surfaces (Miocene marine terraces, delta gravel deposits, Pliocene foothill surfaces, Quaternary terraces and alluvial fans) were often preserved by hard travertine deposits capping them (fig. 4). A part of these geomorphological surfaces are predominantly erosional (foothill surfaces, glacis), others were formed by the joint work of accumulation and erosion. The most different elevation of Miocene foothill surfaces, marine terraces and Danube delta gravel renders their correlation difficult. In the Visegrád Gorge of the Danube valley pediments were formed on andesitic rocks, presumably during the same interval.

During the Quaternary some horst groups of the TM were further uplifted in a different manner (max. 200 to 250 m). In this period valley terraces, alluvial fan terraces, cryoplanation glacis surfaces were shaped which are juvenile erosional and accumulational surfaces. The number and elevation of different geomorphological levels are decreasing toward the forelands and basins (Pécsi & *alii*, 1988).

In the Danube bend, near Visegrád, the Mesozoic surface of the TM lies about 1-1.5 km below the sea level, covered by thick Oligocene to Middle Miocene epicontinental molasse-like deposits. Volcanic rocks of the Visegrád Mountains and, partly, of the Börzsöny Mountains, cover thick middle Miocene (Badenian) sandy deposits (Juhász & *alii*, 1995). Along the Danube Bend there is a Tertiary molasse corridor, where these volcanic mountains formed during a rather short time, between 15 and 14 Ma BP. This young volcanism along the molasse trough could hinder but not prevent the flow of the Paleo-Danube the carrying water and sediment of confluent rivers from the foreland of the northern Alps, the eastern Alps and western Carpathians towards the Great Hungarian Plain. Consequently, the Paleo-Danube most probably acted as a morphological and sedimentation agent in the molasse trough between the Buda-Pilis Mts. and Naszály of the TM. Thus, the Miocene quartz-pebble containing delta remnants, high valley foothill surfaces and half plains of planation may be interpreted on the volcanic build-ups around the Visegrád-Gorge.

EROSIONAL SURFACES AND DENUDATION CHRONOLOGY

In the Transdanubian Mountains the Mesozoic horsts on which bauxite-bearing ancient tropical karst forms are found overlain by thin Upper Cretaceous or Eocene sediments are regarded as remains of the Cretaceous tropical etchplain from a geomorphological point of view (fig. 3). Depending on their orographic position, these buried horsts may occur in uplifted position (summit level), as lower-situated steps or also in threshold position. Their surfaces, however, as fundamental morphogenetic surfaces existed already in the Cretaceous and considerable reshaping did not follow during the subsequent repeated exhu-

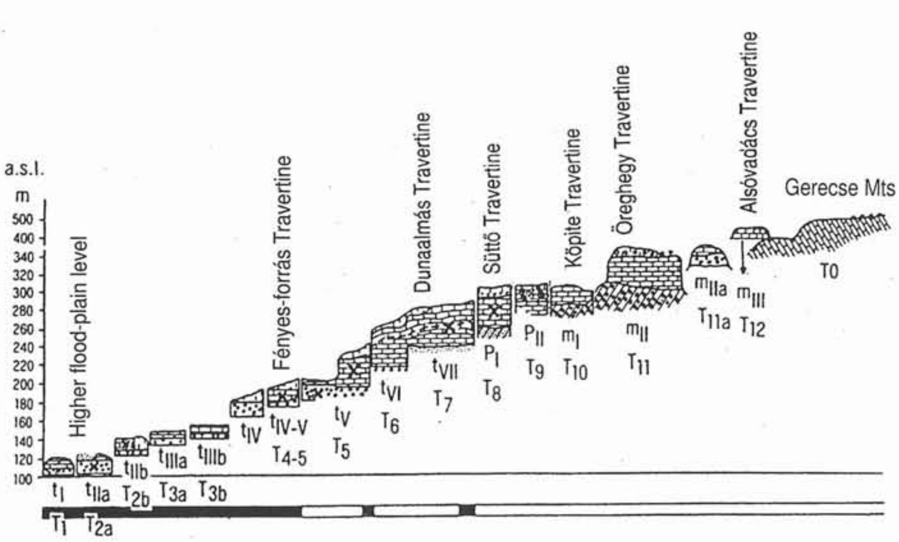

FIG. 4 - Geomorphological surfaces and travertine horizons in the Gerecse foreland (Pécsi, Scheuer & Schweitzer, 1988). t_I-t_{VII}) river terraces usually covered by travertines (T_1,-T_7) and loess; P_I-P_{II}) Pliocene pediment surfaces covered by travertines (T_8-T_9); m_I-m_{III}) Upper Pannonian (Upper Miocene) raised beaches covered by travertines (T_{10}-T_{12}); T_0) Paleogene-Neogene planation surface sculptured by Oligocene-Miocene pedimentation with sporadic gravels. Paleomagnetic polarity according to Marton & Pevzner.

mation accompanying uplift. It is also common that the Oligocene sandstone covers conformably the ancient etchplain characterised by tropical tower karst, bauxite and red clay (fig. 3). In most cases, during exhumation only the Tertiary sedimentary cover was removed from the horst etchplanated in the Cretaceous and buried in the Tertiary, thus the exhumed ancient etchplain represents the geomorphological surface.

There are horsts in great number covered by Eocene and Oligocene clastic rocks, whose ancient surfaces were not merely lowered but also remodelled. In this case the surface of the horst is identified as a younger reworked e.g. Oligocene geomorphological surface.

It is occasionally difficult to determine the age of remodelling of the uncovered exhumed horst. In these cases one may start from the fact that the surface of horsts of the Transdanubian Mountains was planated already in the Cretaceous, the surface of those of low position slightly changed during the Tertiary, it is inherited. The uncovered horsts of morphologically higher position could be pediplanated in the course of the Paleogene and became pedimented at their margin during the Neogene. Each of the horsts etchplanated in the Cretaceous then buried, semi-exhumed and being uncovered may occur at different elevations (fig. 5). Some types can be found eg. at the same height besides each other within the same mountain unit. It is also common that the planated horsts covered by Oligocene sandstone overlie stepwise one another. The surfaces of different heights of these horst types do not represent geomorphological surfaces of different ages.

In the mountain margins the Neogene marine terraces represent usually younger geomorphological surfaces that the uplifted and exhumed horst surfaces. Nevertheless, it is common that the Pannonian marine formations overlie horsts uplifted to 400 to 500 m height which were buried in the Paleogene (Buda Mountains), elsewhere upper Pannonian travertine occurs on the Mesozoic geomorphologic surface (Balaton Upland, ca 300 m above sea level). In some cases we find foothill surfaces in marginal positions, transformed by Paleogene and/or Neogene pedimentation. These may be further shaped by Quaternary cryoplanation and accumulative glacis formation. This way generations of surfaces of different ages may be preserved on horsts or on their vicinities.

On the margins of horsts of the Transdanubian Mountains the Late Cainozoic geomorphological surfaces (marine terraces, pediments, river terraces) were preserved by the hard strata of travertines from the subsequent erosion. Travertines were formed by karst springs in the base level. In the Transdanubian Mountains 12 Neogene and Quaternary geomorphological surfaces were preserved by travertines. This phenomenon is characteristic of the mountain margins and of some larger valleys. In the valley-side terraces a lower sequence of travertines is deposited (between 120 and 250 m altitudes). The higher situated sequence of travertine covers the pediments and marine terraces. To determine their age, fauna remnants paleomagnetic and absolute chronological data were available (Pécsi & *alii*, 1988).

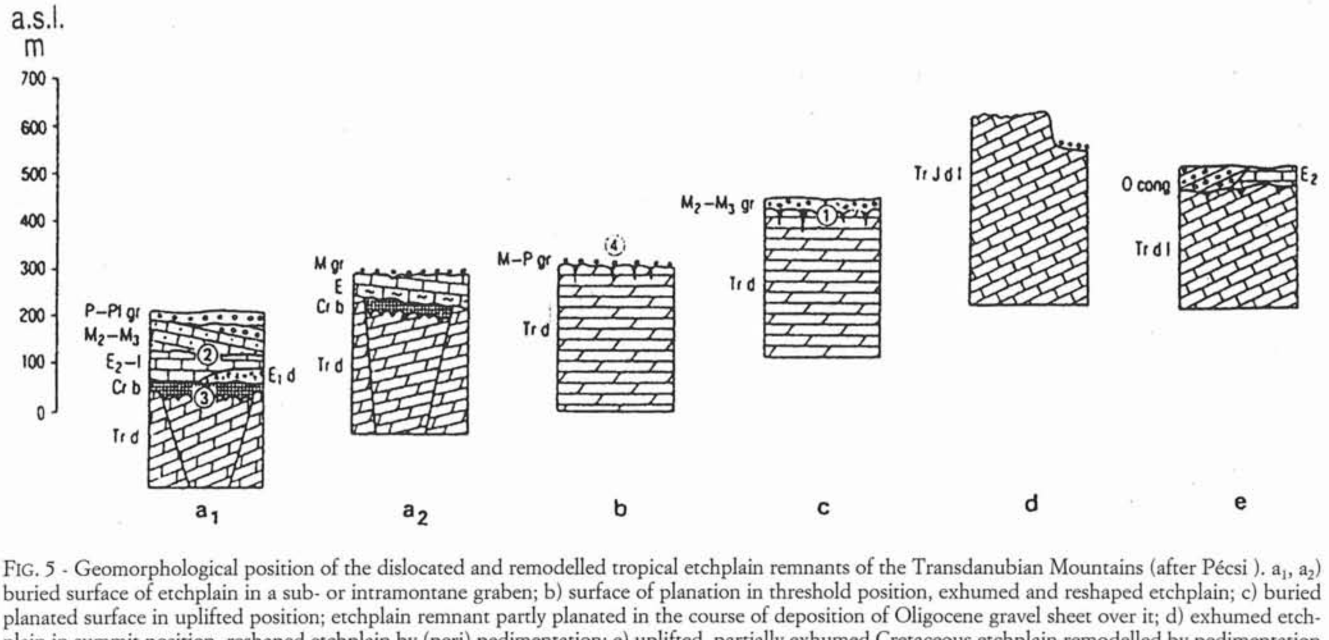

FIG. 5 - Geomorphological position of the dislocated and remodelled tropical etchplain remnants of the Transdanubian Mountains (after Pécsi). a_1, a_2) buried surface of etchplain in a sub- or intramontane graben; b) surface of planation in threshold position, exhumed and reshaped etchplain; c) buried planated surface in uplifted position; etchplain remnant partly planated in the course of deposition of Oligocene gravel sheet over it; d) exhumed etchplain in summit position, reshaped etchplain by (peri) pedimentation; e) uplifted, partially exhumed Cretaceous etchplain remodelled by pedimentation during the Tertiary (eg. Oligocene) in the forelands of the crystalline massifs, with conglomerate covers over their subsided part; P-P_1gr) Pliocene-Pleistocene gravel; M_2-M_3) Middle Miocene marl, limestone and gravel; E_2l) Middle Eocene limestone; E_1d) Lower Eocene dolomite detritus; Crb) Upper Cretaceous bauxite; Tr_3d) Triassic dolomite; M-Pgr) Miocene-Pliocene gravel; Mgr) Miocene gravel; M_2-M_3gr) Middle and Upper Miocene gravel and conglomerate; Tr., J.d.l) Triassic and Jurassic dolomite and limestone; O.cong.) Oligocene sandstone and conglomerate; 1) remains of tropical weathering, with kaolinite and red clays; 2) unconformity; 3) tower karst remnant of a tropical peneplain; 4) gravel patches on the surface.

CONCLUSIONS

Based on comparative geomorphological observations, a model of surface evolution through alternating erosion and accumulation is proposed, which is here used as a tool for understanding the evolution of surfaces on horsts and grabens in the Transdanubian Mountains (TM). This model aims at an improving of accuracy of terminology (Pécsi 1970a,b, 1975, 1993). The basis of this model for alternating erosion and accumulation is that formerly developed (by tropical etchplanation, pedimentation, pediplanation) surfaces of erosion are repeatedly reshaped by erosion and accumulation during subsequent geological times. The morphostructural element is repeatedly uplifted and subsided and horizontally displaced by tectonic processes.

This model proposes that in the TM the conditions resulting in erosional surfaces, due to tropical tower-karstic planation and accompanied by bauxite formation, were interrupted by the beginning of the Tertiary. This was mainly caused by changes in climate and in tectonic activities. During the Tertiary the bulk of the TM was repeatedly buried by tectonic subsidence under sedimentary sequences of different thickness. Some regions were partially or entirely elevated and exhumed twice or three times (during the Paleogene, Neogene and Quaternary). The karstic etchplain surface of Cretaceous origin was further eroded or buried under sediments during these repeated burial and exhumation events (e.g. by peripedimentation, formation of marine terraces, or alluvial fans). The TM, subdivided by grabens, contains five different groups of geomorphological surfaces:

1. horsts of etchplanation in summit level, partly exhumed;
2. buried horsts of etchplanation in uplifted position;
3. horsts of etchplanation in threshold position, buried or exhumed and reshaped, mainly by pedimentation;
4. buried etchplain in basins (cryptoplain);
5. peripediments, rocky pediments, glacis, partly covered by alluvial fans.

On the «Geomorphological Map of Hungary» (Pécsi, 1976) and on the «Geomorphological Map of the Danubian Countries» (Pécsi, 1977, 1980) and regional landscape monographs on the TM (Pécsi, 1988, (Pécsi & Juhász, 1990) the term erosional-accumulational surface evolution was used for the development of those geomorphological surfaces for which sufficient information was available, according to the principles and criteria of the proposed model. The model explaining and classifying the erosional surface evolution describes the surfaces of planation, buried surfaces, repeatedly exhumed and eroded planes, illustrates the polycyclic process of their superposition and reveals the main phases of the changes.

TABLE 1 - Geomorphological surfaces in the Hungarian mountains (Pécsi, 1985)

I. REMNANTS OF OLD EROSION SURFACES

1. *Remnants of Mesozoic etchplains with tower karst*
   - buried under lower Cretaceous clay or limestone in plateau position (in the E. Bakony), or in threshold position (in the S. Bakony, Halimba)
   - buried by Eocene limestone in summit position (in the Buda Mts.)
   - buried under Eocene limestone (at Gánt, Vértes Mts.; Nyírád, Bakony Mts.)
   - buried under Oligocene sandstone (in the Buda Mts.) on different elevations
   - remnants of an exhumed etchplain in summit position (in the Buda Mts., Keszthely Mts.)
2. *Remnants of Paleocene (and mostly Mesozoic) etchplains resculptured by Oligocene and Miocene pedimentation*
   - etchplain buried by Miocene gravel in summit position (at Farkasgyepü, Bakony Mts.)
   - exhumed etchplain with patches of Miocene gravel in summit position (in the Gerecse Mts.)

II. REMNANTS OF NEOGENE SURFACES OF PLANATION

1. *Miocene raised beaches*
   - Surface with Karpatian conglomerate (in the northern foreland of Bakony Mts.)
   - Surface with Badenian littoral sandy-gravely limestone (in the Visegrád and Börzsöny Mts.)
   - Sarmatian raised beach (in the Buda Mts., Balaton Upland)
   - Sarmatian pediment (in the Mátra and Zemplén Mts.)
2. *Pannonian (Upper Miocene) raised beaches and travertine horizons*
   - Lower Pannonian (Monacian) raised beach (at Sóskút,. Diósd, in the Buda Mts. and on the Balaton Uplands)
   - Delta deposits (Precsákvárian-Csákvárian, the «Billege» and «Kálla» gravel on the Balaton Upland)
   - Upper Pannonian (Pontian) raised beach - two surfaces (in the Bakony, Vértes and Buda Mts.).
   - Upper Pannonian (Csákvárian - Sümegian - Baltavárian) travertine occurring on two or three surfaces (Nos 10-12, at Nagyvázsony, Veszprém Plateau and Várpalota in the Bakony Mts., on Széchenyi- and Szabadság-hill in the Buda Mts., two surfaces in the Gerecse Mts.)
   - Upper Pannonian deltaic gravel (on Köpite hill in the Gerecse Mts.).
   - Upper Pannonian-Pliocene basalt lava on pediment (subdivided into two levels?) (e.g. on Kabhegy and Somló hills in South Bakony Mts.).
3. *Uppermost Miocene - Pliocene pediments and travertine levels*
   - Mio-Pliocene pediment (Baltavárian) locally lowers down and forms a double surface of planation (between 360 and 220 m above sea level along the margins of the Transdanubian Mountains).
   - Pliocene (Ruscinian-Csarnótian) travertine horizons on pediment (Nos 8 and 9; in the Buda Mts., on the Köpite-hill at Süttö in the Gerecse Mts)
4. *Upper Pliocene (Ruscinian - Csarnótian - Lower Villányian) old alluvial fans and travertine horizons*
   - the Kemeneshát - Ezüsthegy - Kandikó gravel sheet
   - terrace No VIII and travertine No 8 (in the Danube Bend Mts.)
   - terrace No VII and travertine No 7 (terrace hills of the Kemeneshát)

III. QUATERNARY FLUVIAL TERRACES, ALLUVIAL FAN TERRACES AND TRAVERTINE HORIZONS

- Terrace No VI and travertine No 6 (Upper Villányian)
- Terrace No V (Kislángian - Biharian) and travertine No 5 (Middle Biharian?, of reversed polarity)
- Terrace No IV (Middle Biharian, Vértesszölös phase), > 350 Ka, terrace and travertine are of normal polarity
- Terrace No IIIa and travertine No 3a (270 Ka) (in the Gerecse Mts.)
- Terrace No IIb (R3-W1) with travertine cover (120 to 70 Ka old)
- Terrace No IIa (W3), ca 26 to 12 Ka
- flood-plain No I and Holocene travertine No 1, from 11 Ka to present

After three decades of observations in this field we think that the explanation is not just valid for the individual Intracarpathian Mountains, but may be applied in the cases of the Alpine-Dinarid mountain system, of some European ancient mountains, or of mountains and massifs of various continents. The superposition of geomorphological levels of different ages could be demonstrated in the case of the units of the TM, using the procedures of denudation- and accumulation chronology (table 1). The particular case of it has been published several times in Hungarian and in other languages, summarised in a monograph of the Transdanubian Mountains (Pécsi, 1970a,b, 1993; (Pécsi & Juhász, 1990; (Pécsi, & *alii*, 1985; Székely, 1972). In the Gerecse, Buda, and Pilis Mountains (TM) the presence of almost all young geomorphological levels could be demonstrated in some sections, in addition to older ones. In the forelands of these Mountains the higher levels were represented by 3 or 4 Neogene marine terraces and deltas, by 1 to 2 foothill surfaces, and by 4 to 6 Quaternary fluvial terraces (fig. 4). These geomorphological levels were protected against subsequent denudation by travertines capping them. Thus a reconstruction of long-term morphological evolution of geomorphological surfaces became feasible (Pécsi, 1975, 1993; (Pécsi, & *alii*, 1985).

The chronological classification of the geomorphological surfaces gave us a key to outline the geomorphic evolution of TM during the Cainozoic era.

NOTES

[1] The genetic and topographic interpretation of the concept of relief planation is rather diverse in the literature. Taking into consideration all definitions, both narrow and broad, it emerges that surfaces of planation are considered (plane) surfaces of considerable extent and low relief energy, over a stable or gently rising base. They are sculptured by processes of destruction, and by a well-defined equilibrium of uplift and degradation.

While some authors consider surfaces of planation to be results of sculpturing by a single erosive agent, others think that they are polygenetic; i.e. they result from the interaction of several processes the rates of which vary in time and space. Some authors believe that surfaces of planation are polygenetic also in space. Their complex of forms includes not only surfaces of erosion, but also surfaces of accumulation.

[2] Davis assumed periods of long tectonic rest in the evolution of a mountain; the evolution during such a period produces a peneplain in the penultimate stage of the cycle of erosion, which subsequently undergoes repeated uplifting. On the mountain margins, at the base level of erosion, partial peneplains come into existence. Wherever and whenever the periods of tectonic stillstands were not sufficiently long for the process of peneplanation to completely wear away the relief formed during the previous cycle and subsequently uplifted, there, according to Davis, occur remnants of older peneplains at higher altitudes, in a stepwise arrangement.

[3] In the Penckian interpretation of stepped Rumpfflächen (piedmont benchlands) the initial surface is the «Primärrumpf», but it may also be the Davisian peneplain, the «Endrumpf», «Endpeneplane». As a result of arching, a process extending in area and accelerating in time, the longitudinal profiles of rivers are broken and the valley flanks gradually retreat and broaden at the expense of the higher surface. The broadening arch embraces an increasingly wide area and thus and increasingly number of younger step surfaces are connected to the most highly elevated central arch. It is this system of stepwise repeated surfaces of planation that was called «Piedmonttreppen» by an ever broadening area, rather than to a protracted and constant-rate uplift.

[4] Pediplains have usually been deduced from pediments (Maxson & Anderson 1935, Howard 1942, Mackin 1970). It was in connection with these forms that American geologists and geomorphologists first came to attribute a decisive role to climatic factors. They interpreted as pediplains a number of extensively planated surfaces regarded as peneplains by Davis. King (1962) has lately expressed the view that pediplanation is the most general form of surface lowering, substituting, as it were, the periplanation concept for the Davisian peneplain concept. In this way, however, King (1949, 1962) gave an unduly broad context to the term pediplain, under which heading he included all the extensive planated surfaces of all continents as far back as the Cretaceous. In King's opinion pediplains are typical of semiarid tropical zones, but may also develop at lower intensities under moderately humid conditions. He considers the differences between forms developed in arid, semiarid and moderately humid climatic zones to control merely the intensity of development.

Another open question concerns the criteria of identification for the pediplain, as a remnant of some planated surface outside the semiarid zone.

[5] Tropical surfaces of planation, the concept of etchplanation. Wayland (1933) introduced the concept of etchplain, the etchplanation has been attributed to tropical deep weathering followed by removal (stripping) of the thick regolith zone. The idea has been elaborated and further developed by Büdel (1957), partly modified by Bulla (1958), Louis (1957) and some others.

The concept, that extensive surfaces of erosion are most readily formed under humid or alternately humid and arid tropical climates, has become more and more widely accepted. The initiators of the theory explained the lowering and smoothing of large surfaces by extensive colloidal and subcolloidal weathering as well as by large scale slopewashing. Büdel interpreted the evolution of the tropical surfaces of planation by developing the theory of «duplicate planation surfaces» (doppelte Einebnungsflächen).

In the zone of tropical slopewash, the surfaces are thickly covered with products of weathering, underlain by a less thoroughly smoothed but still hummocky relief of unweathered rock (e.g. granite). This deeper interface is the basal front of planation, smoothed by weathering. Double planation takes place, on one hand, by slopewash on the surface cloak of weathering products (Spüloberfläche) and, on the other hand, by subsurface weathering on the deeper interface.

[6] Sporadically in the Carpathian Basin red clays occurring in subaeral Neogene deposits, in basin position, are interfingered by series of variegated clays, sandy clays, silts and sands. These sequences, under optimal geological and climatic conditions, could cover most of the Pliocene and the start of their formation can be dated to the late Miocene (ca 2-5.6 Ma, Pécsi 1985; Pécsi & *alii*, 1988). The red clay together with the intercalated sequence are also products of cyclic climatic changes. They represent subtropical subhumid climate with alteration of warm-rainy and warm-dry seasons, succeeded by warm semiarid climatic intervals preventing red clay formation but favouring pediment development.

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