GEOGRAPHICAL RESEARCH INSTITUTE
HUNGARIAN ACADEMY OF SCIENCES

# GEOMORPHOLOGICAL REGIONS OF HUNGARY

BY M. PÉCSI

BUDAPEST 1996

GEOMORPHOLOGICAL REGIONS OF HUNGARY

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Geographical Research Institute
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# GEOMORPHOLOGICAL REGIONS IN HUNGARY

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by
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# PREFACE

The 3rd European Regional Conference of the International Association of Geomorphologists (IAG) is to be held in Hungary in April 1996. The local Organising Committee expresses its gratitude to the Executive Committee of the IAG and the General Assembly of the 3rd International Geomorphological Conference (Hamilton, Canada, 1993) for conferring this honour on the Hungarian representatives of the discipline.

The first edition of the *Geomorphological Regions of Hungary* was published over a quarter of century ago as the sixth volume within the series *Studies in Geography in Hungary* (1970). Since then several volumes of studies in this series (Nos 8, 16, 19, 25 and 26) have been devoted to the geomorphological, geoecological and Quaternary investigations, most of them dedicated to international meetings. A volume entitled *Environmental and Dynamic Geomorphology* was published for the 1st International Conference on Geomorphology (Manchester, UK, 1985), another one, *Geomorphological and Geoecological Essays,* was dedicated to the 2nd Conference (Frankfurt am Main, FRG, 1989). Some of these publications covered topics on the geomorphology of Hungary while others concerned research methodology and techniques (see the list of volumes).

In this updated edition of the *Geomorphological Regions of Hungary* an attempt was made to present our knowledge on the landforms and relief conditions of Hungary which accumulated during the past 25 years from the research activities of various teams in the country.

In a short introductory chapter of the book a hierarchical subdivision of the country's territory into geomorphological regions and subregions is presented and shown on a sketch map with an emphasis on the main relief types they constitute.

An overwhelming part of Hungary are plains with a characteristic homogeneity of landforms (floodplains, alluvial fans, etc.).

The mountain ranges offer a greater variety of topography (mountains of different evolution and structure, valleys, intramontane basins, etc.).

Even mountain ranges or groups, regarded as individual units on the basis of their homogeneity, show remarkable features of heterogeneity. This is why the geomorphological regions of Hungary are treated briefly through seeking for homogeneous or nearly homogeneous landform types within the mountainous regions or between them and interpreting them according to evolution and structural features.

We were striving to provide as much information as possible using figures and maps, although part of the documented sections cannot be found in the field presently.

A special chapter is devoted to the concept of and explanations to the *Geomorphological Map of Hungary* which was a completed and updated version of an earlier geomorphological map and published as a sheet in the second edition of the National Atlas of Hungary (1989).

Budapest, March 1996

The Author

# GEOMORPHOLOGICAL REGIONS OF HUNGARY

## 1. Introduction

Hungary is located in Central Europe, in the middle of a basin of complicated structure, encircled by the Alps, Carpathians and Dinarids *(Fig. 1)*. In the literature of the earth sciences and often in everyday conversation too the basin is mentioned as Carpathian, Pannonian or Middle Danube Basin. These names do not cover geographically identical areas, but any of the three terms can be applied to the location of Hungary. In geographical literature the Carpathian Basin is a more common denomination, while geologists seem to prefer the name Pannonian Basin.

The basin as geomorphological feature came to exist only in the Neogene. It became a continental basin in a geomorphological sense in the Upper Miocene and Quaternary periods. In a morphotectonic sense, however, the Pannonian Basin is a young structural depression filled by marine and subsequently by fluvio-lacustrine, fluviatile and eolian sediments. The subsidence was partly due to the comprehensive synorogenic-plate tectonic displacements of the surrounding folded mountains and to volcanic eruptions in the intra-Carpathian volcanic belt.

In the (late) Tertiary basement of the Pannonian Basin, southwest to northeast belts and mosaical units of various age alternate *(Fig. 2)*. There are opposing views on the origin, contacts and movements of the structural-morphological units of the basement. There is an agreement, however, that the different tectonic units developed in geological/geographical environments at great distances and drifted into each other's neighbourhood through complicated plate tectonic movemnents along major lineaments.

## 2. Distribution of relief classes in Hungary

The relief classes are fundamental for the description of landform assemblages, irrespective of their origin: plains, hills, footslopes, valleys and mountains. The main landform classes are further subdivided by their shape, position, altitude and relative relief (see enclosed map *'Relief types of Hungary'*).

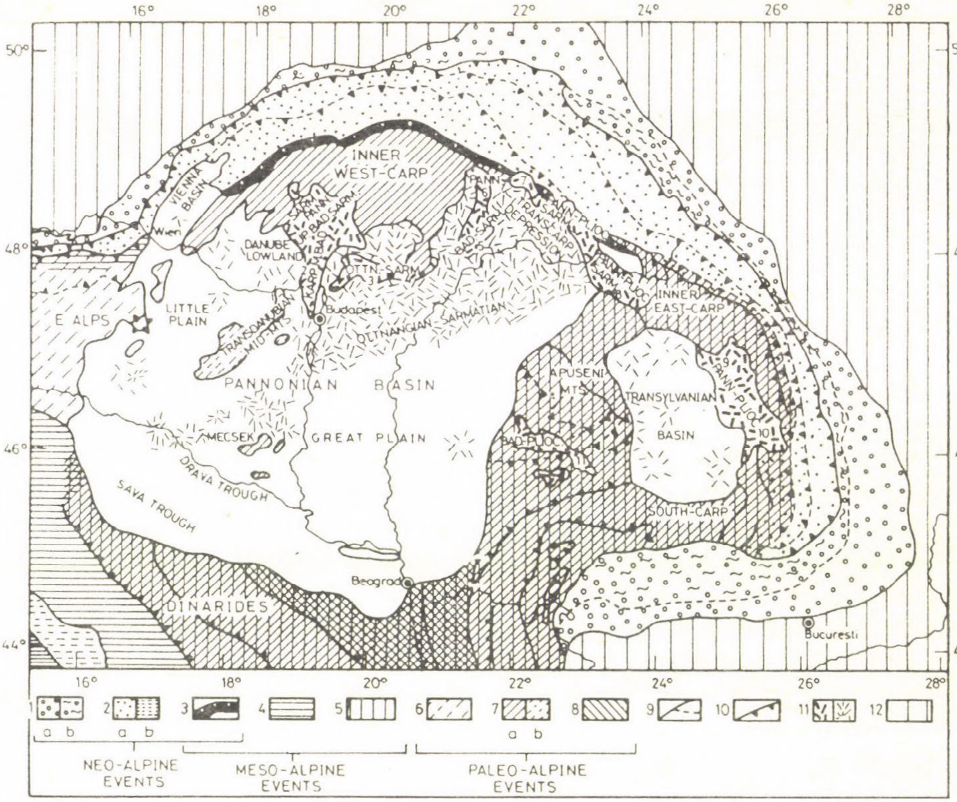



*Fig. 1.* Tectonic sketch of the Pannonian back-arc basin and the associated folded area (in STEGENA, L. and HORVÁTH, F. 1984). 1 = foredeep molasse; undeformed (a), folded during the Pliocene-Quaternary (b); 2 = Outer (Flysch) Carpathians strongly deformed during the Late Oligocene-Early Miocene (a); other tectonic units deformed during this interval (b); 3 = Pienniny Klippen belt, strongly deformed during the Late Oligocene-Early Miocene and the Latest Cretaceous-Paleocene intervals; 4 = area of Late Eocene-Early Oligocene deformation; 5 = area of Latest Cretaceous-Paleocene deformation; 6 = area of Late Cretaceous deformation; 7 = area of mid-Cretaceous intensive (a) and slight (b) deformation; 8 = area of Late Jurassic-Early Cretaceous deformation; 9 = first-order and second-order tectonic boundaries; 10 = main thrust; 11= Neogene calc-alkaline volcanic rocks exposed (a) and below younger sedimentary cover (b); 12 = foreland. The numbers indicate main units of the volcanic area: 1. Central Slovakia; 2. Börzsöny Mts.; 3. Mátra Mts.; 4. Bükk Mts.; 5. Tokaj Mts.; 6. Prešov Mts.; 7. Vihorlat Mts.; 8. Gutin Mts.; 9. Calimani Mts.; 10. Harghita Mts.; 11. Apuseni Mts.; 12. stable European foreland

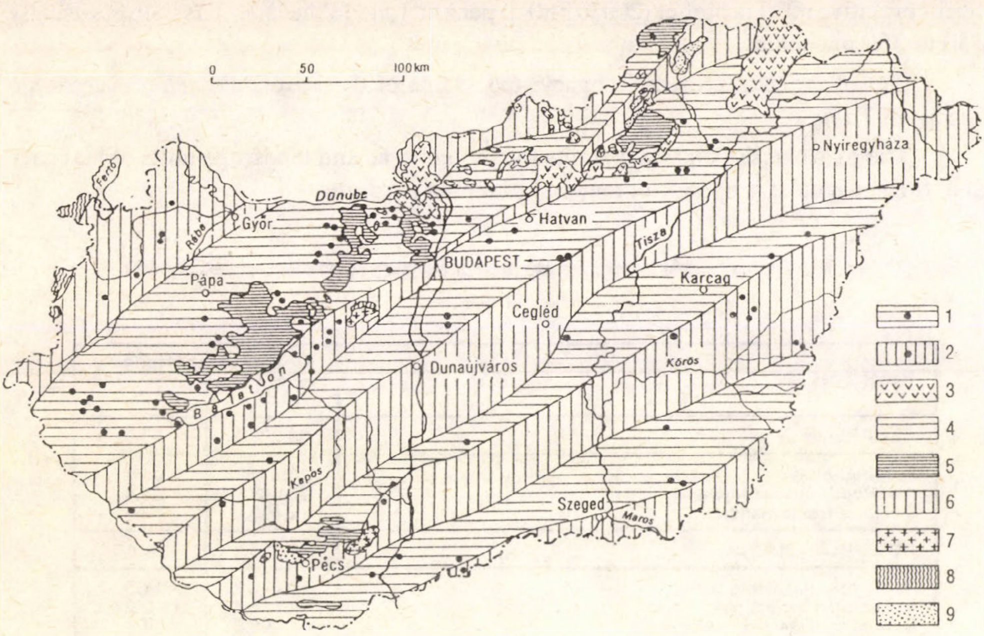



*Fig. 2.* Assumed pre-Tertiary basement under the territory of Hungary (after SCHMIDT, E.R.). 1= borehole terminating in Mesozoic formations; 2 = borehole terminating in Paleozoic formations; 3 = exposed Cainozoic volcanics; 4 = Mesozoic in the basement; 5 = Mesozoic on the surface; 6 = Paleozoic in the basement; 7 = Paleozoic plutonites; 8 = Paleozoic crystalline rocks; 9 = Paleozoic sedimentary rocks

The relief of Hungary is characterised by the *predominance of plains* (flat or alluvial-eolian lowlands). In several cases, spatial pattern or relative relief is decisive in subdividing the plains into subclasses. Surfaces up to 200 m elevation with relative relief below 50 m per km$^2$ were classified as plain relief types.

Plain and *hill relief* classes are distinguished locally. Low ridges are delimited at 130 m above sea level, since their boundaries cannot always be drawn along the 200 m contour line. Similarly, when distinguishing between hill and medium-height mountain regions (German: Mittelgebirge), the 350 m contour was not always taken as a boundary. (For instance, the category of hill relief extends to 550 m above sea level in mountain forelands.)

The *mountains* of consolidated rock in Hungary were classified as *low mountains* (350 to 750 m altitude) and *medium-height mountains* (750 to 1014 m). In both classes mountain relief types with crests and with broad ridges and plateaus are found. In the former relative relief is higher (200 to 350 m per km$^2$) and in the latter this value is usually 150 to 250 m per km$^2$.

Out of the total area of Hungary, the shares of the individual *relief classes* are shown in *Table 1*.

The map of relief classes delimits the topographic and landscape units of Hungary and, furthermore, it is useful for regional planning purposes.

*Table 1. Shares relief-classes from the area of Hungary (Compiled by PÉCSI, M.)*

| Relief types | Of total area of Hungary | |
|---|---|---|
| | km² | % |
| FLAT PLAIN | 36,278.9 | 39.0 |
| 1. Flood-plain<br>1.a. Poorly drained lowland<br>2. Flood-free lowland | <br>23,603.7<br>12,675.2 | <br>25.4<br>13.6 |
| IRREGULAR PLAINS | 31,765.8 | 34.15 |
| 3. Slightly undulating plain<br>4. Enclosed basinal plain<br>5. Slightly dissected lowland<br>6. Undulating plain<br>7. Slightly dissected plain of medium elevation<br>8. Dissected plain of medium elevation | 10,479.3<br>2,034.4<br>4,496.8<br>7,151.3<br>2,657.1<br>4,946.9 | 11.3<br>2.2<br>4.8<br>7.7<br>2.85<br>5.3 |
| VALLEYS | 2,334.1 | 2.5 |
| 9. Valley floors of small streams in medium-height mountain or hill | 2,334.1 | 2.5 |
| HILLS, FOOTHILLS | 18,530.9 | 19.9 |
| 10. Low foothill ridges and slopes<br>11. Plateaus, hill ridges and foothill slopes at medium elevation<br>12. Dissected hill ridges<br>13. Dissected hills in medium-height mountain basins<br>14. Dissected hills in mountain foreland | 7,511.8<br>5,811.5<br>2,568.4<br>1,878.2<br>761.0 | 8.1<br>6.2<br>2.8<br>2.0<br>0.8 |
| MEDIUM-HEIGHT MOUNTAINS | 4,120.3 | 4.45 |
| 15. Low mountain with narrow ridge<br>16. Low mountain with broad ridge<br>17. Medium-height mountain with narrow ridge<br>18. Medium-height mountain with broad ridge<br>19. Medium-height mountain with high and narrow ridge<br>20. Plateau in low mountain<br>21. High plateau in medium-height mountain | 585.9<br>2,303.7<br>363.5<br>465.3<br>71.8<br>285.3<br>44.8 | 0.6<br>2.5<br>0.4<br>0.5<br>0.1<br>0.3<br>0.05 |

## 3. Geomorphological subdivisions of Hungary

Relying on the '*Geomorphological map of Hungary*' compiled by the Hungarian Geomorphological Working Group and following the methodology elaborated by author, the area of Hungary was subdivided into a hierarchical system of geomorphological regions (*Fig. 3.* PÉCSI, M. and SOMOGYI, S. 1969).

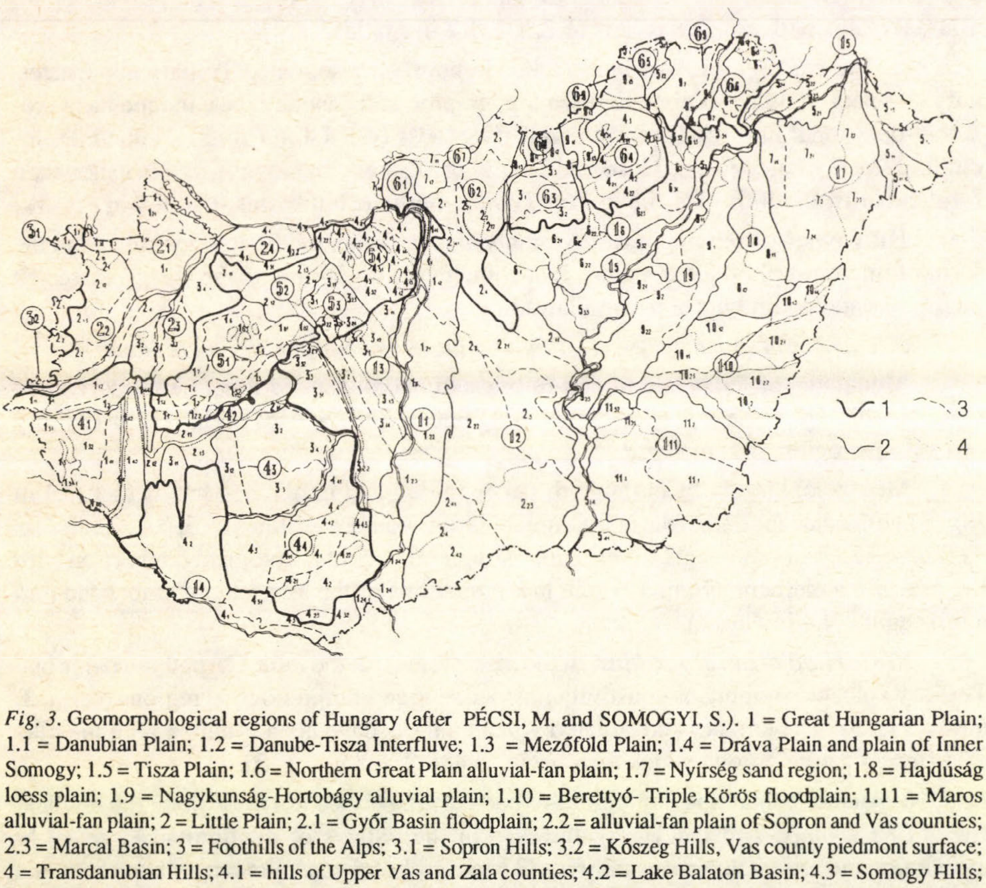


*Fig. 3.* Geomorphological regions of Hungary (after PÉCSI, M. and SOMOGYI, S.). 1 = Great Hungarian Plain; 1.1 = Danubian Plain; 1.2 = Danube-Tisza Interfluve; 1.3 = Mezőföld Plain; 1.4 = Dráva Plain and plain of Inner Somogy; 1.5 = Tisza Plain; 1.6 = Northern Great Plain alluvial-fan plain; 1.7 = Nyírség sand region; 1.8 = Hajdúság loess plain; 1.9 = Nagykunság-Hortobágy alluvial plain; 1.10 = Berettyó- Triple Körös floodplain; 1.11 = Maros alluvial-fan plain; 2 = Little Plain; 2.1 = Győr Basin floodplain; 2.2 = alluvial-fan plain of Sopron and Vas counties; 2.3 = Marcal Basin; 3 = Foothills of the Alps; 3.1 = Sopron Hills; 3.2 = Kőszeg Hills, Vas county piedmont surface; 4 = Transdanubian Hills; 4.1 = hills of Upper Vas and Zala counties; 4.2 = Lake Balaton Basin; 4.3 = Somogy Hills; 4.4 = Mecsek Mountains and Tolna-Baranya Hills; 5 = Transdanubian Mountains; 5.1 = Bakony Mountains; 5.2 = hills in the Bakony and Vértes mountain foreland; 5.3 = Vértes Mountains and Velence Hills; 5.4 = Danube Bend Mountains; 6 = North Hungarian Mountains and intramontane basins; 6.1 = Börzsöny Mountains; 6.2 = Cserhát Hills; 6.3 = Mátra Mountains; 6.4 = Bükk Mountains; 6.5 = North Borsod Karst; 6.6 = Tokaj-Zemplén Mountains; 6.7 = Middle Ipoly Basin; 6.8 = hills between the Zagyva and Tarna rivers; 6.9 = Sajó-Hernád Basin; a = boundary of macroregions; b = boundary of mesoregions; c = boundary of subregions, d = boundary of microregions

Traditionally, six geomorphological macroregions are identified:

1, *Great Hungarian Plains*; 2, *Little Plain*; 3, *the Foothills of the Alps*; 4, *Transdanubian Hills*; 5, *Transdanubian Mountains* and 6, *Intra-Carpathian Mountain Range* with intramontane basins. Some of these regions extend beyond the national borders into the territories of neighbouring countries.

Within the geomorphological macroregions of Hungary, a number of types of geomorphological regions can be distinguished, each with a certain degree of homogeneity in structure and evolution.

a. The *plains* are referred into three genetic types of mesoregion: flood-plains and low alluvial-fan plains (1.1, 1.4, 1.5, 1.9, 1.10, 1.11, 2.1 in *Fig. 3*); alluvial-fan plains above storm flood level, covered with fluviatile deposits (1.2, 1.6, 2.2, 2.3, 2.4 in *Fig. 3*); alluvial plains with eolian deposits (1.2, 1.3, 1.7 in *Fig. 3*).

b. The *hill regions*, largely modelled in poorly consolidated Tertiary and Quaternary deposits could be referred to three topographic and genetic types: independent erosional-derasional hills, dominantly mantled by loess (4.1-4.4 in *Fig. 3*) - sometimes including smaller Paleozoic or Mesozoic knolls (eg. Mecsek-Baranya Hills, 4.4); mountain foreland hills, foothills (5.2, 6.8 in *Fig. 3*); intramontane hill basins (6.7, 6.9 in *Fig. 3*).

Hilly types of relief almost invariably also accompany the low mountains in the form of micromorphological regions and combined with intramontane basins, dissected pediments and pediments of accumulation.

c. There are three main types of *mountainous geomorphological regions:*

Mountains of Paleozoic folded-imbricated and/or faulted type. (An independent region of this type is the extension of the crystalline core of the Alps to Hungarian territory - Subalpine region, 3.1. in *Fig. 3*.).

Mesozoic, largely block-faulted, partly folded and imbricated horsts (5.1, 6.4 in *Fig. 3*) with adjacent Paleozoic crystalline hills and young volcanics (5.3, 5.4, 6.5 in *Fig. 3*). These accessory elements are in a close structural and morphological connection with the prevailing elements. Similarly, the low mountains of the Mecsek are embedded into a hill region (4.4 in *Fig. 3*).

*North Hungarian Mountains*. In the macroregion of the intra-Carpathian range late Tertiary volcanic mountains constitute independent geomorphological regions (6.1, 6.3, 6.6 in *Fig. 3*). The smaller and isolated volcanic units have been grouped with the hills of different nature among which they occur (5.4, 6.2, 6.8 in *Fig. 3*).

d. An independent *valley type* have been distinguished not only along the lowland rivers (the Danube and the Tisza), but also in the valleys of medium-sized rivers in mountains and hills. They are usually small geomorphological units intercalated between and differing fundamentally from the adjacent regions. Small valleys do not attain the rank of an independent (micro) region. The distinction of valleys as independent morphological units is justified, not only from academic aspects, but also from the viewpoint of land use.

## 4. Description of the geomorphological regions of Hungary

### *THE GREAT HUNGARIAN PLAINS*

This geomorphological macroregion encompasses almost a half of the country's area. Its structural or geomorphological boundaries are not sharp everywhere *(Fig. 4)*. The macroregion is more uniform both for its evolution and its morphology than other regions in Hungary. It is a true plain, formed by the accumulation of Pleistocene and recent fluvial and eolian deposits.

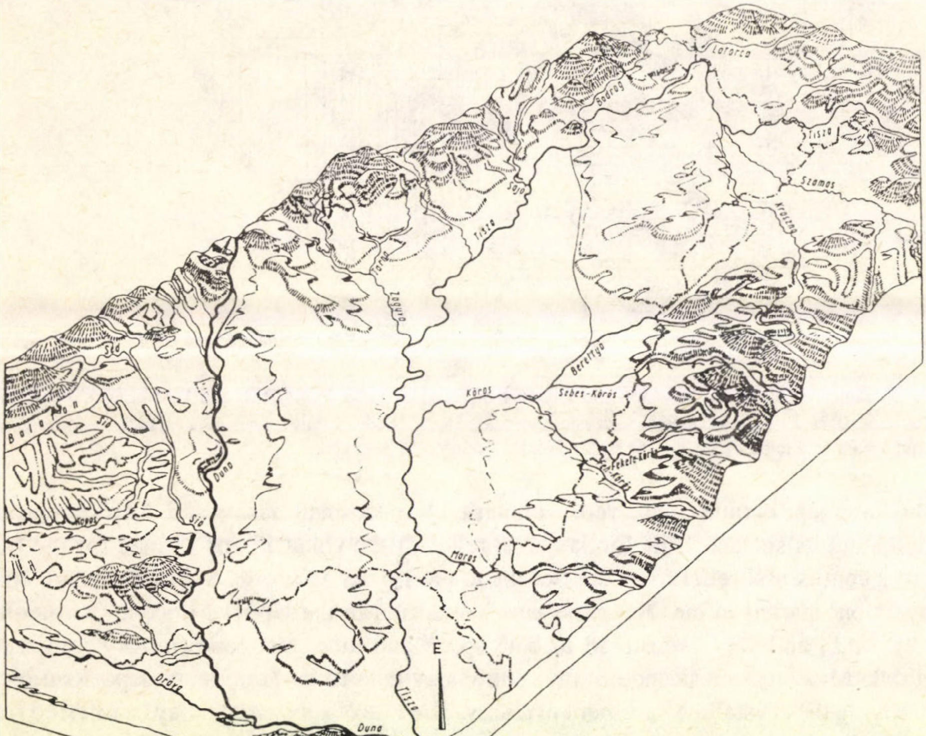



*Fig. 4.* The Great Hungarian Plains and its environs (after CHOLNOKY, J.)

Recently, prospect wells and geological/geophysical surveys have added considerably to the knowledge of its geology. Data collected until now have revealed the basin basement to be a system of buried ranges of parallel, southwest to northeast strike and Paleozoic to Mesozoic rocks. The Paleozoic includes gneiss, clay shales and mica-schists, whereas the Mesozoic largely consists of dolomites, limestones and clay marls *(Fig. 5)*.

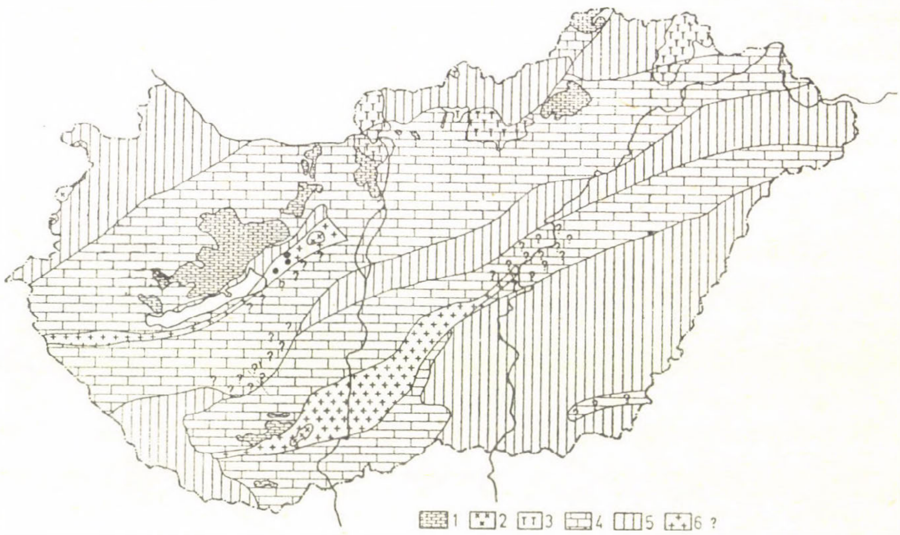



*Fig. 5.* Sketch of basement lithology and structure of Hungary (after FÜLÖP, J. and DANK, V.). 1 = exposed Mesozoic rocks; 2 = exposed Paleozoic crystalline rocks; 3 = exposed volcanics; 4 = Mesozoic rocks of the basement; 5 and 6 = Paleozoic basement and crystalline rocks; ? = inferred basement

The basement is rather shattered, with buried horsts, small basins and deep depressions dissecting its surface. This fundamental relief of the Great Plains formed for the most part a continental relief from the Eocene to the Lower Miocene. Subsidence and 'relief inversion' started in the Neogene and intensified in the Upper Miocene (Pannonian) *(Fig. 6a,b)* and was interrupted in both space and time. Neogene (mostly Lower and Middle Miocene) subsidence in the centre is evidenced by Pannonian deposits directly overlying the crystalline basement in places. The rate of subsidence may be inferred from the thickness of the clay, marl and sand sequence of the shallow Pannonian sea, which locally exceeds 3000 m and is more than 1000 m over large areas *(Figs. 7* and *8)*.

In the uppermost Miocene and in the Pliocene, the uplifting basin margins cut off the Pannonian sea from the main body of the Euxinian-Mediterranean. At first, it was connected through the present-day Iron Gate with the Black Sea, but subsequently it contracted to a shallow lake similar to the Caspian Sea. This was then filled up by increasing amounts of sediment brought in by the rivers running off the encircling

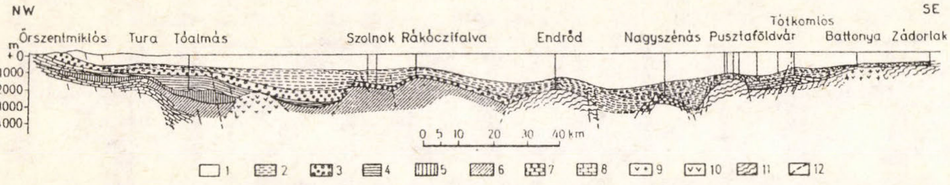



*Fig. 6a.* Generalised geological profile across the Great Hungarian Plain (after KERTAI, Gy.). 1 = Upper Pannonian sand and clay; 2 = Lower Pannonian clay and clay marl; 3 = Miocene clay, sand, conglomerate and tuff; 4 = Oligocene clay and sandstone; 5 = Eocene calcareous marl; 6 = Paleogene and Cretaceous flysch; 7 = Jurassic marl; 8 = Triassic dolomite; 9 = granodiorite, slightly metamorphosed; 10 = inferred igneous and metamorphic masses; 11 = Early Paleozoic metamorphics; 12 = fault zones

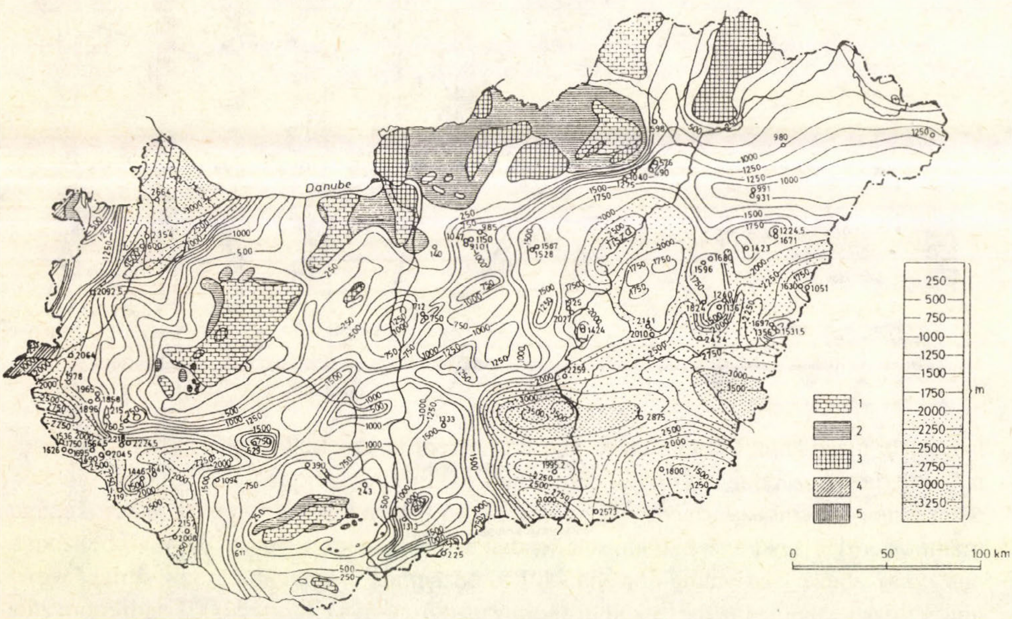



*Fig. 6b.* Thickness of sediment younger than Sarmatian (Middle Miocene) in Hungary (after KERTAI, Gy.). 1 = exposed Paleozoic and Mesozoic; 2 = exposed Tertiary sediments; 3 = volcanic rocks; 4 = metamorphic rocks; 5 = rocks of magmatic origin and metamorphic rocks. Scale: thickness of sediment younger than Sarmation (mostly Upper Miocene, Pliocene and Pleistocene, from 0 to 3500 m)

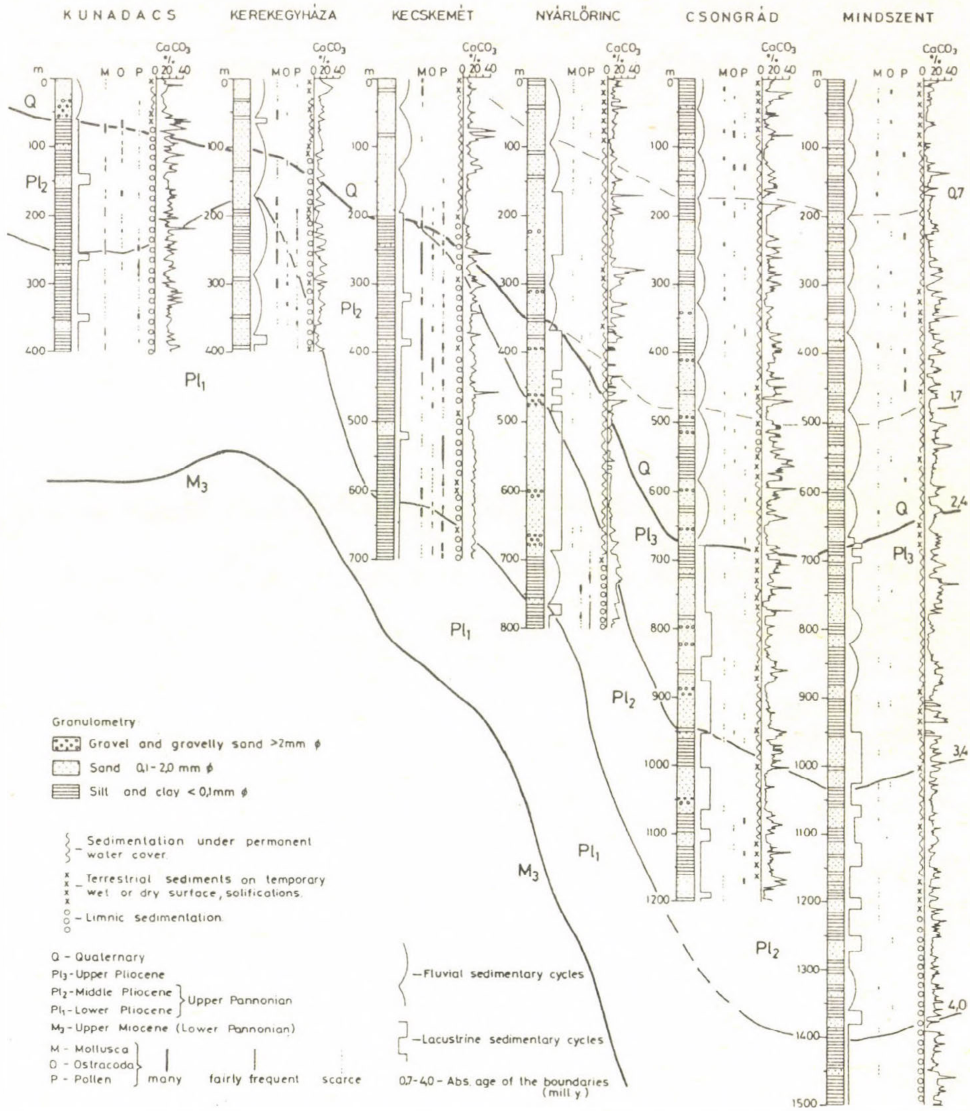



*Fig. 7.* Sedimentological and geochronological borehole profiles across the Danube-Tisza Interfluve (after RÓNAI, A. 1985)

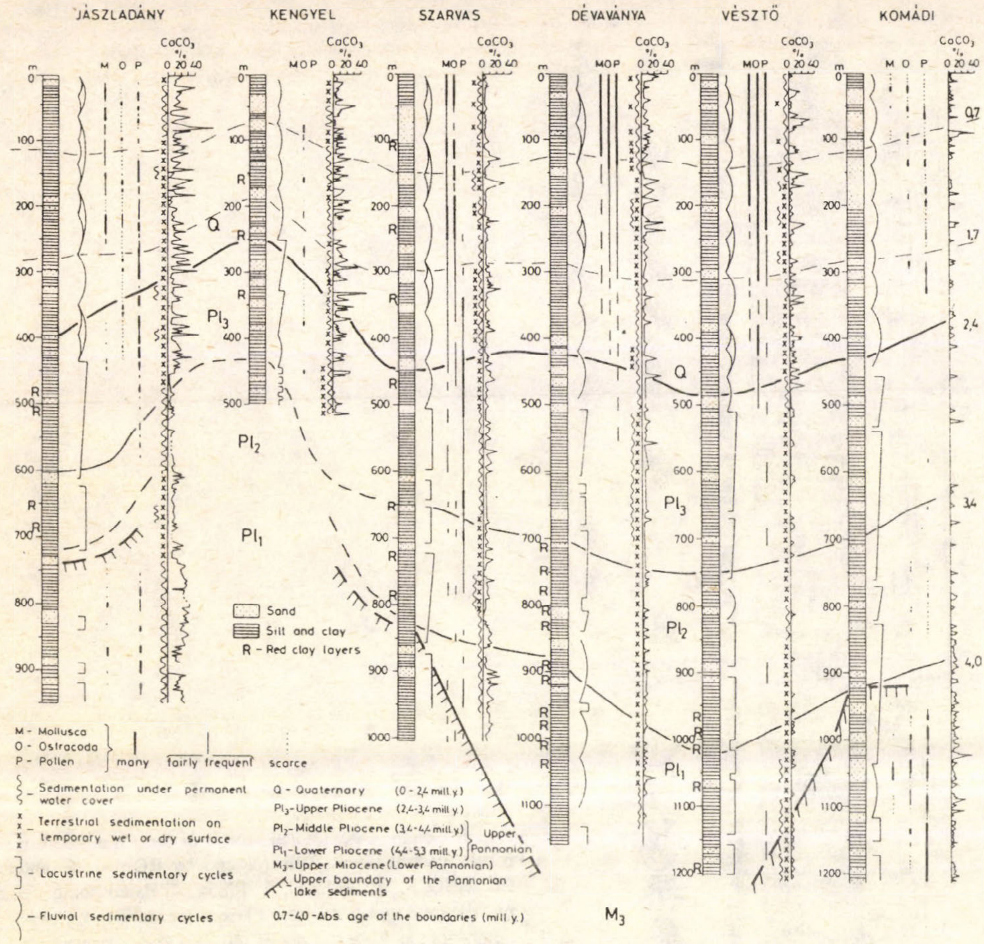



*Fig. 8.* Borehole profiles in local depressions of the Great Hungarian Plains (after RÓNAI, A. 1985)

mountain frame. The subsidence of the central part of the Great Plains basin also went on even after the full disappearance of the Pannonian sea. In the subbasins, subsiding at unequal rates, several hundred metres of fluviatile and subaerial sediments came to be deposited over the marine Pannonian. The subaerial sequence is thickest in the southern Great Plains, where it is largely composed of Pliocene adn Quaternary sands, clays and silts more than 1000 m thick *(Fig. 9)*. Observations indicate that subsidence is still going on today.

By the end of the Paleogene the extensive basin was replaced by block-faulted mountains dismembered by tectonic lineaments and grabens. The basin of today gradually came into existence, as a result of a subsidence which began in the early Neogene and

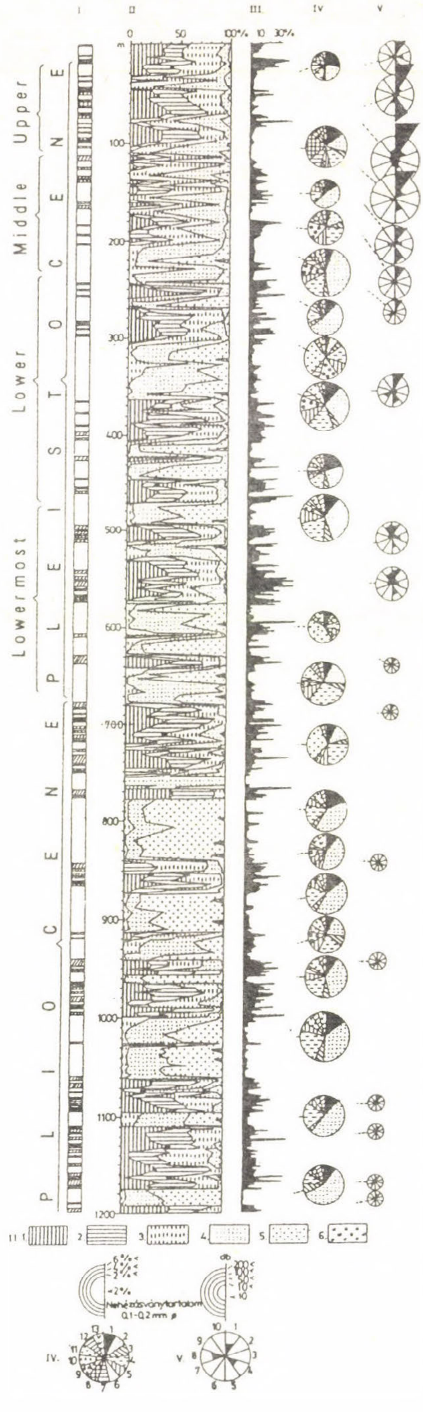



*Fig. 9.* Complex geological profile of the Csongrád borehole, central Great Plain (plotted by RÓNAI, A. and FRANYÓ, F., in: RÓNAI, A. 1985a). I. Paleosols in the profile: total number of the Pleistocene series: 55; total number of the Pliocene series: 40. II = granulometry: 1 = clay; 2 = fine silt; 3 = coarse silt; 4 = fine sand; 5 = medium and coarse sand; 6 = gravel. III = $CaCO_3$ content. IV = heavy minerals: 1 = hematite, magnetite, ilmenite, leucoxene; 2 = garnet; 3 = disthene, staurolite, chloritoide; 4 = epidote, pistacite, piemontite, zoisite, clinasoisite; 5 = tremolite, actinolite, anthophyllite, glaucophane, sillimanite; 6 = green amphibolite; 7 = brown amphibole and lamprobolite; hypersthene; 9 = augite; 10 = biotite; 11 = chlorite; 12 = rutile, brookite, athanase, zircon, titanite, tourmaline, apatite; 13= limonite, pyrite, siderite, carbonates, clay minerals. V = Ostracoda finds: 1 = *Candona parallela* G.W. MÜLLER; 2 = *Candona neglecta* G.O. SARS; 4 = *Candona protzi* HARTWIG; 5 = *Ilyocypris gibba* RAMDOHR; 6 = *Cyclocypris laevis* O.F. MÜLLER; 7 = *Cyclocypris huckei* TRIEBEL; 8 = *Lymnocythere inopinata* BAIRD; 9 = *Lymnocythere sanctipatricii* BRADY-ROB; 10 = *Cytherissa lacustris* G.O. SARS

continued at an accelerated rate and expanded in space. The last brush strokes on the picture were the the evolution of Quaternary drainage network and wind action *(Fig. 10* - see enclosed map no 2 '*Geomorphological map of Hungary*').

### *Alluvial fans (higher than flood-plains)*

Among the rivers in Hungary, it was the Danube that formed the largest alluvial fan. The alluvial fans of the smaller streams issuing from the Transdanubian Hills into the Great Plains coalesce with that of the Danube and constitute the region *Danube-Tisza Interfluve*. They rise above the flood-plains of the mentioned rivers (1.2 in *Fig. 3*). Most of the Interfluve is covered with wind-blown sand dunes of northwest to southeast trend. In addition to wind-blown sands, there are some loess zones of northwest to southest trend and the Bácska region further to the south mantled by fairly thick loess *(Fig. 11a,b)*. During the Pleistocene and in the early Holocene, sands were blown by northeasterly winds out of the alluvial fan of the Danube. There are still some spots where sand is moving and winds produce fresh features (west of Kecskemét and in the southern part). They are, however, only vague traces of previous conditions *(Fig. 11)*.

Early in the last century, most of the dunes were covered by grass and this favoured grazing. Since then, however, drifting sands have been stabilised by afforestation and orchard and vineyard plantations. This activity has resulted in the formation of a rich topsoil layer on the sands. On the Danube-Tisza Interfluve, between longitudinal and parabolic dunes, ther are wet and waterlogged areas. These undrained hollows once contained alkali ponds, now dained through an intricate system of dykes.

The northernmost part of the Interfluve, reaching into the administrative area of Budapest is the Pest Plain. In this microregion, even Miocene delta gravels and sands, Pliocene and early Pleistocene alluvial-fan terraces of the Danube are exposed. In the Pest Plain four Pleistocene alluvial-fan terraces are observed *(Fig. 12a)*. They supply evidence that on the margin of the Great Plains the formation of the gravelly alluvial fan of the Danube was a continuous process from the early Pleistocene. The Ancient Danube may have appeared along this section in the early Neogene at the latest. Since then, alon with its tributaries, it has built a delta of sands and gravels in the Great Plains *(Fig. 12b,c)*. The delta formations subsided into ever deeper positions towards the centre of the basin and were overlain by a thick Plio-Pleistocene subaerial sequence *(Fig. 13)*.

Morphologically, the *Mezőföld* (1.3 in *Fig. 3*) is part of the Great Hungarian Plains. It consists of Plio-Pleistocene alluvial-fan zones of southeastern alignment with loess ridges intercalated between them *(Fig. 10)*. Both types overlie Pannonian clay and sand, exposed in the steep bluffs looking down on the Danube, together with the loess mantle of locally 60 m thickness *(Fig. 14a,b)*.

The Plain is bordered on the N by a *belt of alluvial fans* formed in the Plio-Pleistocene by smaller streams (1.6 in *Fig. 3*). In the Upper Quaternary, the continued subsidence of the Great Plains resulted in the dissection of the formerly contiguous


*Fig. 10.* Distribution of main Quaternary lithological formations in Hungary (after PÉCSI, M.). *Areas of loess formations:* 1 = thick typical loess; 2a = loessy sand; 2b = sandy loess; 2c = compact loess; *Areas of loess-like formations,* deriving from fluviatile deposits: 3 = thin Pleistocene floodplain loess overlying alluvial fans ('infusion loess'); 4 = Holocene loes-like silt overlying alluvial fans; *Areas of slope loess,* deriving from diferent silty deposits (eolian, fluviatile, molasse etc.) redeposited by sheet wash, solifluction, pluvionivation: 5 = laminated loess parallel to slope, locally with rock debris; 6 = sandy, silty, clayey laminated slope loess; 7 = redeposited loess-like loam, locally with debris; 8 = brown loess loam, loess-like slope debris with clayey sand ("loess derivate"); *Areas of wind-blown sand:* 9 = sand cover (Holocene and Pleistocene); 10 = semi-stabilised blown-sand dunes overlying alluvial fans; 11 = riverbank dunes; 12 = sand dunes covered by a thin sandy loess mantle or chernozem; *Areas of fluviatile formations:* 13 = alluvia on floodplains and on valley bottoms of smaller streams; 15 = gravelly alluvial fans; 16 = peat and peat mud in floodplain depressions; *Areas of mountains and plateau eluvium:* 14 = eluvium and slope debris with silt and loam on various bedrocks; 17 = altered basalt on basalt-capped buttes and basalt covers

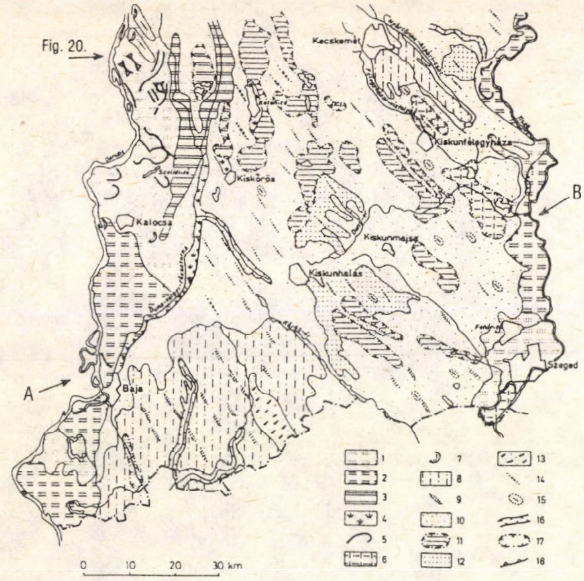



*Fig. 11a.* Generalised lithology and geomorphology of the southern Danube-Tisza Interfluve in Hungary. Geomorphological features (after PÉCSI, M.): 1 = higher floodplain level covered by loess mud; 2 = lower floodplain level with alluvial silt and clay; 3 = salt-affected clays on the floodplain; 4 peaty backswamps and interdune depressions; 5 = filled meander or backswamp; 6 = meadow soil on the higher floodplain level; 7 = riverbank dunes on the higher floodplain level; 8 = alluvial fan covered by sandy loess and chernozem; 9 = longitudinal dunes with loess cover; 10 = alluvial fan covered by blown sand and cover sand; 11 = salt-affected interdune depressions characterised by thick Ca-Mg carbonate caliche and mud; 12 = semi-stabilised sand dunes; 13 = sand dunes with chernozem; 14 = stabilised sand dunes; 15 = blow-out; 16 = small valley; 17 = salt-affected soils in enclosed basins; 18 = inactive steep bank

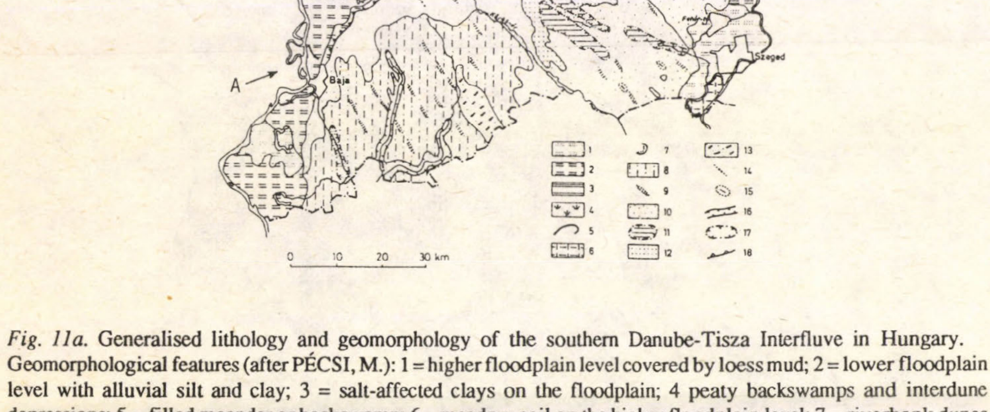



*Fig. 11b.* Geological profile across the Danube-Tisza Interfluve between Baja and Szentes (A-B) (after MIHÁLTZ, I. and MOLDVAY, L. in MIHÁLTZ, I. 1953, 1967). 1 = Upper Pannonian (Upper Miocene) marine sediments; 2 = Pliocene fluvial sediments transported by the Danube river system; 3 = Pleistocene fluvial sediments deposited by the Tisza river; 4 = Pleistocene loess; 5 = loess-like deposits; 6 = blown sand; 7 = paleosols; 8 = alluvial deposits; 9 = aleurite; 10 = fine sand; 11 = medium-grained sand; 12 = coarse-grained sand

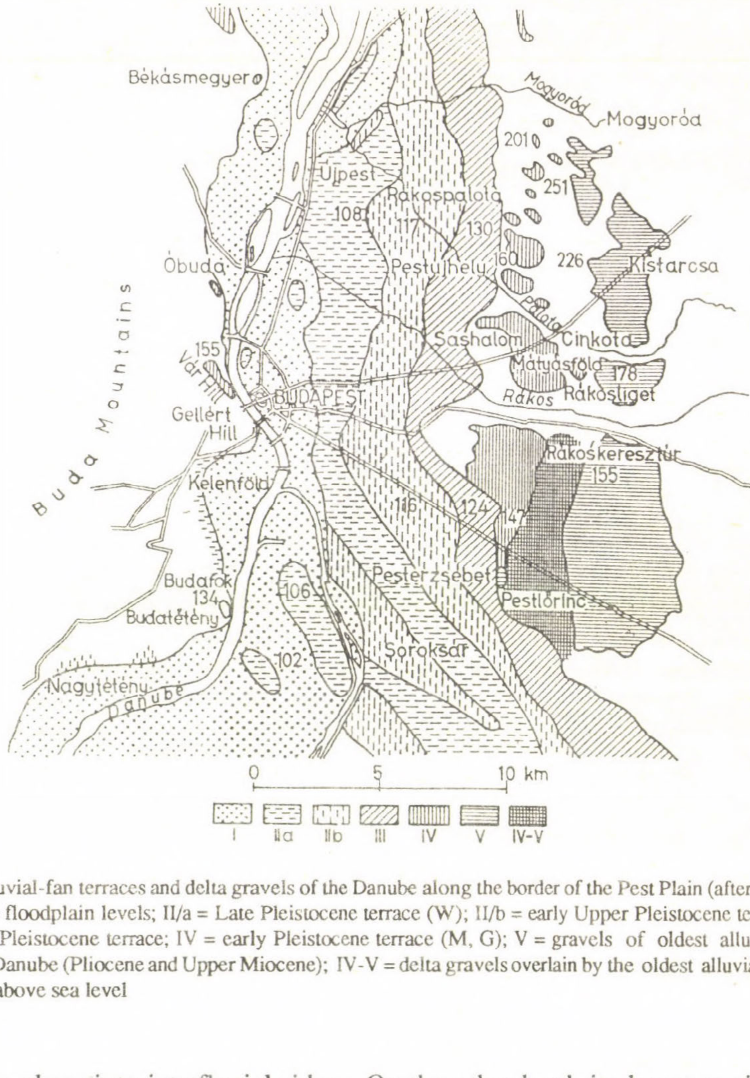



*Fig. 12a.* Alluvial-fan terraces and delta gravels of the Danube along the border of the Pest Plain (after PÉCSI, M.). I = Holocene floodplain levels; II/a = Late Pleistocene terrace (W); II/b = early Upper Pleistocene terrace (R-W); III = Middle Pleistocene terrace; IV = early Pleistocene terrace (M, G); V = gravels of oldest alluvial fans and deltas of the Danube (Pliocene and Upper Miocene); IV-V = delta gravels overlain by the oldest alluvial-fan gravel; 102 = metre above sea level

alluvial-fan slope into interfluvial ridges. On the other hand, its lower portion in the *Nagykunság* (1.9. in *Fig. 3*) was separated by the Holocene flood-plain of the Tisza from its root region *(Fig. 15a,b).*

The Nyírség (1.7 in *Fig.3*) is a large Pleistocene alluvial fan of the Tisza and its tributaries in the NE corner of the Great Plains. Its relief resembles to some extent to the alluvial-fan plain of the Danube. This region was slightly uplifted against its environs in the early Holocene and, consequently, it was by-passed by all the river which formerly crossed it (BORSY, Z. 1961). In the eastern, most extensive part, the fluviatile deposits are overlain by a thick cover of wind-blown sand *(Fig. 16).* The central part of the Nyírség is likewise covered with blown-sand, but its surface is lower and dissected by a number

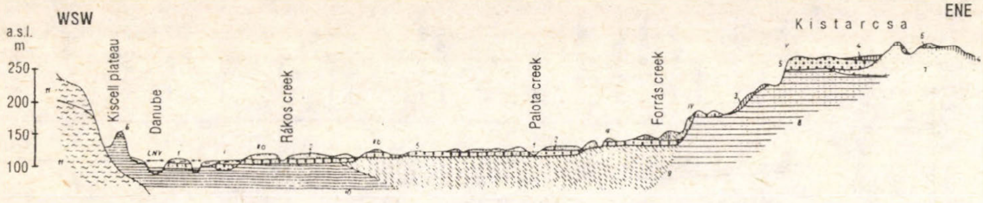



*Fig. 12b.* Profile of terrace morphology across the Pest Plain between the Kiscell Plateau (Old Buda) and Kistarcsa (suburban village of Budapest) (after PÉCSI, M.). 1 = floodplain silt; 2 = blown sand; 3 = loess with slope debris; 4 = loess; 5 = terrace gravel and sand, locally overlying the oldest alluvial fan and delta gravel (terraces nos I-IV); 6 = travertine; 7 = Upper Pliocene fluviatile sand; 8 = Pannonian clay and sand; 9 = Mediterranean beds; 10 = Kiscell Clay (Oligocene); 11 = Bryozoan and Buda Marl (Eocene)

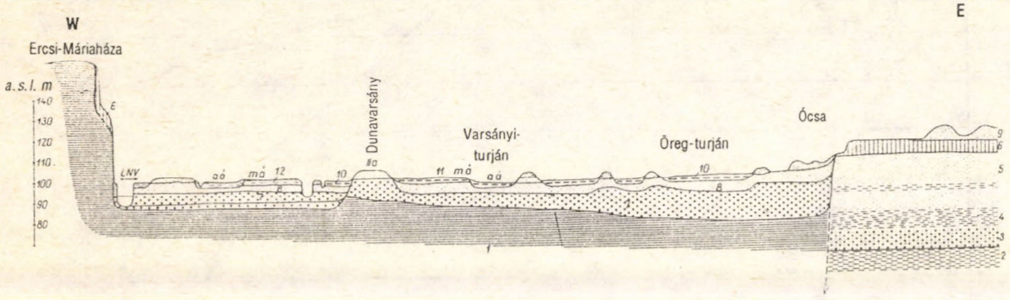



*Fig. 12c.* Profile of terrace morphology across the southern Pest Plain between Ercsi and Ócsa (reambulated by author from data by Sümeghy, J. [1945-1947]). 1 = Pannonian clay (Upper Miocene); 2 = Pannonian sandy clay; 3 = Pannonian delta gravel and sand of the Danube; 4 = Uppermost Pannonian clayey sand; 5 = cross-bedded coarse sand (Uppermost Pannonian); 6 = loess; 7 = Miocene- Pliocene old alluvial fan and delta gravel of the Danube in the Ócsa depression (locally more than 40 m deep); 7a, 7b = Middle and Upper Pleistocene terrace gravel; 8 = gravelly sand (Pleistocene-Holocene); 9 = blown sand and riverbank dunes; 10 = meadow clay and locally peat; 11 = salt-affected meadow clay; 12 = sandy-silty alluvium; aá = lower floodplain level; má = higher floodplain level; LNV = highest water level of the Danube; V = inferred fault

of small N to SD valleys between asymmetric elongated parabolic dunes. In the West-Nyírség, the dunes are covered by a thin mantle of loess, gradually thickening to west. This loes mantle forms a transition towards the Hajdúhát (1.8 in *Fig. 3*), to the west of the Nyírség, which is overall covered by a continuous blanket of loess. The sands of the Nyírség were drifted largely with northerly winds. The sand surface was stabilised by Robinia trees, orchards, plantations of the world-famous Jonathan apple and potato and tobacco cultivation was also introduced.

The *alluvial fan of the Maros river* (1.11 in *Fig. 3*) is located in the southeastern part of the Great Plains. A surface of late Pleistocene and early Holocene alluvium, it

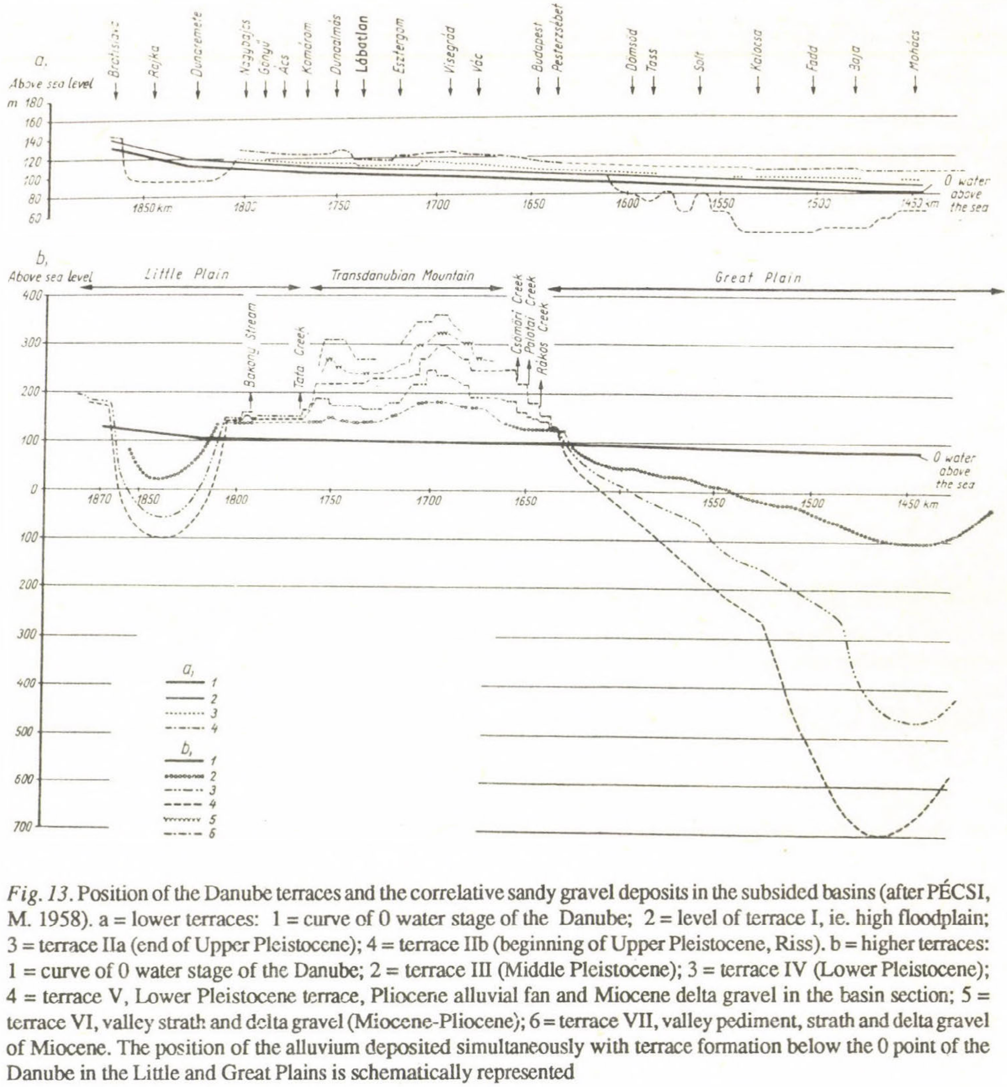


*Fig. 13.* Position of the Danube terraces and the correlative sandy gravel deposits in the subsided basins (after PÉCSI, M. 1958). a = lower terraces: 1 = curve of 0 water stage of the Danube; 2 = level of terrace I, ie. high floodplain; 3 = terrace IIa (end of Upper Pleistocene); 4 = terrace IIb (beginning of Upper Pleistocene, Riss). b = higher terraces: 1 = curve of 0 water stage of the Danube; 2 = terrace III (Middle Pleistocene); 3 = terrace IV (Lower Pleistocene); 4 = terrace V, Lower Pleistocene terrace, Pliocene alluvial fan and Miocene delta gravel in the basin section; 5 = terrace VI, valley strath and delta gravel (Miocene-Pliocene); 6 = terrace VII, valley pediment, strath and delta gravel of Miocene. The position of the alluvium deposited simultaneously with terrace formation below the 0 point of the Danube in the Little and Great Plains is schematically represented

rises only slightly above the present-day flood-plains. The main body of the fan consists of sands and gravels, overlain by a very thin blanket of flood-plain loess loam or sandy loam (*Fig. 17* and see the enclosed Geomorphological map of Hungary). Its monotonously flat surface is only diversified by a few abandoned river channels, oxbows. Along the meanders and oxbows, there are elongated patches of river-bank dunes. Since the sands and gravels of the alluvial fan are close to the surface, groiundwater is high and the loess loam over the alluvia has been altered into alkali soils in places. The typical soils are, however, (meadow) chernozems of high fertility.

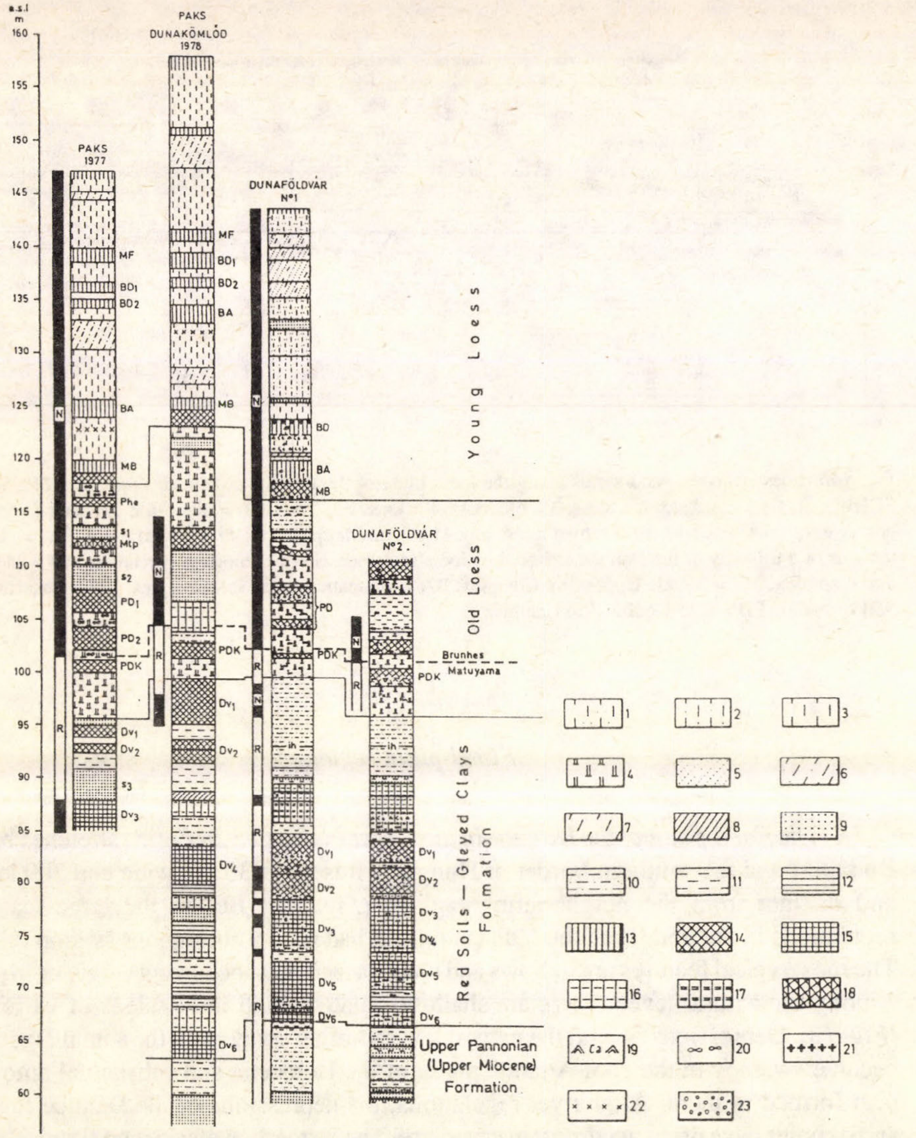



*Fig. 14a.* Loess-paleosol-sand sequence of the loess bluff of the Danube along the margin of the Mezőföld Plain (after PÉCSI, M., SZEBÉNYI, E. and SCHWEITZER, F., paleomagnetic data by PEVZNER, M.A..). 1 = loessy sand; 2 = sandy loess; 3 = loess; 4 = old loess; 5 = slope sand; 6 = sandy slope loess; 7 = slope loess; 8 = semipedolite; 9 = fluvial-proluvial sand; 10 = silty sand; 11 = silt, gleyed silt; 12 = clay; 13 = steppe-type soil, chernozem; 14 = brown forest soil; 15 = red clay; 16 = hydromorphic soil; 17 = alluvial meadow soil; 18 = forest soil (on floodplain); 19 = calcium carbonate accumulation; 20 = loess doll; 21 = charcoal; 22 = volcanic ash; 23 = sandy gravel; MF = 'Mende Upper' forest-steppe Soil Complex (Mo. 421 29,800 years BP, HV 27,855±599 years); BD = 'Basaharc Double' forest-steppe Soil Complex; BA = 'Basaharc Lower' chernozem soil; MB = 'Mende Base' Soil Complex (brown forest soil + forest-steppe soil); Phe = Paks sandy forest soil; Mtp = Paks marshy soil; PD = 'Paks Double' Soil Complex (brownish- red Mediterranean-type dry forest soil); PDK = Paks-Dunakömlőd brownish-red soil; $Dv_1$-$Dv_6$ = red soils (Dunaföldvár Formation); ih = silty sand; $S_1$-$S_3$ = sands

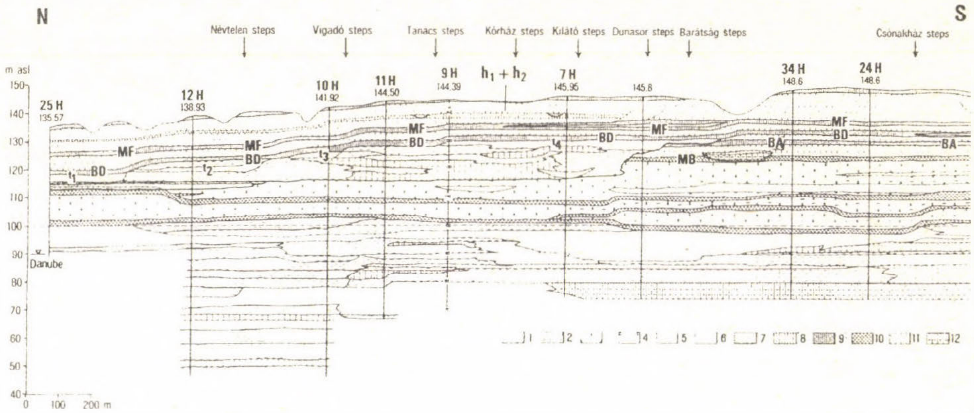



*Fig. 14b.* Loess-paleosol-sand series along the loess bluff of the Danube at Dunaújváros (after PÉCSI, M. and SCHEUER, Gy.). 1 = sand; 2 = loess; 3 = old loess; 4 = loess silt; 5 = silt; 6 = sandy silt; 7 = clay; 8 = embryonic humic soil; 9 = steppe soil; 10 = brown forest soil; 11 = hydromorphic soil; 12 = meadow soil; $t_1$-$t_4$ = alluvial-fan terraces of a tributary of the Danube, covered by loess sequence. H = hydrological boreholes; MB = Mende Base Soil Complex; MF = Mende Upper Soil Complex; BA = Basaharc Lower Soil Complex; BD = Basaharc Double Soil Complex; PD = Paks Double Soil Complex

### *Flood-plain regions*

The *flood-plain of the Danube in the Great Plains* (1.1 *in Fig. 3*) stretches between Budapest and the southern border of Hungary. It is up to 30 km wide and 200 km long and distinct from the neighbouring regions *(Fig. 10).* Before the large-scale river regulations in the middle of the 19th century, it had been a contiguous swamp or marsh. The most typical features are oxbows and river-bank dunes, occurring singly or in groups. Among the natural levees there are shallow isolated alkali depressions of various size *(Fig. 18).* Depressions behind the natural levees farther away from the actual Danube bed became swampy in the cool Atlantic phase of the Holocene and substantial amounts of peat formed in them. After river regulations, the depressions of the Danube meanders and oxbows have dried up almost everywhere. The formerly waterlogged flood-plain was also drained. The 'waterworld' was replaced by arable land. Protected by man-made levees, the flood-plain along the Danube has undergone a rapid anthropogenic transformation *(Fig. 19).*

In the Upper Pleistocene and Holcene the floodplain along the Danube separated itself from the older Pleistocene alluvial fan of teh Danube and from the Mezőföld. River incision was probably triggered by a somewhat more intense subsidence of the southern Great plains. The borderline between the Danube flood-plain and the Mezőföld is particularly sharp, a steep bluff 30 to 50 m high *(Fig. 20).*

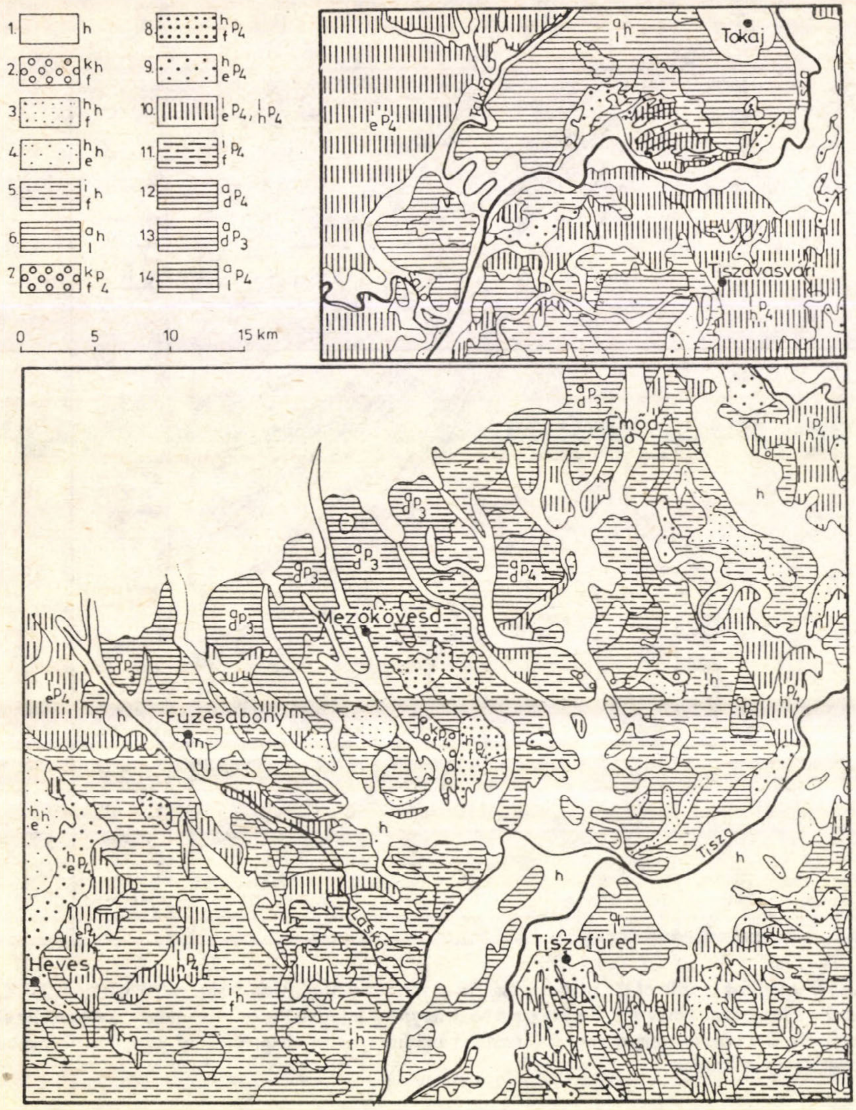



*Fig. 15a.* Example of morpho-lithological map of the alluvial fans along the northern margin of the Great Plains (mesoregion: Mezőség) (after RÓNAI, A. 1985). Holocene: 1 = floodplain deposits undifferentiated; 2 = alluvial-fan gravel; 3 = fluvial sand; 4 = blown sand on the river bank; 5 = loess-like alluvial sandy silt; 6 = alluvial silty clay; 7 = gravel and sandy gravel of alluvial fans; 8 = fluvial sand of the alluvial fan; 9 = blown sand; 10 = loess, sandy loess, deluvial and infusion loess overlying the alluvial fans; 11 = floodplain silt and clay; 12 = deluvial, colluvial caly, red-brown clay and brown earth; 13 = older Pleistocene slope deposit, brown loam and clay on the higher levels of alluvial fans; 14 = marshy clay and silt

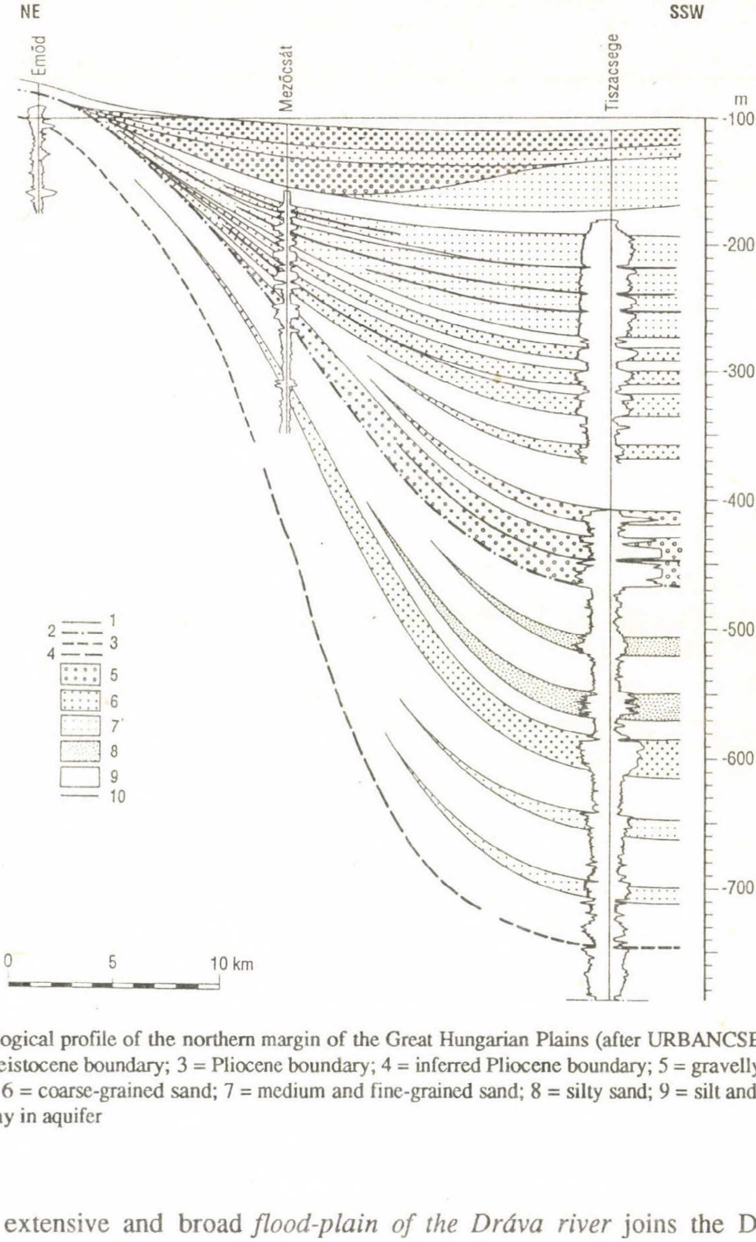



*Fig. 15b.* Geological profile of the northern margin of the Great Hungarian Plains (after URBANCSEK, J.). 1 = surface; 2 = Pleistocene boundary; 3 = Pliocene boundary; 4 = inferred Pliocene boundary; 5 = gravelly sands and sandy gravels; 6 = coarse-grained sand; 7 = medium and fine-grained sand; 8 = silty sand; 9 = silt and clay; 10 = interbedded clay in aquifer

The extensive and broad *flood-plain of the Dráva river* joins the Danubian flood-plain beyond the national border, in Croatia. Its lower section is accompanied by a broad band of low alluvial-fan plain mantled by infusion loess, which also belongs to this region (1.4 in *Fig. 3*).

The *Tisza flood-plain* is less distinct than the Danube valley. Prior to river regulation measures, the Tisza roamed over a vast area and, during floods, inundated its

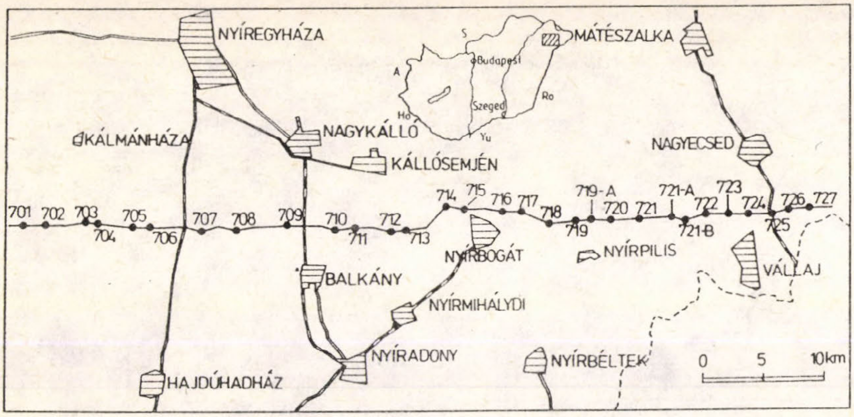



*Fig. 16a.* Location of the geological profile of the Nyírség, Northeast-Hungary

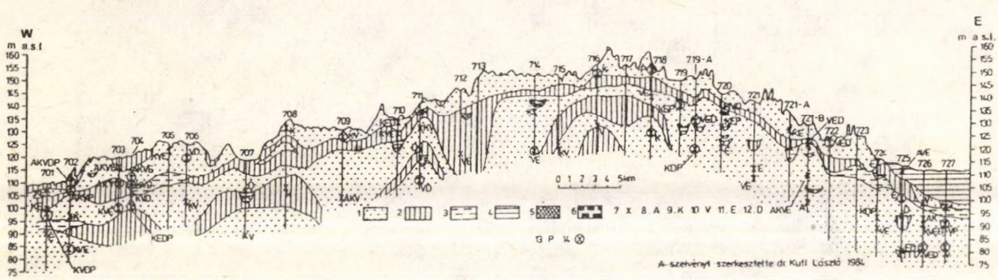


*Fig. 16b.* Geological profile of the Nyírség subregion with sampling sites and the samples studied (after MOLNÁR, B. et al. 1995). 1 = sand; 2 = coarse silt; 3 = fine silt; 4 = clay; 5 = carbonate mud; 6 = peat; 7 = sites of sampling for scanning electron microscopic analyses; 8. A = grain type of host origin, 9. K = grain type affected by chemical process, 10. V = grain type of water transport, 11. E = grain type of eolian transport, 12. D = grain type of diagenetic effects, 13. P = grain type with polygonal network of cracks; 14 = samples

flood-plain *(Fig. 21)*. When the floods were over, large waterlogged areas remained in the deeper parts of the flood-plain. Along the river there are everywhere natural levees, riverbank dunes, point bars, oxbow lakes and higher flood-plain levels usually covered by infusion loess (*Figs. 10* and 22). Marshes, forested backswamps, peat bogs, willow and poplar groves added to the colours of the countryside.

The meandering channels of the Tisza were continuously shifting. In the latest Pleistocene it still flowed south of the Nyírség, along the present Berettyó-ér stream towards the plain interior. It was only in post-glacial times that it made the detour around

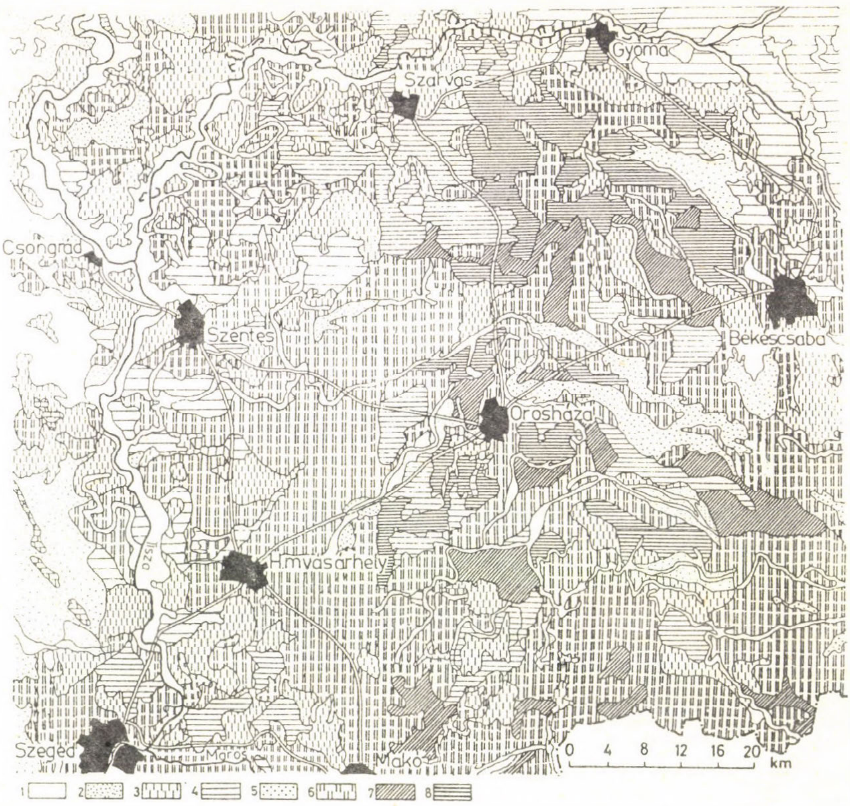



*Fig. 17.* Lithological map of the Körös-Maros-Tisza interfluve (after RÓNAI, A. 1985). Holocene: 1 = floodplain alluvium; 2 = blown sand; 3 = fluviatile silt; 4 = meadow clay (Pleistocene); 5 = sand of alluvial fan, riverbank dunes; 6 = infusion loess, sandy silt; 7 = loessy silt; 8 = clayey floodplain deposits

the Nyírség. Leaving the Tokaj Gate, during the Holocene it sometimes turned to the south, across the *Hortobágy steppe plain* (along the present-day Hortobágy watercourse).

The *Hortobágy* steppe, almost as flat as a table, is characterised by alkali soils *(Fig. 23a,b,c)*. After its drainage, hundreds of cut-off meanders filled up rapidly. The lower-lying parts are used as mown meadows and pastures. The meadow soils of the higher flood-plain level were turned into arable land. South of the Middle Tisza flood-palin there is an almost uninterrupted string of river-bank dunes dissected by majestic arcs of isolated oxbows. They belong to the *Nagykunság-Hortobágy* alluvial plain *(Fig. 22)*, which lies only a few metres above the Tisza flood-plain (1.9 in *Fig. 3.*). Most of this plain is covered by a thin blanket of infusion loess *(Fig. 10)*.

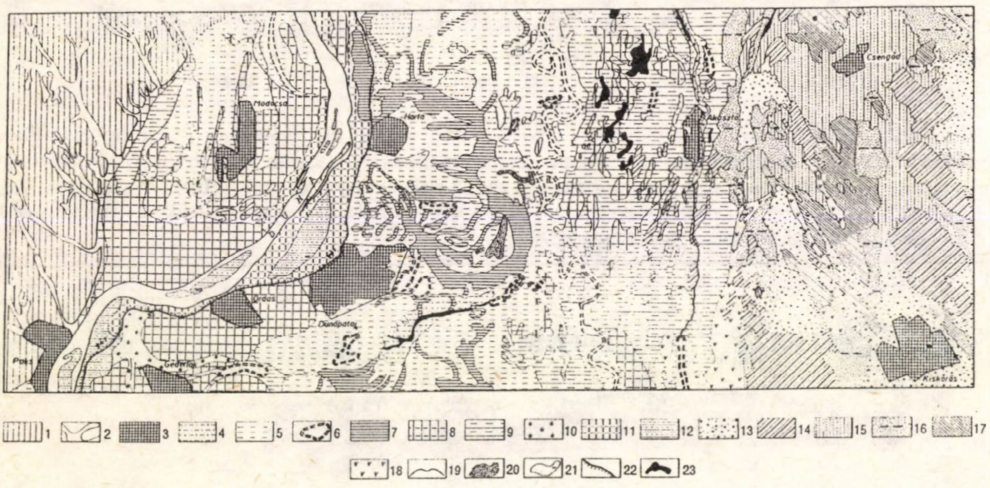



*Fig. 18.* Morphofacies of the Danube floodplain and western margin of the Danube-Tisza Interfluve between Géderlak and Kiskőrös (after PÉCSI, M. and SZILÁRD, J.).

Ecofacies:

1 = loess plain - cultivated; 2 = narrow and deep valleys – meadows, pastures and fish-ponds; 3 = terrace island – settlements; 4 = higher sandy floodplain level – cultivated; 5 = higher silty floodplain level – cultivated; 6 = salt-affected flats of the higher floodplain level – meadows and pastures; 7 = seasonally waterlogged tracts of the higher floodplain level; 8 = lower floodplain level with salt-affected soils – meadows and pastures; 9 = lower floodplain level, seasonally waterlogged – reed-beds and peat meadows; 10 = meanders – high sedge-beds; 11 = higher level between dykes – elm-ash-oak gallery forests, now arable; 12 = lower level between dykes – willow-poplar gallery forests and pastures; 13 = wind-blown sand – 'sand puszta grass' and poplar-juniper groves; 14 = stabilised sand dunes – vineyards and orchards; 15 = loess and sand surfaces – arable; 16 = flats – meadows and pastures; 17 = waterlogged areas – reed-beds and meadows; 18 = sodaic ponds – peat meadows; 19 = steep bank, escarpment liable to erosion; 20 = flood-free surfaces – gardens and vineyards; 21 = salt-affected flats, seasonally waterlogged; 22 = dykes (man-made); 23 = permanent water surfaces

Morphofacies:

1 = plain on typical and redeposited loess; 2 = erosional-derasional valleys; 3 = Latest Pleistocene terrace island covered by sandy silt, site of settlements; 4 = higher floodplain level covered by sand and sandy silt flood deposits; 5 = higher floodplain level covered by loessy, sandy and calcareous silt; 6 = Early Holocene meanders with redeposited loessy silt, sandy silt, locally with fluviatile sand; 7 = Early Holocene meanders filled with silt, meadow and bog clay; 8 = lower floodplain level covered by silt, calcareous silt and salt-affected meadow clay; 9 = lower floodplain with bog clay, peat and peaty meadow; 10 = Late Holocene meanders with high sedges; 11 = recent higher floodplain, seasonally waterlogged; 12 = recent lower floodplain with flood deposits, seasonally waterlogged; 13 = Early Holocene-Pleistocene wind-blown sand surface with longitudinal dunes and other semi-stabilised features; 15 = sandy loess, loessy sand, infusion loess, loessy silt; 16 = calcareous silty sand, sandy silt; 17 = calcareous silt in the furrows between dune rows; 18 = basin filled with peat and peaty earth; 19 = escarpment due to faulting and erosion; 20 = floodplain islands covered by fixed sand with calcareous silt; 21 = enclosed floodplain depressions; 22 = dykes of the Danube; 23 = enclosed depressions with intermittent water body, salt pond

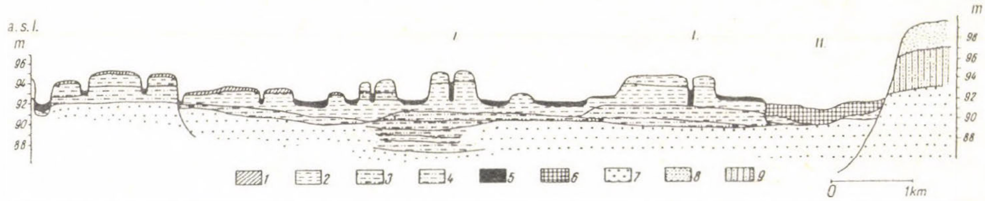



*Fig 19.* Floodplain flats with alkali soils enclosed by natural levees along the Danube in the Great Hungarian Plains (after PÉCSI, M.) I = natural levees of parameanders; II = old channel near the margin of the floodplain, filled with peat and covered by swamp vegetation; 1 = meadow soil; 2 = alluvial loess silt (pale yellow); 3 = sandy silt (pale yellow); 4 = silty sand; 5 = swamp clay, meadow clay; salt-affected clayey soil; 6 = peat bog; 7 = fluviatile sand; 8 = wind-blown sand; 9 = loessy sand, sandy loess

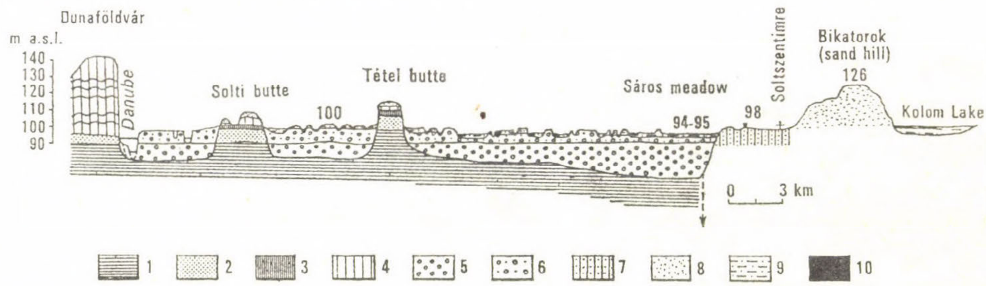



*Fig. 20.* Cross-section of the Danube floodplain in the Great Plains (plotted by PÉCSI, M. from data by ERDÉLYI, M. and SÜMEGHY, J.). 1 = Pannonian clays; 2 = Pannonian sands; 3 = Pliocene red clays; 4 = Dunaföldvár loess with four or five paleosols; 5 = Danube gravels (late Pleistocene) becoming finer with increasing distance from the Danube; 6 = sands and silts with pebbles (Holocene); 7 = loessy sand; 8 = wind-blown dune sands; 9 = floodplain deposits, silts; 10 = meadow clays and swamp clays


*Fig. 21.* Areas affected by inundation by occasional floods and excess water before the 19th century (after LÁSZLÓFFY, W.). 1 = floodplain; 2 = seasonally inundated area

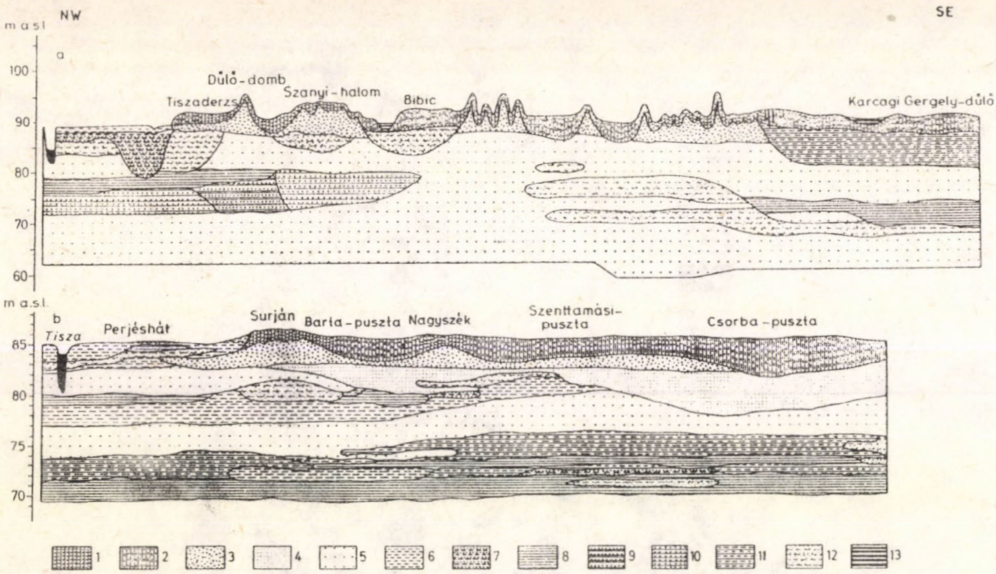



*Fig. 22.* Morphological profile of the Middle Tisza region (plotted by BORSY, Z. from data by SÜMEGHY, J. and his own surveys). 1 = loessy sand; 2 = floodplain loess, loess-like deposits; 3 = wind-blown sand; 4 = fine-grained fluviatile sand; 5 = fine to medium-grained fluviatile sand; 6 = silt; 7 = sandy silt; 8 = clay; 9 = sandy clay; 10 = clayey sand; 11 = clayey silt; 12 = silty clay; 13 = meadow clay

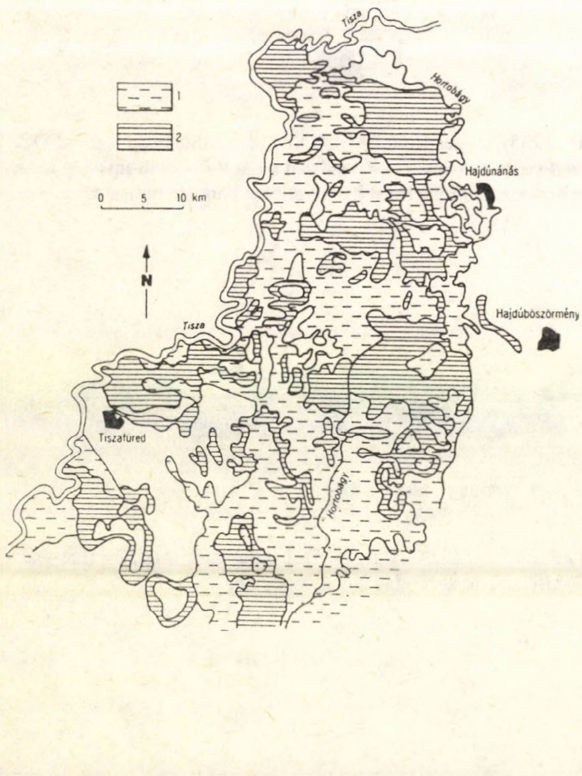



*Fig. 23a.* Drainage of the Hortobágy Plain before river conservation (after LÓCZY, D.). 1 = areas inundated during floods; 2 = areas inundated over most of the year

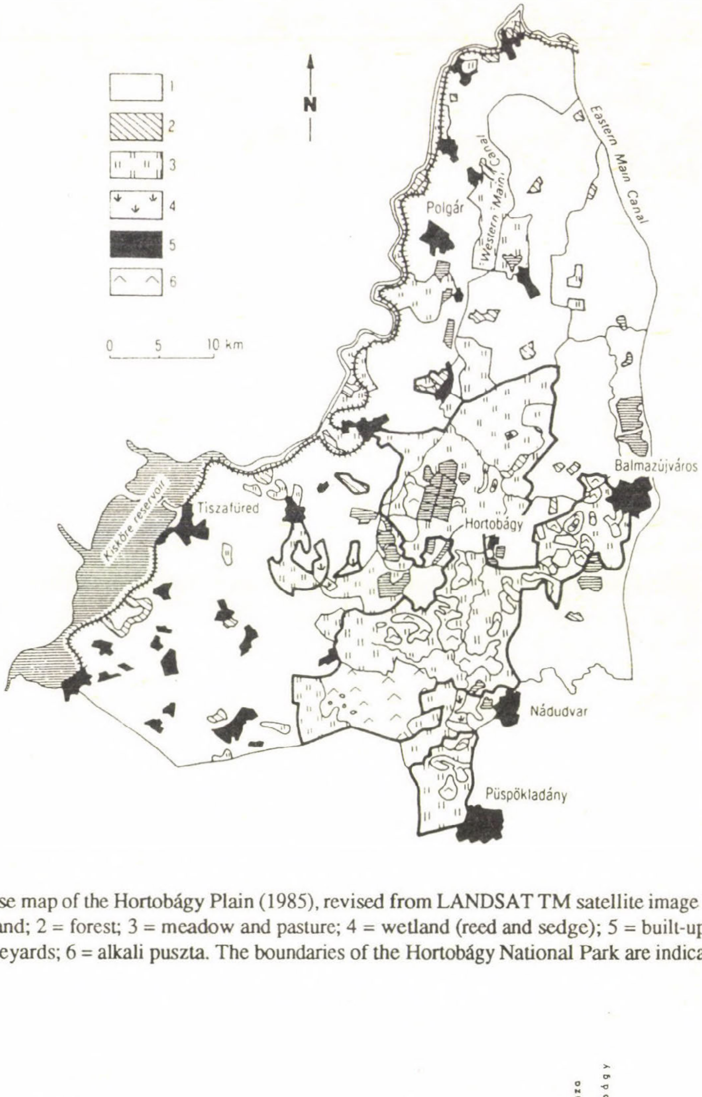



*Fig. 23b.* Land use map of the Hortobágy Plain (1985), revised from LANDSAT TM satellite image (after LÓCZY, D.). 1 = arable land; 2 = forest; 3 = meadow and pasture; 4 = wetland (reed and sedge); 5 = built-up area, gardens, orchards and vineyards; 6 = alkali puszta. The boundaries of the Hortobágy National Park are indicated

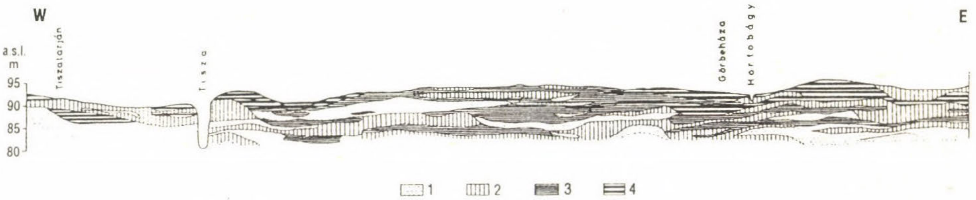



*Fig. 23c.* Lithological profile of the Hortobágy Plain (after RÓNAY A. 1985). 1 = fluviatile sand; 2 = fine-grained fluviatile silt; 3 = coarse fluviatile silt; 4 = salt-affected meadow clay in the floodplain

There is a vast flood-plain penetrating into the interior of the Great Plains: the *alluvial plain of the Berettyó and Körös rivers* (1.10 in *Fig.3*). It is in effect a system of coalesced alluvial fans, whose base is mostly sand covered with alluvial clayey loess. Among the alluvial fans built by river branches, deeper-lying backswamps and peat-bogs developed. Prior to human intervention, the alluvial silts deposited by meandering streams raised the level of the river beds and banks. The natural levees enclosed small undrained backswamps. Inundated during floods, the latter retained some of the flood discharge in their small alkali and salt lakes. In the dry summers, their waters evaporated and alkali soils formed. The massive drainage measures transformed the landscape: former swamps are now arable land or pastures and the alkali lakes can only be traced in spots of alkali soils and salt-affected meadow soils. To the natural microforms *(Fig. 24).* man-made hillocks, pre-Magyar tumuli occur all over the plain east of the Tisza river. Other common landscape elements are flood-control dykes and irrigation canals.

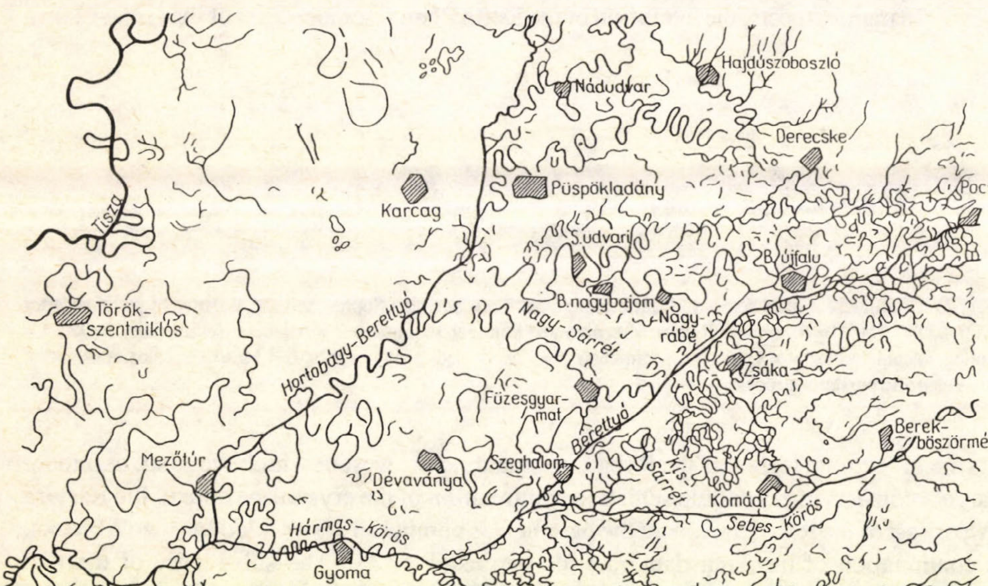



*Fig. 24.* Cut-off meanders of the Körös floodplain (after PAPP, A.)

The alluvial fans fringing the Great Plains store huge *reserves of groundwater*. Particularly along the flood-plains, subsurface water currents develop in alluvial fan deposits after snowmelt and after spring and early summer rains. In the long dry summer months, on the other hand, there is a marked shortage of water. it is something of a paradox, but nonetheless true, that most of the flood-plains and alluvial-fan surfaces need irrigation in the dry season. Water for irrigation is supplied partly by surface reservoirs behind dams and partly out of artesian wells sunk into the confined groundwater aquifers.

## *THE LITTLE PLAIN*

Located in Western Hungary, along the Danube entering into the Carpathian Basin and along one of its tributaries, the Rába, the Little Plain can be subdivided morphologically into a *young alluvial fan at flood-plain level* in the centre (2.1 in *Fig. 3*) and a *dissected older alluvial-fan plain on the margin of the basin* (2.2, 2.3 and 2.4). The latter is linked to the east to the glacis of erosion of the Transdanubian Mountains and to the west to the similar features of the Alpine foothills.

In many aspects, the evolution of the Little Plain resembles that of the Great Plains.

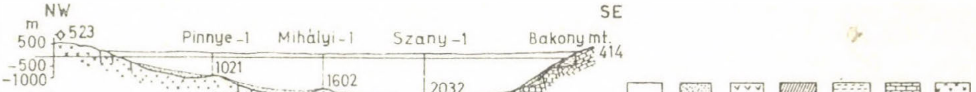



*Fig. 25*. Geological profile across the Little Hungarian Plain between Sopron and the Bakony Mountains (after KŐRÖSSY, L.). 1 = Pannonian (Upper Miocene) and younger sediments; 2 = Miocene sedimentary rocks; 3 = young volcanic rocks; 4 = Oligocene sediments; 5 = Eocene sedimentary rocks; 6 = Mesozoic calcareous rocks; 7 = Paleozoic crystalline rocks

Its major tectonic feature is the Rába Lineament, to the west of which the basin basement largely consists of crystalline schists, a continuation of the crystalline core of the Eastern Alps. East of the Rába Lineament the basement is composed of subsided Mesozoic blocks, a continuation of the Transdanubian Mountains *(Fig. 25)*. The subsidence of the two different basement units was not uniform: the Mesozoic blocks had begun to sink earlier (in the early Tertiary), while the rapid subsidence of the crystalline basement only began in the Middle Miocene. Therefore, in the western part of the basin, the crystalline basement was partly still exposed in the second half of the Miocene. Deep drilling has confirmed the subsidence of the area to have taken place predominantly during the Pannonian transgression. This latter produced more than 1000 metres of sediment from a landlocked sea. Subsidence slowed down at the end of the Upper Miocene and fluviatile and particularly deltaic sedimentation was intensified by the uplifting of the mountain frame. As a result, the sea retreated at a fast rate. The retreat of the inland sea was also promoted by the change to warm semiarid climate. This resulted in increased evaporation from the inland sea. At the same time, intensive disintegration affected the crystalline rocks of the mountain frame and the large amounts of sand and silt produced were accumulated by water-courses and winds over extensive areas under semiarid conditions. It seems probable that the wind erosion features of semidesert origin along the margins of the Little Plain and in the Transdanubian Mountains first described by LÓCZY, L. (1913) and then CHOLNOKY, J. (1926) date back to this period of alternating semiarid and semihumid climates. The concepts of early authors are amended by recent research (PÉCSI, M. 1985; SCHWEITZER, F. 1992).

In the Uppermost Miocene (6 to 5 Ma BP) the Ancient Danube and its tributaries accumulated large amounts of sand (Baltavarian fluvio-lacustrine series) unconformably over the Pannonian marine deposits. Infilling of the basin and erosion along the uplifting margins ran parallel. This sandy basin fill extends all over the entire Little Plain up to the feet of the Transdanubian Mountains and indeed also farther south and southwest, to the Transdanubian Hills.

Fluviolacustrine deposits are locally preserved in thicknesses up to 100 m. According some authors (SZÁDECZKY-KARDOSS, E.; SÜMEGHY, J.), they were not produced by the Ancient Danube alone, but are joint deposits of the Alpine-Carpathian drainage, penetrating into the area of the former Pannonian sea.

On the western and eastern margins of the Little Plain, basaltic volcanism took place in the Upper Pannonian and mainly in the Pliocene. Simultaneously, the Transdanubian Mountains underwent an uplift, which diverted the drainage system of the Ancient Danube and its tributaries to the northeast and east, towards the Visegrád Gorge. In the gorge the Danube presumably followed a pre-existing valley in the young Paratethys molasse belt beginning in the Lower Miocene and traversed the Transdanubian Mountains, a still rather low range at that time.

The landforms dominating the present-day surface of the Little Plain include the Pleistocene terraced alluvial fans and flood-plains of the Danube, the Rába and tributaries. Along the southern margin of the Little Plain (2.2 and 2.4) a large-scale removal of basin fill during the Neogene and particularly in the Quaternary took place. This is attested by erosional residual hills (Somló Hill in the Marcal Basin) and glacis of erosion formed over heavily eroded Pannonian strata *(Fig. 26)*.

### *Young and old alluvial-fan plains of the Danube and its tributaries*

*Young alluvial-fan plains* (2.1 and 2.4 in *Fig. 3*). The enormous alluvial fan of the Danube in the Little Plain can be subdivided into two generations. The younger plain covers the espanse from Bratislava to Komárom is more than 100 km long and 60 to 80

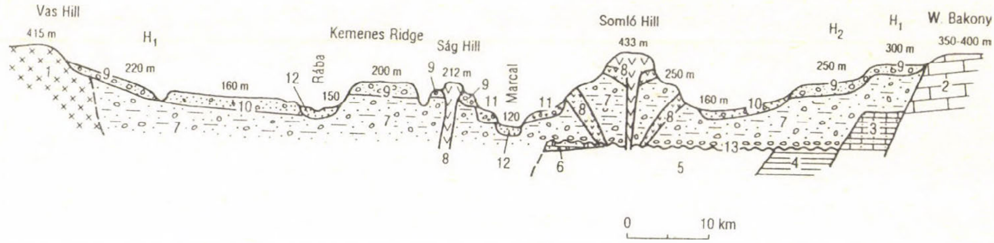



*Fig. 26.* Geomorphological profile in the southern Little Hungarian Plain across the Marcal basin (after PÉCSI, M. using data from JÁMBOR, Á. [ed.] 1981). 1 = Paleozoic crystalline rocks; 2 = Mesozoic calcareous rocks; 3 = Eocene limestone; 4 = Oligocene clay, sand and gravel; 5 = Middle Miocene (Badenian) sediments; 6 = Middle Miocene (Sarmatian) limestone; 7 = Lower and Upper Pannonian (Upper Miocene and Pliocene) clay, sand and gravel; 8 = Pliocene basalt (lava and tuff); 9 = Pliocene gravels of old alluvial fans, on $H_1$, $H_2$ foothill surfaces; 10 = Early Pleistocene alluvial fans; 11 = Middle Pleistocene terraces; 12 = Upper Pleistocene valley floor and low terrace; 13 = Pannonian gravel, unconformity (415 m above sea level)

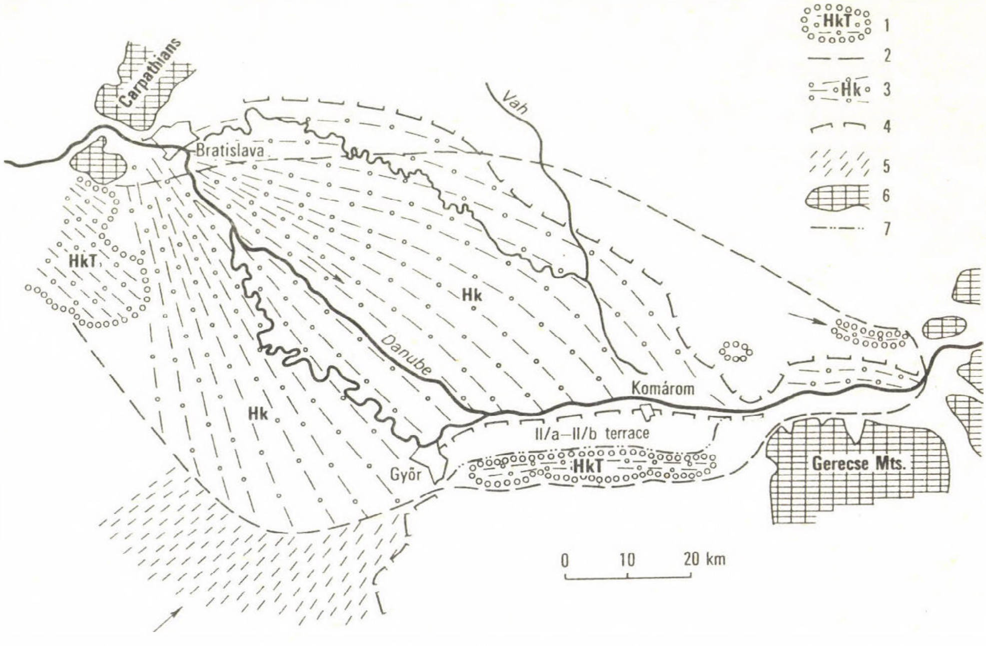



*Fig. 27a.* Alluvial fans of the Danube in the Little Plain (after PÉCSI, M. 1964). 1 = remnants of an older alluvial-fan terrace (Aft) of the Danube; 2 = probable extension of the older alluvial fan from the beginning of the Pliocene to the end of the Mindel Glacial; 3 = extension of the younger alluvial fan (Af) of the Danube; 4 = boundary of the younger alluvial fan formed from the Middle Pleistocene to the present; 5 = alluvial fans of the Rába, Répce and Marcal rivers; 6 = mountain frame; 7 = edges of terraces nos IIa, IIb and locally III between Győr and Komárom

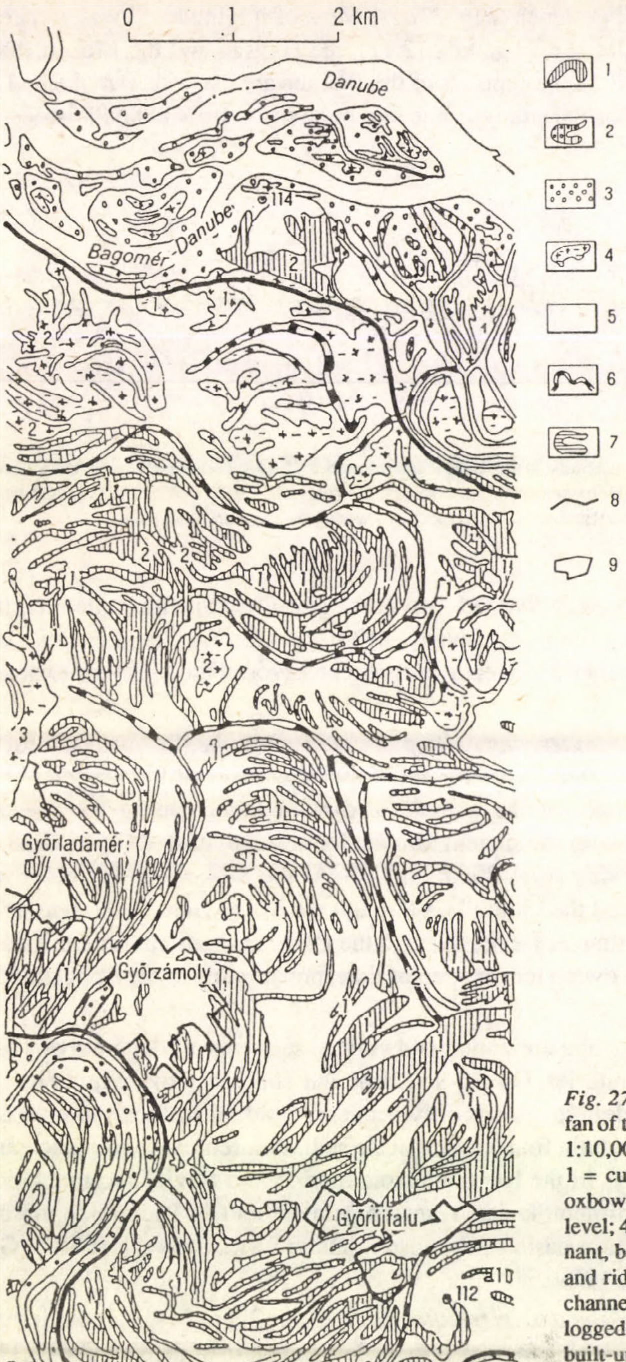



*Fig. 27b.* Morphofacies of the recent alluvial fan of the Little Plain near Győr (original scale 1:10,000, surveyed by BALOGH, J. in 1982). 1 = cultivated oxbow remnant; 2 = forested oxbow remnant; 3 = forest on lower floodplain level; 4 = seasonally waterlogged oxbow remnant, backswamp; 5 = cultivated ol point bars and ridges of the higher floodplain level; 6 = channelised oxbow; 7 = permanently waterlogged oxbow; 8 = flood-control dyke; 9 = built-up area. Depth of oxbow remnants is shown in the following categories: 1 = less than 1 m; 2 = 1–2 m; 3 = more than 2 m

km wide. Its modelling is still going on *(Fig. 27a,b)*. Most of it lying on Slovak territory the Hungarian portion includes the Szigetköz (2.11), the Hanság and the Moson Plain (2.12). In the central Moson Plain the deposits of the Danube are 200 to 250 m thick. The sandy coarse gravels form a normal stratigraphic sequence since the Middle Pleistocene.

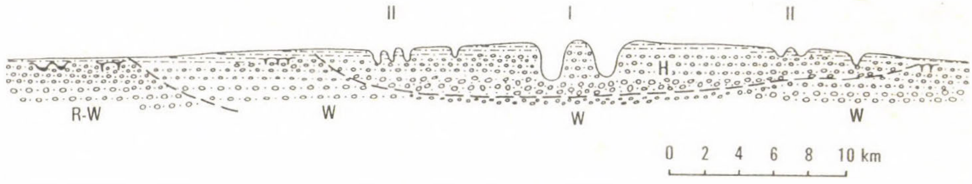



*Fig. 28.* The younger alluvial fan of the Danube in the Little Plain (after PÉCSI, M.). I = main channels with alluvial banks; II = meandering branches; H = Holocene gravel, reworked Quaternary alluvia; W = Würm gravel with traces of cryoturbation; R + W = gravel of the Riss/Würm with traces of several phases of cryoturbation

Until 1993, before the Danube was diverted into a concrete-lined artificial channel, the main branch had flowed along the most elevated belt of the alluvial fan along its axis. Only along the margins are Middle to Upper Pleistocene cryoturbated gravels exposed on the surface *(Fig. 28)*.

*Old alluvial fan and the underlying delta plain of the Danube.* In Austria, west of the Little Plain, the Parndorf Plateau is a remnant of the older alluvial-fan terrace of the Danube. It lies about 50 m above the actual flood-plain level. Up to the Middle Pleistocene, it was connected with the ancient alluvial fan-terraces east of Győr, most of which form terrace 'buttes' today *(Figs 29a,b* and *30)*. At the time when this older fan was formed, the Danube entered the Little Plain through the Bruck Gate on the border of the Leitha Mountains, rather than at Devi(, through the *Porta Hungarica,* where it does today. This fan was deposited over a longer span of time, presumably in the Pliocene and Lower Pleistocene.

The old alluvial consists of a horizontal and vertical sequence of delta gravels and sands of the Danube and tributaries. On the southern and southeastern margins of the Little Plain, Upper Miocene deltaic gravels only occur on residual surfaces. Due to the considerable uplift of the mountain frame, large-scale sediment removal took place and continued into the Quaternary. In the late Cainozoic marine and fluvial sedimentation was almost uninterrupted. Sedimentological research pointed out that Pannonian marine deposits - also in the Little Plain basin - are mostly deltaic formations (JUHÁSZ, Gy. 1994; POGÁCSÁS, Gy. *et al.* 1989).

The *alluvial fan of the Rába and its tributaries* (2.1. and 2.2 in *Fig. 3*) includes the flood-plain of the Rába (2.14), which merges into the low fan plain of the Danube (2.11). On the other hand, the older fan of the Danube merges into the actual alluvial fan terrace

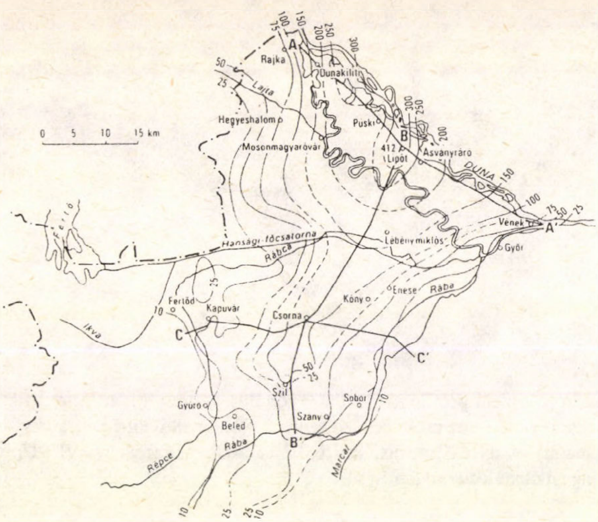


*Fig. 29a.* Thickness of the fluviatile sequence in the Little Plain, metres (plotted by ERDÉLYI, M.). A–A', B–B' and C–C' = alignment of sections in *Fig. 29b*.

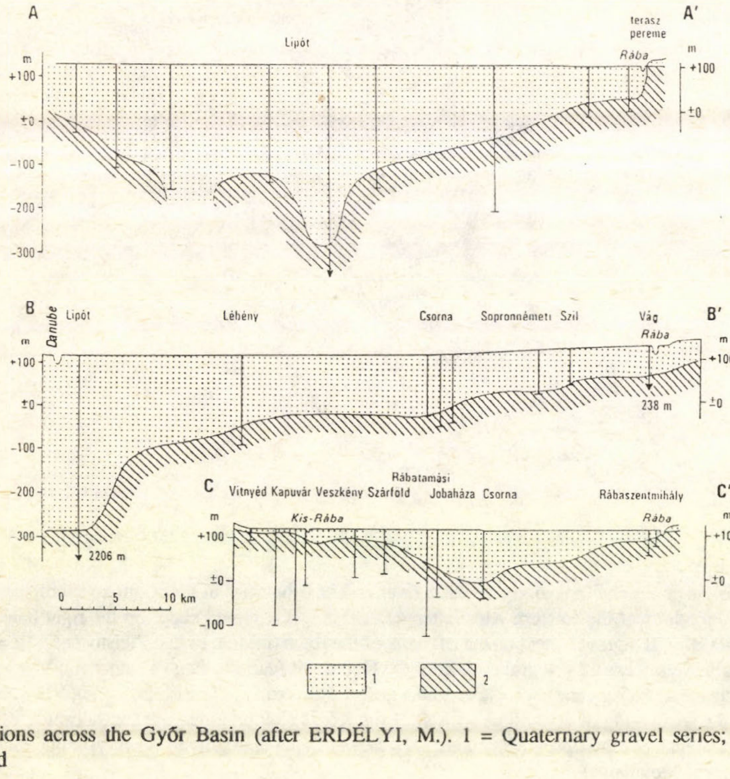


*Fig. 29b.* Sections across the Győr Basin (after ERDÉLYI, M.). 1 = Quaternary gravel series; 2 = Pliocene undifferentiated

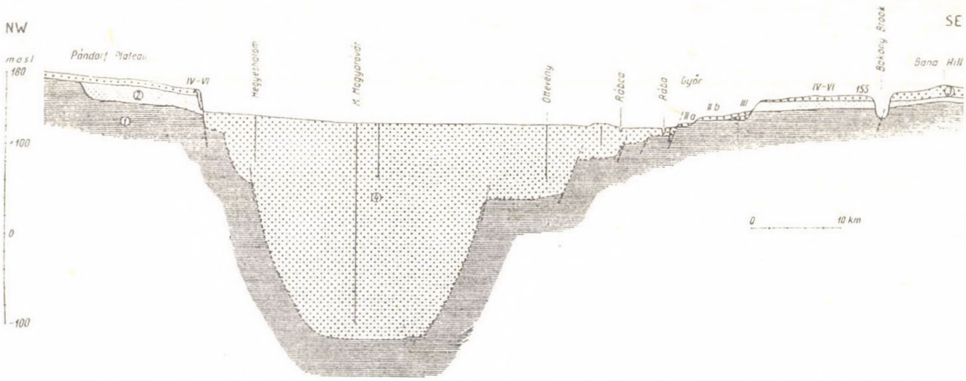



*Fig. 30.* Terrace geomorphological profile across the Győr Basin, Little Plain (after PÉCSI, M.). 1 = Pannonian marine sediments; 2 = Upper Miocene cross-bedded sand; 3 = older alluvial-fan gravels; 4 = fluviatile and deltaic fill of the Győr Basin, mainly sands and gravels; IIa, IIb, III = Danube terraces; IV–VI = Upper Miocene delta gravel of the Danube overlying an older alluvial fan

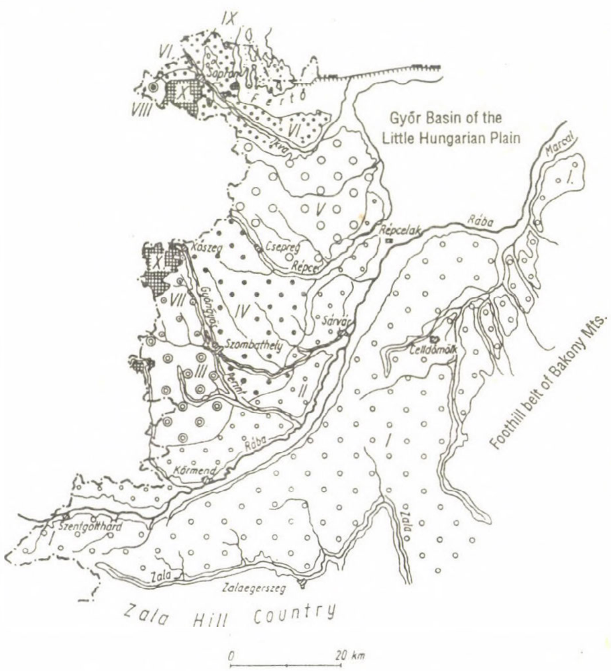



*Fig. 31.* Generations of alluvial fans along the Rába river and its tributaries in the southern subregions of the Little Plain and on the foothills of the Eastern Alps (after ÁDÁM, L.). I = gravel sheet on the right bank of the Rába (Pliocene, Pleistocene); II = gravel sheet on the left bank of the Rába (middle to late Pleistocene); III = gravel sheet of the Pinka (early Pleistocene); IV = gravel sheet of the Gyöngyös (early to late Pleistocene); V = gravel sheet of the Répce (middle to late Pleistocene); VI = Ikva-Vulka gravel sheet (early to late Pleistocene); VII = angular gravels (quartzite from the weathering of crystalline schists) of the Kőszeg Mountains (late Pleistocene); VIII = Miocene gravel and conglomerate of teh Sopron Mountains; IX = Lower Pannonian gravel; X = crystalline block mountains (Sopron-Kőszeg-Vas Mountains)

of the Rába in the *Kemeneshát* region (2.4). However, the Alpine tributaries of the Rába have also accumulated a double alluvial-fan surface, a higher Lower Pleistocene (2.21) and a lower (younger) terraced one (2.22). The latter is the *Sopron-Vas gravel plain (Fig. 10* and *31).*

Similarly to the Rába, the Marcal and its tributaries built bipartite alluvial fans in the *Marcal Basin* (2.3). The lower levels of Upper Pleistocene age are more extensive, while the older ones are restricted to a few remnants and outliers. In contrast to the entirely accumulational Győr Basin, the alluvial-fan plain of the Marcal Basin is a terrain of accumulation and denudation. In the Lower Pleistocene, the Rába first eroded its surface and then deposited an alluvial fan on it. After the subsidence of the Győr Basin, the Marcal and its tributaries incised even deeper and removed at least 100 to 150 m of Pannonian sand and clay *(Fig. 26).*

The typical landforms include some basalt-capped butte, a few of which rising more than 100 m above the basin bottom. The basalt lavas of the Pliocene have preserved some remnants of the ancient relief *(Fig. 26).*

## *THE TRANSDANUBIAN HILLS*

To the south and west of Lake Balaton, stretching to the broad alluvial plain of the Mura and Dráva rivers, there is the rolling surface of the Transdanubian Hills (4 in *Fig. 3*), an assemblage of several, more or less distinct, microregions (see the enclosed '*Geomorphological map of Hungary*'). Geologically, it is a Transdanubian appendix of the Pannonian Basin. In its basement zones of Paleozoic crystalline and Mesozoic sedimentary rocks alternate, more or less parallel to Lake Balaton. Locally, the basement lies at very great depths (more than 4000 m below the western Zala Hills – 4.1). It is overlain by a marine Tertiary, largely Upper Miocene series, whose thickness ranges from 500 to 2500 m *(Fig. 32).* Mostly known from drill cores, outcrops of some of these deposits are also found on the flanks of deeper valleys. In contrast to the Great and Little Plain, Transdanubia had risen rather than subsided after the retreat of the Pannonian sea. This resulted in a more intense dissection of the landscape and remodelling into hills. In the Transdanubian Hills, just the same way as along the southern margin of the Little Plain, the Pannonian sequence is overlain by 100 to 200 m of cross-bedded fluvial-lacustrine and partly wind-blown sediment, mostly sand. In the western portion of the hill region this Upper Miocene sandy formation has been eroded and covered by a gravel sheet spread by the Rába and Mura, rivers emerging from the Alps, in the Pliocene and early Pleistocene. The flat surface of that time was the initial plane of the valley formation that set in in the Pleistocene. The Transdanubian Hills, uplifted in the course of the Quaternary, were minutely dissected by streams running towards the Zala-Balaton drainage system on the one hand, and to the south, towards the floodplains of the Danube and the Dráva on the other. In the meantime, the cross-bedded sands were heavily eroded.

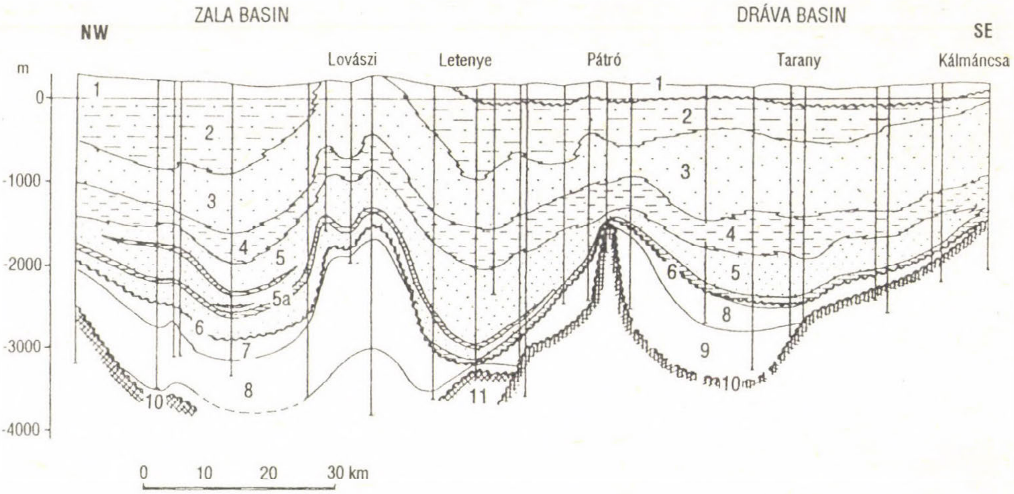



*Fig. 32.* Late Neogene (*s.l.* Pannonian) sedimentological and stratigraphical profile in the western Transdanubian Hills (after JUHÁSZ, Gy. 1994). 1 = Quaternary subaerial deposits; 2 = alluvial plain facies (Upper Pannonian *s.l.*); 3 = delta and littoral facies (Pannonian *s.l.*); 4 = delta slope and nerithic facies (Lower Pannonian); 5 = turbidite facies (Lower Pannonian); 5a = clay-marl facies (Lower Pannonian); 6 = lower boundary of the Lower Pannonian; 7 = Sarmatian (Upper Miocene); 8 = Badenian (Middle Miocene); 9 = Carpathian (Middle Miocene); 10 = Neogene basement; 11 = Eocene sediments

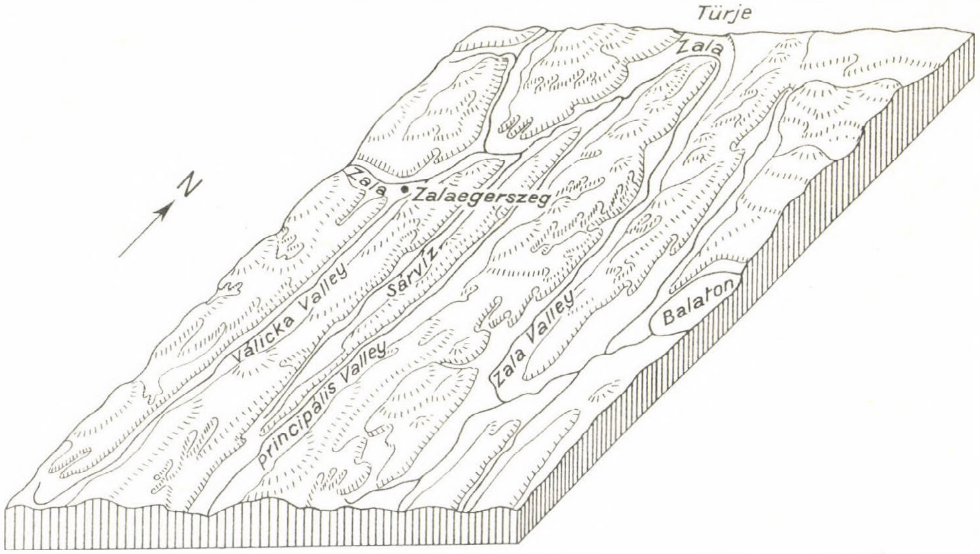



*Fig. 33.* Meridional valleys of the Zala Hills (after IPACH, I.)

In the valleys, fluviatile sands and gravels came to be deposited during the Quaternary, while the slopes were mantled by loess. In the western Zala region, typical loess is replaced by a brown earth or loam on the more humid forested hilltops *(Fig. 10)*.

South of the western Balaton basin, in *Inner Somogy* (1.4 in *Fig. 3*), fluviatile activity was dominant up to the end of the Pleistocene. In the early Holocene, and to some extent also at the end of the Pleistocene, the winds blew dunes out of the these fluviatile sands. Consequently, this region is of plain rather than hill character.

Between the valleys of the Rába, Mura and Upper Zala, the *hills of Upper Vas* and *Zala* (4.1 in *Fig. 3*) are broad interfluvial ridges with a southerly trend. The so-called 'meridional valleys' are particularly typical of the eastern part of the Zala region *(Fig. 33)*. They dissect the region into flat-topped parallel ridges of fairly uniform height (200 to 300 m). This strange topography elicited several explanations from researchers active in the region. Some contended that they were produced by fluvial erosion along fault-lines (BULLA, B. 1962; SÜMEGHY, J. 1953). Others associated them with wind erosion in desert climate and the elongated ridges between them were interpreted as yardangs. The valley flanks are covered with a deep mantle of stratified loamy loess of deluvial and soliflluctional origin. Locally this loess mantle reaches down beneath the present-day valley floors, thus providing evidence to the part played by mass wasting in modelling the valley flanks. Early in the Holocene, on the other hand, on the poorly drained valley floors swamps and peat bogs developed *(Fig. 10)*.

Recently, it was suggested that the *meridional valleys of eastern Zala* had been existed before the deposition of cross-bedded sands, because the sands are also found on the slopes of parallel yardangs. Consequently, the possibility cannot be excluded that part of the meridional valleys had been shaped by wind action under semiarid or desert conditions during the Uppermost Miocene (Messinian salinity crisis). Subsequently, they were buried and exhumed again and reshaped by variable processes during the Plio-Pleistocene (PÉCSI, M. 1986 and SCHWEITZER, F. 1992).

South of Lake Balaton, the *Somogy Hills* (4.3 in *Fig. 3*) resemble the previous one in many respects, but its meridional valley system is less regular, modified by younger and more distinct valleys perpendicular to the meridional set. Thus, the relief shows a checkerboard pattern. The east-west valleys are rather asymmetrical and tectonically stepped. The north-faced flanks are steep, while the south-faced ones are covered under a thick slope loess. The cover is dissected by broad and flat derasional valleys. The highest interfluvial ridges had once (in the Pliocene and Lower Pleistocene) been gently sloping piedmont surfaces (soft rock pediments of erosion) of the Transdanubian Mountains. It was only during the Middle and Upper Pleistocene, concurrently with the formation of the Balaton depression and the valleys parallel to it that they were dissected by tectonic and erosional and derasional processes *(Fig. 34)*.

The *Lake Balaton Basin* of northeast-southwest trend separates the Transdanubian Mountains and the Somogy Hills *(Fig. 35)*. It is a graben formed by cyclical subsidence. Its southwestern part presumably assumed its present form as early as the Lower

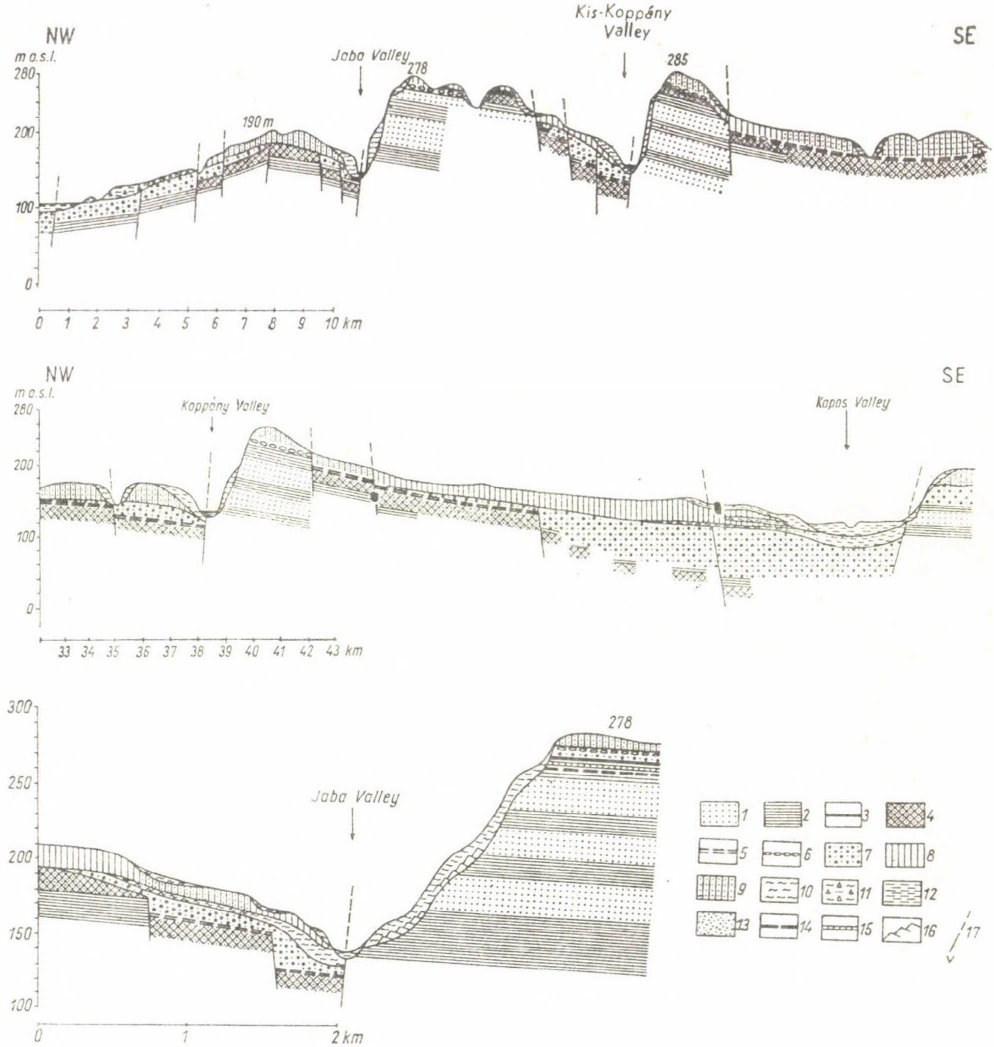



*Fig. 34.* Geological profiles of the Outer Somogy Hills (after SZILÁRD, J.). 1 = Upper Pannonian sand; 2 = Upper Pannonian clay; 3 = red clay; 4 = Upper Miocene cross-bedded sand; 5 = Pliocene greyish-yellowish foliated sand; 6 = travertine, calcareous concretion; 7 = Pleistocene coarse sand; 8 = loess; 9 = sandy loess; 10 = slope deposits; 11 = slope deposits with coarse dolomite gravels; 12 = alluvial deposits; 13 = fine sand; 14 = lignite-bearing clay; 15 = bank of calcareous sandstone; 16 = slope deposits liable to landslides; 17 = fault zone

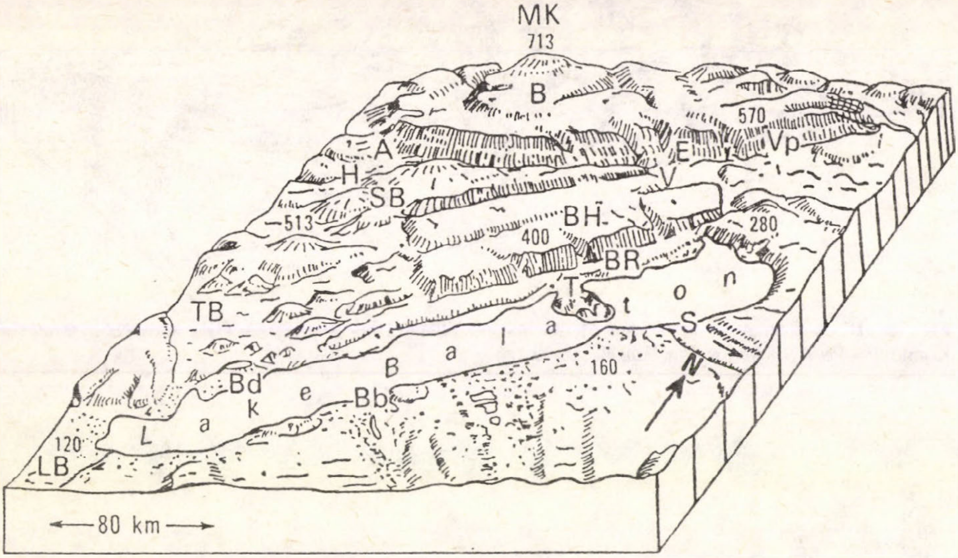



*Fig. 35.* Block diagram of the Bakony Mountains and Lake Balaton area (after PEJA, Gy.), altitudes in metres. A = Ajka; B = Northern Bakony; Bb = Balatonboglár; Bd = Badacsony; BH = Balaton Uplands; BR = Balaton 'Riviera', SB = Southern Bakony; E = Eplény; H = Halimba; LB = Little Balaton; MK = Mount Kőris; S = Siófok; T = Tihany; TB = Tapolca Basin; V = Veszprém; Vp = Várpalota

Pleistocene and other subbasins followed to develop only in the later parts of the Pleistocene. The southern shore is lined with dunes and sand bars.They separate from the main body of the lake undrained basins of lagoons, which turned into peat bogs in the Holocene (see the Geomorphological map of the Lake Balaton region).

The *Mecsek Mountains and the Tolna-Baranya Hills* are located south of the Kapos River valley. Towards the south the hills pass almost imperceptibly into the isolated mountains of horst type, the Mecsek (4.41 in *Fig. 3*). The latter, however, rises above the *Pécs Plain* with a steep stepped slope. As a southern cornerstone of this region, the small *Villány Hill* near the national border also consists of Mesozoic limestones *(Fig. 36a,b)*. Between the two Mesozoic horsts, adjoining the southern foothill of the Mecsek, the *Mórágy block* (4.422) is a granite mass, an element of the crystalline basement.

The Mecsek is a locally folded and universally faulted mountain of southwest to northeast strike, exhumed in the Neogene. The Villány group of hills (4.423 in *Fig. 3)*, of similar structure, has on the contrary a west to east trend and an imbricate structure. The sub- and microregions lying west and north of the Mecsek are minutely dissected plateaus of Upper Miocene clays and sands. They are overlain by a thick loess blanket with 8 to 10 intercalated paleosols. Beneath the loess there are locally remnants of red clay *(Fig. 37a,b)*.

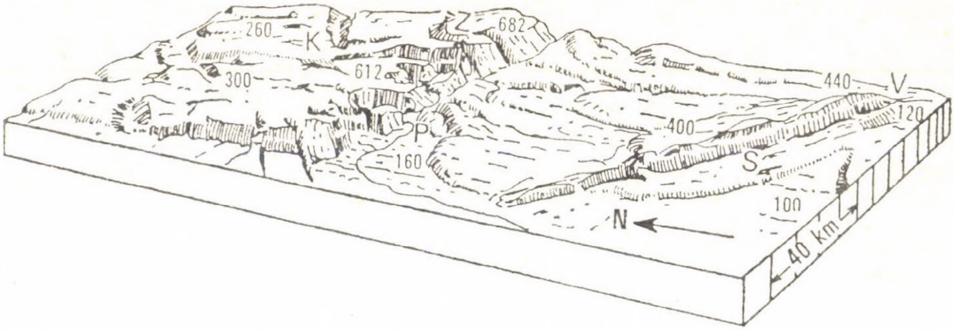



*Fig. 36a.* Block diagram of the Mecsek Mountains and Villány Hills (after PEJA, Gy.), altitudes in metres. K = Komló; P = Pécs; S = Siklós; V = Villány; Z = Zengő

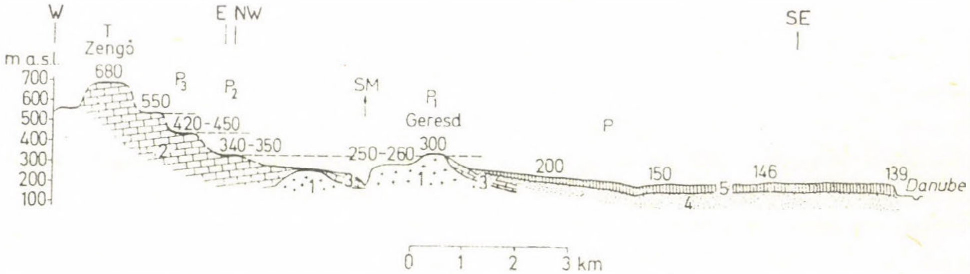



*Fig. 36b.* Surfaces of planation in the Mecsek and its foreland (after PÉCSI, M. and WEIN, Gy.), altitudes in metres. T = remnants of an Upper Cretaceous surface of erosion; $P_1$ = Pliocene piedmont surface, dissected and remodelled in the Pleistocene; $P_2$ = remnants of a Lower Pannonian terrace of abrasion; $P_3$ = remnants of Middle Miocene terrace of abrasion; P = Plio-Pleistocene glacis; SM = submontane basin. 1 = Paleozoic granite; 2 = Jurassic limestone; 3 = Middle Miocene sediments; 4 = Upper Miocene (Pannonian) sediments; 5 = slope loess

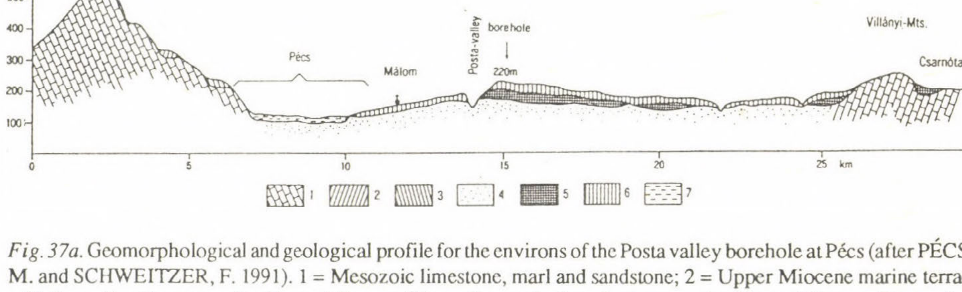



*Fig. 37a.* Geomorphological and geological profile for the environs of the Posta valley borehole at Pécs (after PÉCSI, M. and SCHWEITZER, F. 1991). 1 = Mesozoic limestone, marl and sandstone; 2 = Upper Miocene marine terrace with Sarmatian limestone; 3 = Upper Miocene (Upper Pannonian) marine terrace; 4 = Upper Miocene (Pannonian) sandy formation; 5 = Pliocene reddish paleosols, red clay formation; 6 = Pleistocene loess and paleosol sequence; 7 = Upper Pleistocene-Holocene alluvial sequence

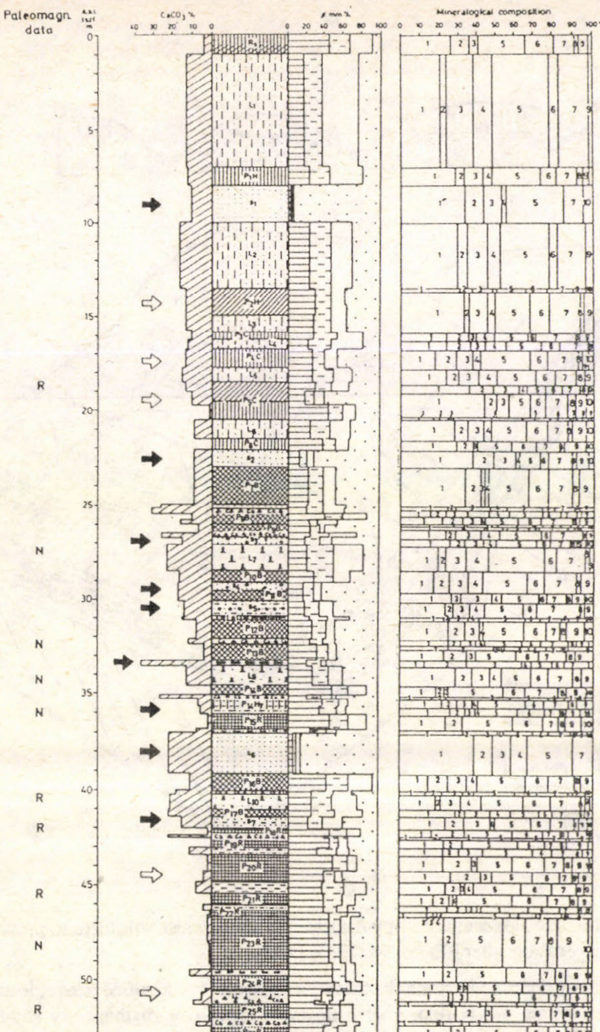



*Fig. 37b.* Loess placosol sequences of the Posta valley at Pécs. (Lithological, paleopedological and mineralogical analyses by PÉCSI, M., SCHEUER, Gy., SCHWEITZER, F., GEREI, L. and REMÉNYI, M.; paleomagnetic data by MÁRTON, P.). R = reverse; N = normal polarity; $L_1$-$L_6$ = young loess; $L_7$-$L_{10}$ = old loess; $S_1$-$S_{10}$ = sandy layers; $P_1H$, $P_2H$ = humic loess, embryonic paleosols; $P_3C$-$P_6C$ = chrnozem-like forest-steppe paleosols; $P_8B$-$P_{14}B$ = brown forest paleosols; $P_{15}R$-$P_{29}R$ = ochre-red paleosols, red clays; $P_{14}Hy$, $P_{29}Hy$ = hydromorphic meadow soils; A = clay (2-10μ); I = fine silt (10-20μ); L = coarse silt (20-50μ); H = sand (50-500μ); 1 = quartz; 2 = felspars; 3 = calcite, dolomite; 5 = micas + hydromicas; 6 = montmorillonite; 7 = chlorite; 8 = kaolinite; 9 = interstrtified minerals; 10 = Al and Fe hydroxides; → = significant unconformity; ⇒ = unconformity

a

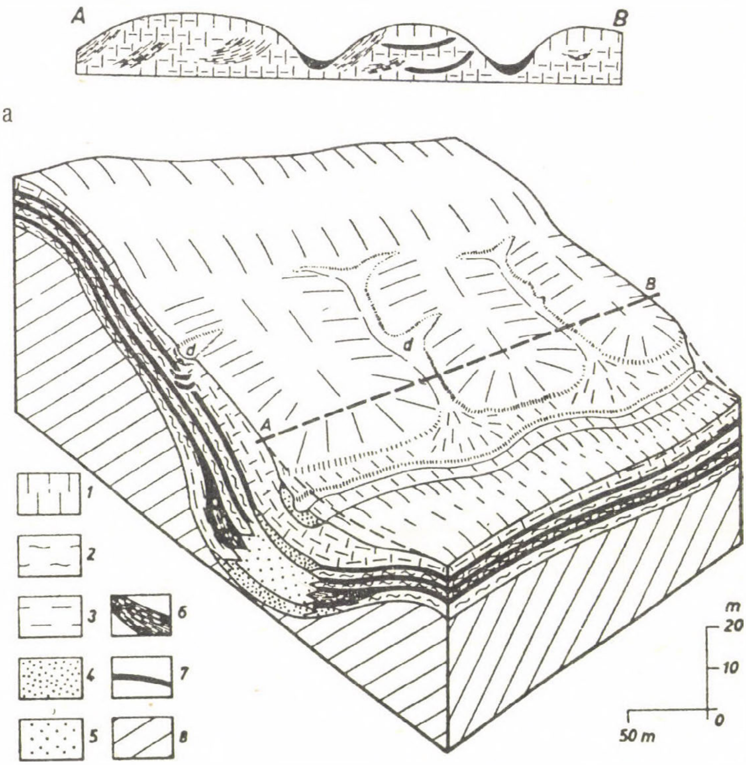


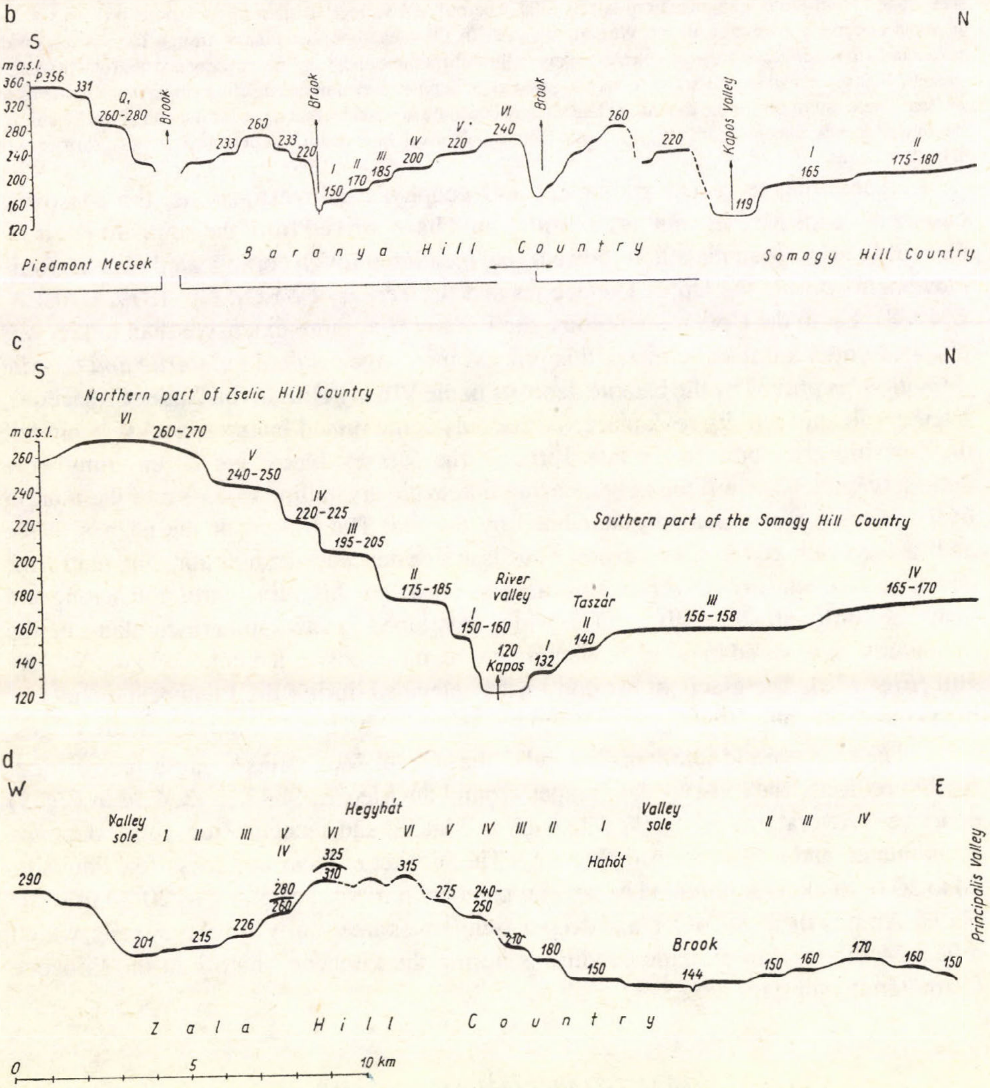

*Fig. 38.* Glacis-terraced valley side sculptured by derasion (ie. sheet wash, solifluction, pluvionivation, alternating weak dell erosion and rill erosion, after PÉCSI, M. 1964, 1967).

*a.* Valley side sculptured by derasion in slope deposits. 1 = loess; 2–3 = stratified sandy, loamy loess deposited by solifluction and pluvionivation, 4–5 = fine, coarse fluviatile sand; 6 = rhythmically stratified slope loess and semipedolite; 7 = paleosols (chernozems); 8 = pliocene sandy clay; d = derasional valley (dell)

*b.* Cross-section of the northern foreland of the Mecsek Mountains and the southern margin of the Somogy Hills. The northern slopes are fairly steep while the southern ones show gently sloping derasional steps. The hills mainly consist of Neogene molasse mantled by loess. P = Upper Pliocene pediment of the Mecsek; $Q_1$ = early Pleistocene glacis of erosion; I-VI = Pleistocene derasion and cryoplanation surfaces

*c.* Derasional-cryoplanational surfaces in the Zselic Hills. On the northern margin of the Zselic there are narrower terraces of derasion with higher rises and various relative heights ranging from five to seven in number which cannot be derived from any of the evolution phases of the Kapos valley, nor can be associated with the valley floor of the Ancient Kapos river. Some of them may have formed by cryoplanation during one glaciation. I-VI = terraced surfaces of derasion

*d.* Cross-section of the meridional valleys of the Zala Hills. On the western and eastern slopes of the Hahót Ridge, cryoplanation and derasion processes produced surfaces of derasion-cryoplanation in number and height different for each individual slope. In some of the lower horizons the sandy loess mantle, stratified parallel to slope, is exposed. Above certain valley floors the number of surfaces of derasion amounts to six or seven (including hilltops)


b
S
N
m a.s.l.
360
320
280
240
200
160
120
P 356
331
Q,
260-280
Brook
260
233
233
220
Brook
I
150
II
170
III
185
IV
200
V
220
VI
240
Brook
260
220
Kapos Valley
119
I
165
II
175-180
Piedmont Mecsek
Baranya Hill Country
Somogy Hill Country
c
S
N
Northern part of Zselic Hill Country
VI
260-270
V
240-250
IV
220-225
III
195-205
II
175-185
I
150-160
River valley
120
Kapos
I
132
Taszár
II
140
III
156-158
IV
165-170
Southern part of the Somogy Hill Country
m a.s.l.
260
240
220
200
180
160
140
120
d
W
E
Valley sole
I
II
III
V
IV
Hegyhát
VI
325
310
VI
V
IV
III
II
I
Valley sole
Hahót
II
III
IV
Principális Valley
290
201
215
226
280
260
315
275
240-250
210
180
150
144
Brook
150
160
170
160
150
Zala Hill Country
0
5
10 km

The crystalline massif constituting the basement of the southern belt of the Mecsek underwent shattering and wearing down in the late Paleozoic. In the Mecsek area of today a basin depression had formed on its surface. It was inundated by the sea where a large amount of sands and gravels deposited. The substance, rich in uranium ore, was eroded from the neighbouring crystalline hills. The red and variegated sandstones formed this way in the Permian occupy a large area in the Western Mecsek. In the meantime, the marine trough further deepened, particularly to the east, and a zigzag coastline of crystalline cliffs came about. A Liassic sequence of a total thickness of some 800 m, containing several coal seams, came to be deposited in slowly subsiding shallow embayments of the sea. The western part of the mountains had already beacome dryland by that time. By the end of the Mesozoic, the entire Mecsek emerged from the sea, but it occurred only much later that it was detached from the surrounding crystalline areas.

According to recent geological and geophysical investigations, the Mesozoic basement of the Mecsek and its environs could have arrived from the southern environment of the European plate to its present-day location through complicated plate tectonic movements during the Upper Cretaceous and the Tertiary (WEIN, Gy. 1979; BALLA, Z. 1988). Up to the Upper Cretaceous, the *Villány Hill*, more extensive than today, was planated under a tropical climate. this process may have resulted in *laterite and bauxite formation*, as proved by the bauxite deposits in the Villány Hill. In the Upper Cretaceous, intense volcanic activity took place. Today only some ruined features, necks, remind of the doleritic eruptions. In the late Tertiary, the Mecsek block and its environs were definitely detached from the neighbouring Paleozoic crystalline masses and the margin of the Mecsek was repeatedly inundated by the sea. The fringes of the islands in the archipelago were covered by marine deposits and in the coastal zones abrasion platforms developed, which are even now visible as raised beaches. After the regression, a long and gentle foothill surface, a glacis of erosion, developed in the southern foreland of the mountains. Sculptured in poorly consolidated marine deposits, it extended to the Villány Hill *(Fig. 37a)*. The glacis of erosion further elevated during the Pleistocene and was dissected by streams flowing down from the central mass into broad interstream ridges.

The northern and southern foreland of the Mecsek Mountains became three distinct foothill regions. The hill-type landscapes around the Mecsek (4.42, 4.43, 4.44 in *Fig. 3*) underwent several cycles of valley incision and lateral and sheet erosion. Slope deposits accumulated and a loess formed *(Fig. 38)*. The blanket of loess and loess-like deposits, 20 to 50 m thick, is subdivided by several paleosol horizons, as many as 20-30 in some places. Among them, the older (and deeper-lying) ones are usually red clayey soils, which reflect Mediterranean climatic conditions during the Pliocene, mainly in the Pliocene Csarnótánum substage *(Fig 37b)*.

## *TRANSDANUBIAN MOUNTAINS*

### *Orography and structural morphology*

Part of the mountain range stretching across the country, the Transdanubian Mountains is a major topographic unit in Hungary *(Fig. 3)*. Orographically, it falls into the category of *low mountains* (German: Mittelgebirge). A major part (60 per cent) of the area, however, is composed of the types *hills (partly in basins), flat mountain margin and low plateau. Plains in basins* represent a subordinate type. The orographic types are arranged in a mosaical pattern (see *'Geomorphological map of Hungary')*. Thus, relief allows a wide range of land use.

*I.* Within the Alpine-Carpathian Mountain System *(Fig. 39)*, the Transdanubian Mountains is a *series of horsts of faulted* (slightly also folded and imbricated) *structure*. On the surface it is primarily constituted of Mesozoic calcareous rocks, mostly etchplanated during the Cretaceous period. In the Tertiary it suffered differentiated faulting, burial and renewed uplift (PÉCSI, M. 1969, 1980). In this manner, the individual horsts and grabens acquired different altitudinal positions. In space and with time, the horsts were alternatingly preserved or reshaped. The variation in their evolution produced some characteristic relief subtypes.

Taken as a whole, the range of Mesozoic horsts of planation with graben-like basins is morphogenetically not a block mountains but a young Alpine structure (WEIN, Gy. 1978).

Along the margin of the Balaton Uplands a narrow zone of crystalline blocks planated during the late Paleozoic occur. Today, these repeatedly reshaped remnants appear as pediments and are also part of the low mountain relief.

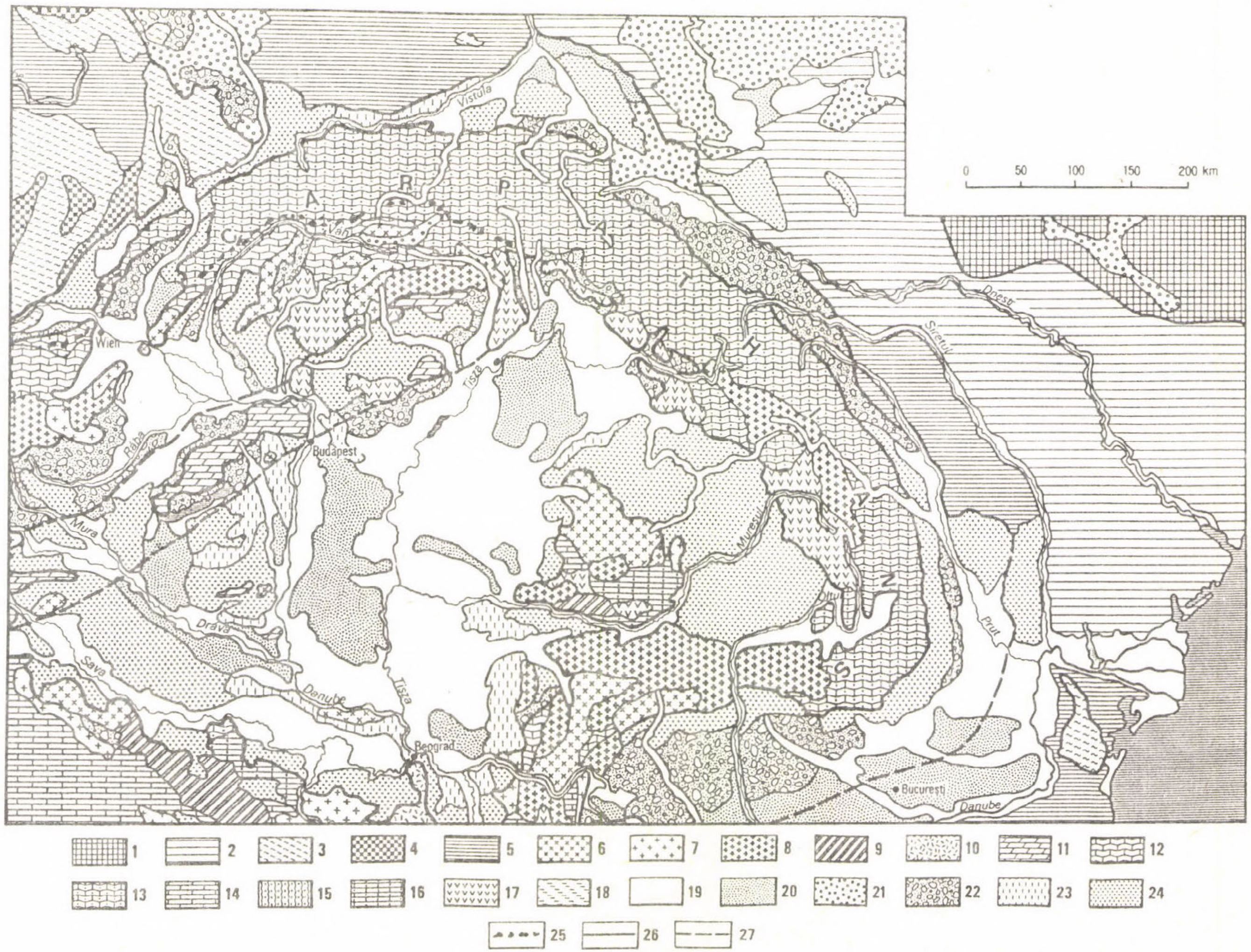
In addition, there are *plutonic* remnants on the surface (like the Velence Mountains). They are members of *planated block mountains of folded-faulted structure*.

*II.* The youngest volcanic elements in the Transdanubian Mountains are the *basaltic* cones *(composite volcanoes)* in the Southern Bakony and the *basalt-capped residual hills* in the Balaton Uplands. The former overlie the planated surfaces of Mesozoic horsts, while the latter prevented unconsolidated Pannonian (Upper Miocene) deposits from removal.

The Transdanubian mountain range also includes late Tertiary andesitic *composite volcanoes*, the Visegrád Mountains in the Danube Bend.

*III.* There are *marginal and intermountain hill regions* associated with the Transdanubian Mountains. For structural geomorphology, both are *hills in basins,* since they developed on basin sediments of unconsolidated Tertiary/Quaternary molasse. In addition to their relative positions within the mountains, the morphogenetic subtypes indicate a range of geomorphic processes (erosion, derasion, eolian processes - see *'Geomorphological map of Hungary')*.

*IV.* Flat surfaces of various size are mostly foothill alluvial fan accumulations or non-dissected erosional pediments *(Fig. 40)*. Among plateaus in lower positions structural surfaces (such as the Tétény and Érd-Sóskút plateaus mantled by Sarmatian limestone), older surfaces of erosion in threshold position (Veszprém Plateau) or abrasional platforms are equally found.



Vistula
Váh
Wien
Rába
Budapest
Tisza
Mura
Dráva
Sava
Danube
Beograd
Mureș
Prut
Siretul
Dnestr
București
0 50 100 150 200 km
1 2 3 4 5 6 7 8 9 10 11 12
13 14 15 16 17 18 19 20 21 22 23 24
25 26 27

*Fig. 39.* Morphostructural units of the Carpathian Region (after PÉCSI, M.)
*A. Denuded tectonic relief.*
*Morphostructural types of shields:*
1 = multiple cycles of intensive planation of ancient shields; 2 = stable tableland on shields, area of alternating subsidence and uplift; surface of planation, partly buried.
*Paleoorogenic area, block-faulted massifs and tablelands:*
3 = ancient massifs of multiple uplift and planation; 4 = plutonised, faulted-folded structures with surfaces of planation; 5 = tableland, partly with surfaces of planation or cuestas and horsts.
*Alpine orogenic belt, consolidated and subsequently remobilised massifs* (possibly fragments of continental or oceanic microplates):
6= autochtonous massifs, plutonised faulted-folded structures with surfaces of planation, exhumed, buried horsts; 7 = polygenetic and polycyclic tectonic complexes (centralide), uplifted high mountain ranges, regionally with surfaces of planation; 8 = overthrust nappes and fault structures of sharp ranges, peripherally with erosion surfaces.
*Younger structures of the Alpine orogenic belt:*
9 = ranges of horsts and grabens, internal ophiolithe zone of orogeny (accretion and subduction belt); 10 = grabens and horsts of planation between parallel lineaments, zone of Vardar flysch, ophiolithe and shale complexes; 11 = karstic horsts of planation and grabens, locally Alpine topography, partly with Paleozoic shale.
*Folded-faulted and overthrust nappe structure in the external zone of orogeny:*
12 = mountain ranges with sharp ridges or karst plateaus; 13 = flat-topped or rounded flysch ranges around the deep lineaments of flysch structures.
*Autochton-like faulted-folded structures:*
14 = ranges of sharp ridges of karst plateaus, partly block mountains, with marginal karst plains; 15 = simple fault structure of foreland orogeny (Albania); 16 = monoclinal structures, slightly dissected plateaus, pediments.
*Young volcanic mountains in the Alpine belt and in the paleo-orogenic area:*
17 = deeply eroded stratovolcanoes, probably related to subduction belt; basalt sheets of late volcanism; 18 = marine-limnic plains, fluvio-palustric plains, coastal plains.
*B. Accumulation relief in basin areas:*
19 = alluvial plains, flood plains, delta plains, valley bottom; 20 = alluvial fans and terraces above the flood plain level, covered by wind-blown sands and sandy loess; 21 = plains of glacio-fluvial deposition, young morainic landscape.
*C. Accumulation-denudation relief in young basins and Tertiary foredeeps dismembered by valleys:*
22 = dissected ancient alluvial fans and foothill surfaces; 23 = slightly and moderately elevated loess plains, loess plateaus with pattern of gullies and derasional valleys (dells); 24 = hilly region of molasse, sculptured by erosion-derasion, regionally covered by loess mantle or loess derivates.
*D. Miscellaneous:*
25 = zone of klippen, isolated tectonic klippen along the subduction belt of Alpine-Carpathian ranges; 26 = boundary of macro-morphostructures; buried boundary of morphostructures in the Hungarian mountains belt.

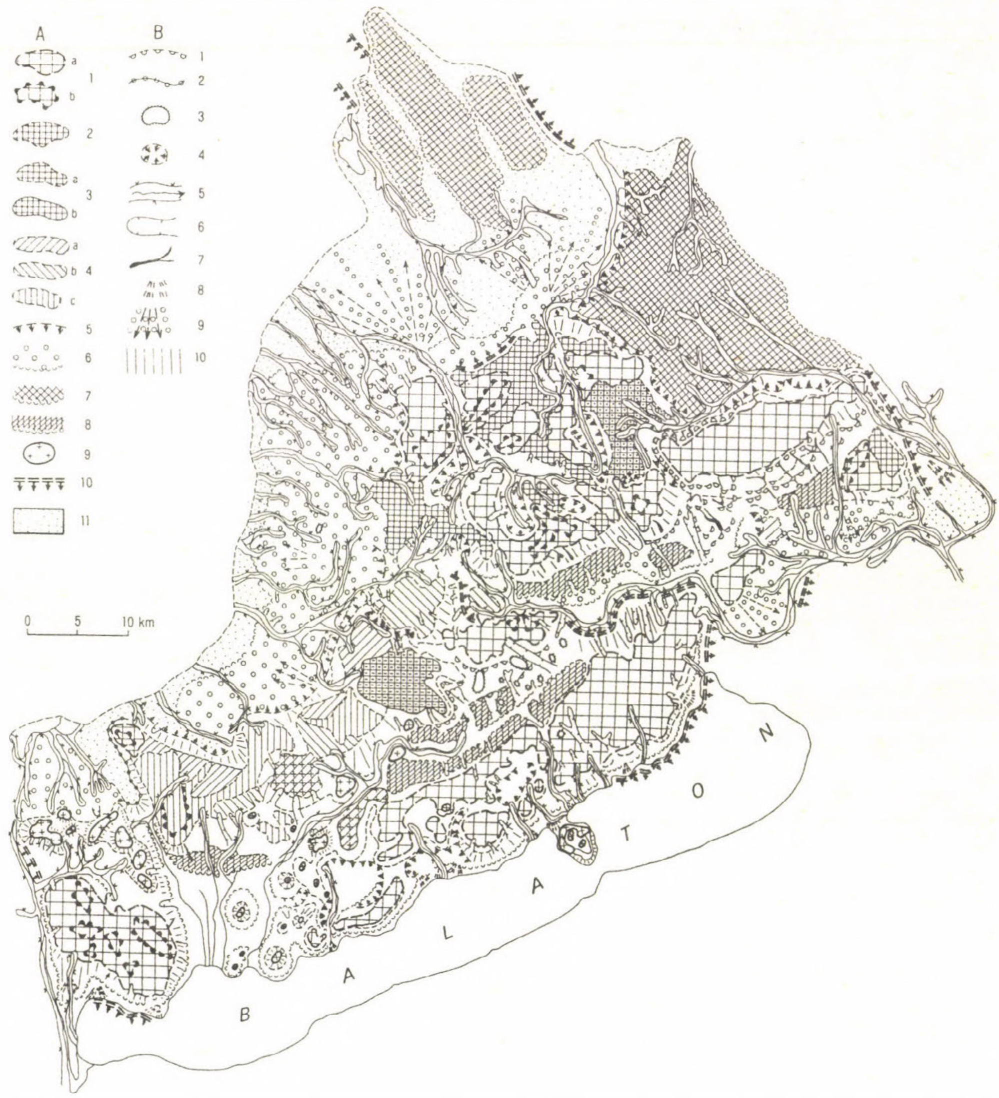



*Fig. 40.* Geomorphological map of the Bakony Mountains (after JUHÁSZ, Á. and PÉCSI, M.). A. Relief types: 1a = exhumed horst of planation in summit position; 1b = exhumed horst with remnants of surface of planation, uplifted to summit position; 2 = partially exhumed horst of planation in uplifted position; 3a = covered by Oligo-Miocene gravel series; 3b = covered by lava flow; 4 = horst of planation in mountain foreland; 4a = buried under basalt or limestone; 4b = semi-exhumed; 4c = exhumed; 5 = graben basin, surface of planation with paleokarst under Tertiary sediments; 6 = slightly dissected glacis; 7 = remnant of foothill surface dissected by a dense network of valleys; 8 = hardrock pediment; 9 = volcanic residual hill; 10 = graben-like depression; 11 = accumulational plain; B = characteristic minor features: 1 = scarp; 2 = remnants raised beach terrace; 3 = monadnock; 4 = small intermountain basin; 5 = erosional valley; 6 = derasional valley; 7 = dry valley on karst; 8 = talus; 9 = alluvial fan; 10 = slope

Along the southern margin of the Transdanubian horst range the basement is exposed in the form of Caledonian crystalline rocks. Next to them, early Hercynian formations occur on the surface. The granitic pluton of the *Velence Mountains* is of Upper Carboniferous age. After it had been stripped of the earlier Paleozoic slate envelope, it was exhumed and repeatedly etchplanated (*Figs. 5* and *41, 42*; JANTSKY, B. 1957; MAJOROS, Gy. 1983).

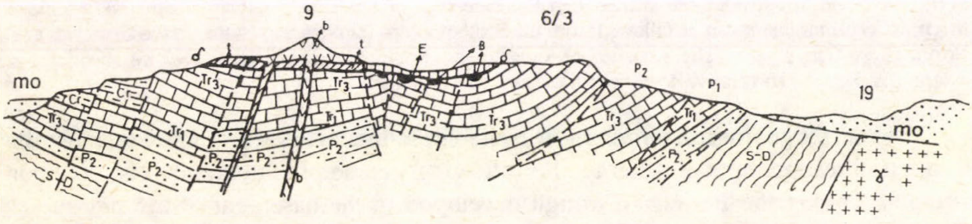



*Fig. 41*. Surfaces of planation on faulted-folded structures of the Bakony Mountains (after PÉCSI, M. and WEIN, Gy.). S, D = Silurian, Devonian phyllite; $P_2$ = Permian red sandstone; $Tr_1$ = Lower Triassic marl; $Tr_3$ = Upper Triassic limestone and dolomite; Cr = Cretaceous limestone; t = Tertiary continental deposits; b = Pliocene basalt volcanoes; Mo = Upper Miocene (Pannonian) sand, clay (molasse) with submontane basin and hill topography; $P_2$ = Upper Miocene pediment; $P_1$ = zone of marine terraces covered by Upper Pannonian travertines; δ = Upper Cretaceous surfaces of etchplanation; γ = Hercynian granite

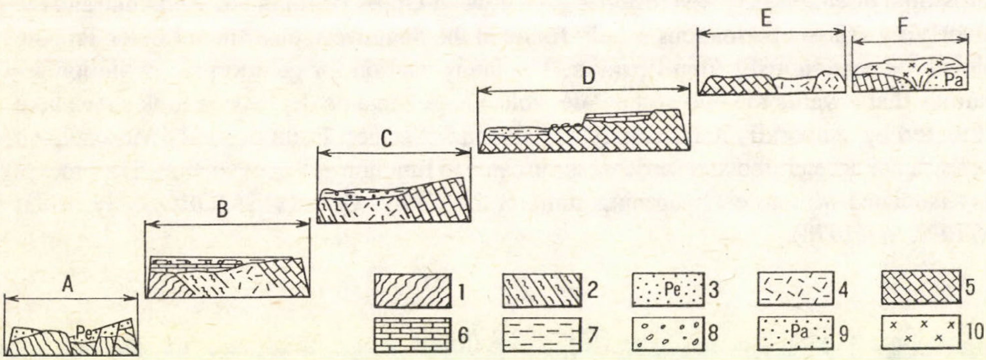



*Fig. 42*. Sketch profile of various surfaces of planation in the subregion Balaton Uplands (after JUHÁSZ, Á.). A = Paleozoic faulted-folded remnants of semi-exhumed surface of planation; B = buried horst of planation in foreland hills position; C = semi-exhumed horst of planation in threshold position of hill foreland; D = buried horsts and plateaus in a moderately uplifted position; E = horsts and plateaus of pediplanation in summit position; F = uplifted horst of pediplanation, buried by basalt lava in summit position. 1 = phyllite; 2 = clay schist; 3 = Permian sandstone; 4 = Mesozoic dolomite; 5 = Mesozoic limestone; 6 = Sarmatian (Upper Miocene) limestone; 7 = Pannonian clay; 8 = conglomerate (Upper Miocene); 9 = Pannonian sand; 10 = Pliocene basalt, basalt tuff

Paleozoic crystalline rocks hardly ever occur in the Transdanubian Mountains. In the southern foreland some small isolated mountain remnants (in the area of Polgárdi: Somlyó, Szárhegy and Kőhegy) rise hardly noticeably above the flat surface of the Mezőföld Plain mantled by Pannonian deposits. From the Balaton Uplands pediment sporadic Paleozoic outcrops are known (at Litér, Alsóörs, Lovas and Révfülöp).

For the reconstruction of geological and geomorphic evolution, the characteristic Middle to Upper Permian (New Red) Sandstone of the Balaton Uplands is of greater significance *(Fig. 41)*. The crystalline mountains uplifted in the Hercynian orogenic cycle were affected by efficient erosion during the Upper Carboniferous and the Lower Permian. Geologists emphasize that red sandstone overlies older Paleozoic crystallines with a marked discontinuity only beginning with the Middle Permian (MAJOROS, Gy. 1983). The red sandstone and conglomerate sequence is located between the Balatonfő and Rába lineaments, found everywhere and in considerable thickness in the basement of the Transdanubian Mountains. Moreover, MAJOROS claims that it can be followed from the Southern Alps (Gröden Sandstone) to the Gemerids in the Northeastern Carpathians. The sequence of sandstones, conglomerates and local clay interbeddings are essentially regarded correlative deposits of the Hercynian basement.

From the geological information available (sediment thickness, grain size distribution, stratification, spatial pattern), the following geomorphic evolution can be reconstructed. During the Permian a trough developed in the basement of the present-day Transdanubian Mountains, within an older Paleozoic (mostly crystalline) system. This trough was gradually deepening and broadening and transversal ridges divided it into subbasins. The grabenform structure collected the removed products of semihumid to semiarid subtropical weathering. The properties of sediments indicate fluvial accumulations in mountain forelands, on pediments of accumulation and locally deposition in lagoons or shallow seas of high salt content (occasionally with evaporite formation).

In contrast, Middle Permian sandstone overlies the older Paleozoic invariably with erosional discontinuity. An erosional gap between Upper Permian red sandstone and the overlying Triassic formations is only found in the southwest, elsewhere Lower Triassic develops continuously from Permian. The interpretation for geomorphic evolution assumes that towards the end of the Paleozoic a huge tectonic depression took shape here affected by temporally and spatially variable uplift stages. From the early Mesozoic on subsidence accelerated and the depression came to function as a geosyncline. The process is associated with an early opening stage of the Tethys Ocean (MAJOROS, Gy. 1983; WEIN, Gy. 1978).

### *Mesozoic horsts*

#### Geosyncline stage

Most of the calcareous rocks constituting the low mountain relief deposited in the Tethys, first of all in shallow tropical sea environments, broadening during the Mesozoic. From the evaluation of paleomagnetic polarity (MÁRTON, E. and MÁRTON, P.) and paleontological evidence (GÉCZY, B.) in limestone and dolomite sequence, it is assumed thatthe calcareous rocks formed along the souther coast of the Tethys Ocean, in the vicinity of the African plate. In the geosyncline a sequence of more than 3000 m thickness accumulated over the ca 50 Ma of the

Triassic. Deposition at even rate was occasionally interrupted by short spells of uplift. In the Upper Triassic the geosyncline partially uplifted and its southern flank (the 'Pelso ridge') became dry land. In the meantime, along the axis of the range sedimentation continued even in some stages of the Jurassic (60 Ma) and Cretaceous (70-75 Ma).

During the long Mesozoic evolution (180 Ma) *intricate plate tectonic and orogenic movements* (only briefly outlined here) affected the area and produced macrostructural transformations.

The portion of the Transdanubian Mountains emerged from the sea as early as the Upper Triassic or immediately thereafter was exposed to tropical subaerial weathering and erosion over a long interval (ca 100 Ma). Even over surfaces emerging after Jurassic and Lower Cretaceous transgressions, subaerial erosion went on for tens of millions of years (BÁRDOSSY, Gy. 1977). As a consequence, in areas of calcareous rocks (limestone, dolomite) *extensive etchplanation* surfaces developed with tower karst (PÉCSI, M. 1970, 1993).

Evaluating structural evolution from plate tectonics and other geological information, it is probable that tropical etchplanation took place mainly along the Thetys coasts of the African continent. The Transdanubian Mountains drifted to its present location only much later, within the interval between the Upper Cretaceous and Middle Neogene. The manner and date of drifting has recently been interpreted in various ways. A common element in the interpretations is that the Transdanubian Mountains used to be a detached part of the Austroalpine macrostructural unit and arrived to its present site after many hundreds of kilometres of drifting (MAJOROS, Gy. 1983; BÁLDI, T. 1983; KOVÁCS, S. 1983; KÁZMÉR, M. 1984; WEIN, Gy. 1978; BALLA, Y. 1982, 1988; FÜLÖP, J. 1989).

It is important to underline here that in the exposures of bauxite mines the *cockpits and towers of the karst all remained vertical* - in spite of the large-scale horizontal and repeated vertical tectonic displacements. This phenomenon also supports the conclusion that the Mesozoic mass of the present-day *Transdanubian Mountains drifted* to its present location in unity with part of the crystalline basement as a *microplate*.

## Tropical karstic planation and bauxite formation

According to the concept of tropical etchplanation (WYLAND, E.J. 1934), intense chemical weathering and overwhelming sheet erosion induces parallel retreat over surfaces slowly emerging above the sea level, while over hillslopes backwearing and downwearing occur simultaneously *(Fig. 43)*. Supposing tectonic quiescence, the mountain range may finally be consumed entirely, only sporadic 'inselbergs' remain on the surface of erosion (this is pediplanation as conceived by L. KING). The surfaces of erosion formed on limestone or other calcareous rocks survived for longer geological periods.

Emerging from the sea in the late Triassic, the southern zone of the Transdanubian Mountains developed until the Middle Cretaceous to *a surface of karst planation in low position*. In its southern foreland an also etchplanated crystalline range rose to higher elevation. The clay and lateritic products of tropical weathering removed from this range accumulated in the area of the Transdanubian Mountains. These deposits and the weathering residues of calcareous rocks (intercalated clay and marl strata) were the sources of red clays trapped in the dolines of the surface of karst planation or washed into minor depressions or bays *(Fig. 44)*. If geomorphological and hydrogeological conditions were favourable, the argillaceous material further weathered, desilicified and turned into bauxite (BÁRDOSSY, Gy. 1977; MINDSZENTY, A. *et al.* 1984). Bauxite occurrences, (lateritic) red clays and tropical tower karst remnants attest to *tropical etchplanation*

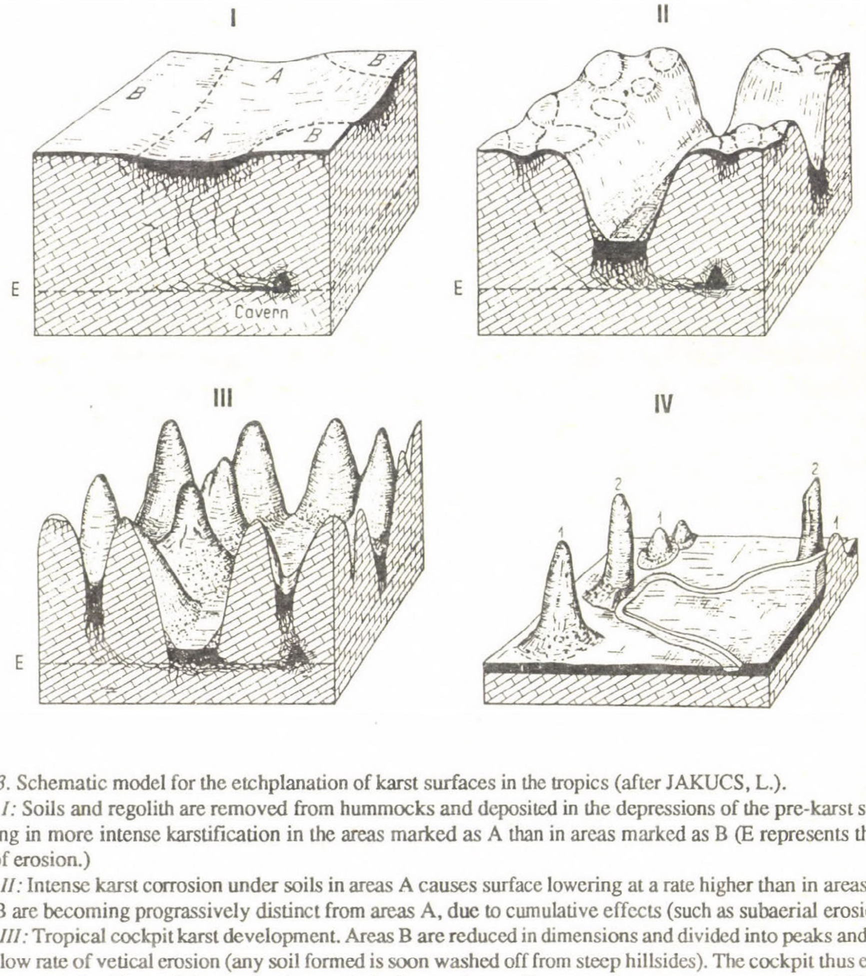



*Fig. 43.* Schematic model for the etchplanation of karst surfaces in the tropics (after JAKUCS, L.).
*Phase I:* Soils and regolith are removed from hummocks and deposited in the depressions of the pre-karst surface, resulting in more intense karstification in the areas marked as A than in areas marked as B (E represents the base level of erosion.)
*Phase II:* Intense karst corrosion under soils in areas A causes surface lowering at a rate higher than in areas B; the areas B are becoming prograssively distinct from areas A, due to cumulative effects (such as subaerial erosion).
*Phase III:* Tropical cockpit karst development. Areas B are reduced in dimensions and divided into peaks and ridges with a low rate of vetical erosion (any soil formed is soon washed off from steep hillsides). The cockpit thus evolves as a permanent landform of the tropical karst. At its base, where soils accumulate, erosion rates are tenfold higher than at the summit.
*Phase IV:* Lateral erosion and river corrasion occurs at the base level in areas A. Cockpits are remodelled into karst towers through undercutting. During this process former underground streams cut channels on the surface of areas A. Later these surfaces widen into intermontane plains, while the area occupied by karst inselbergs, left over from former areas B, is gradually reducing (1 = cone karst; 2 = tower karst)

affecting the whole mountain range and completed by the Upper Cretaceous. Most of the surviving landforms and weathering products occur on Upper Triassic limestone and dolomite. These surfaces, however, were later uplifted or subsided and the landforms are now found in different altitudinal positions (in dolines of eroded horst surfaces, tectonic grabens or along fault-lines, mostly buried under Cretaceous and Paleogene sediments *(Fig. 45)*.

*Dismembering of the surface of etchplanation*

At the end of the Upper Cretaceous, Alpine orogenic movements, starting from the Lower Cretaceous, intensified. The tectonic activity deeply affected both the Mesozoic mass and the basement of the Transdanubian Mountains. This is manifested in the Bakony and Vértes by horizontal displacements, imbrication and slight folding, while by strike-faults and nappe formation in the Buda Mountains (CSÁSZÁR, G. *et al* 1989; FÜLÖP, J. 1989; KŐRÖSSY, L. 1964; WEIN, Gy. 1977, 1978).

The formation of the Mesozoic surface of planation with bauxite deposits and paleokarst remnants along the axis of the mountain range and north of it stopped as early as the Middle and Upper Cretaceous and locally in the Eocene. Towards the end of the Upper Cretaceous and particularly in the Paleogene very intensive tectonic movements took place. In subsequent stages subsidences and uplifts of locally variable degree occurred. Compressions, dilatations and possibly horizontal displacements were equally considerable in various places. As a consequence, the formerly contiguous planated surface of the Transdanubian Mountains was largely dismembered by the Neogene. From the late Cretaceous to the early Eocene, the mountain range remained to be mainland, but it consisted of series of horsts and grabens separated by marked faults (DUDICH, E. – KOPEK, G. 1980).

It is probable that Paleogene Transdanubian Mountains was surrounded by elevated crystalline ranges. The present-day mountain range was a sedimentation trough. At that time the extensive downwearing of the whole mountain range was succeeded by overwhelming peripedimentation. These processes reshaped the margins of horsts or buried them under subaerial or marine deposits.

According to the plate tectonics approach, the Transdanubian Mountains drifted to its present location passing highly variable petrographic, tectonic and morphological environments. It has to be remembered that its geographical position changed substantially from one geological period to the other. The plate tectonics interpretations are helpful in identifying the source areas of gravels found on the karst surfaces of planation of the mountain range ('alien' in their present environment).

The late Lower Eocene to Middle Eocene tectonic movements resulted in subsidences highly varied in extent by macroregions. Some portions (Buda mountains and its environs) or grabens were entirely buried under marine sediments. The Eocene limestone was only locally eroded during this short uplift interval ('infra-Oligocene denudation').

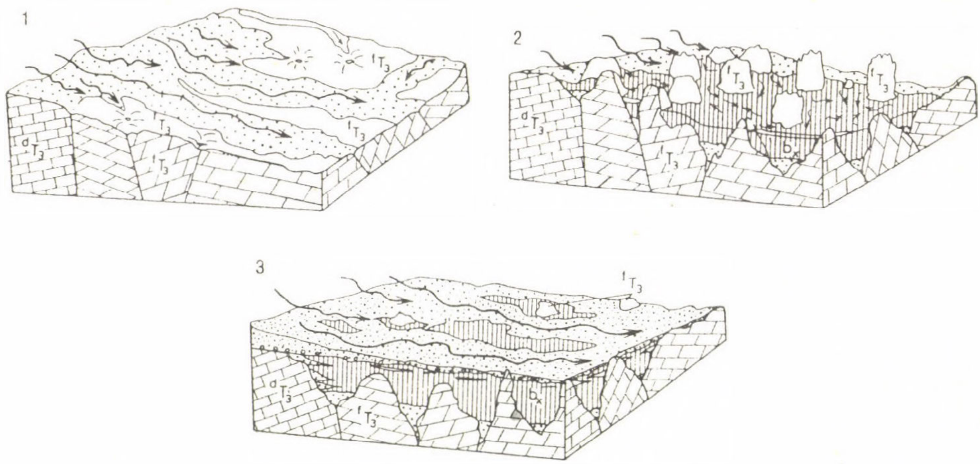



*Fig. 44.* Morphological model for the evolution of the Iharkút area, Bakony Mountains, at the time of bauxite accumulation (after MINDSZENTY, A. et al. 1994). $^{d}T_3$ = Triassic limestone; $^{f}T_3$ = Triassic dolomite; bx = bauxite

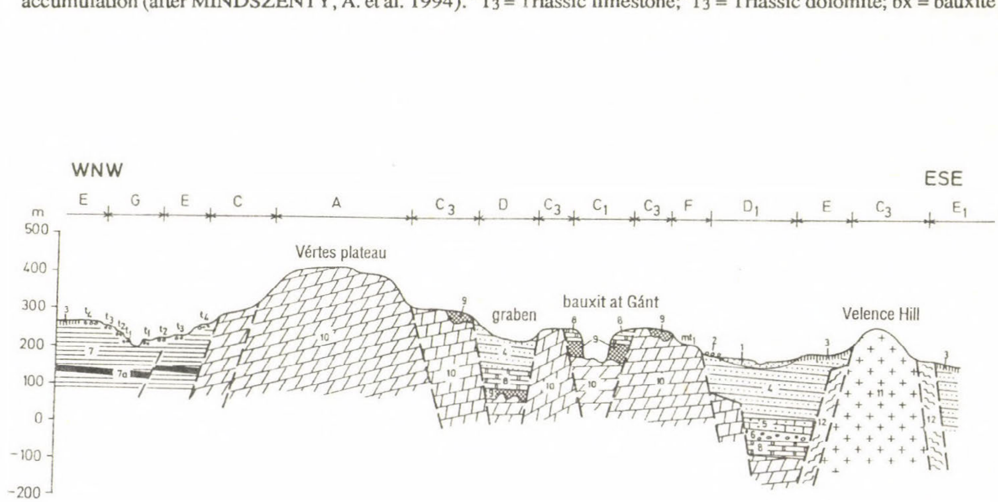



*Fig. 45.* Geomorphological surfaces of the Vértes Mountains (after PÉCSI, M.). A = Exhumed horst in summit position, a remnant of the slightly remodelled Cretaceous etchplain; C = horst in foothill position; $C_1$ = totally buried; $C_3$ = totally exhumed; D = buried surface of planation in intramontane graben position; $D_1$ = intramontane graben, filled by molasse and alluvial fans; E = glacis d'erosion with terraces; $E_1$ = rock pediment and glacis d'erosion; F = remnant of marine terrace (Upper Pannonian), 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 deposits; 4 = Pannonian sandy and clayey formation; 5 = Miocene Sarmatian formation; 6 = Miocene gravel and sand; 7 = Oligocene sand on clay formation; 7a = Oligocene lignite; 8 = Eocene limestone; 9 = bauxite (Cretaceous); 10 = Triassic dolomite and limestone; 11 = granite; 12 = metamorphic rocks (Carboniferous)

Repeated burial and exhumation

According to a previous view, tropical surface of planation was continuously active in the geomorphic evolution of most of the Transdanubian horsts until the Middle Miocene (BULLA, B. 1956, 1962). The terrestrial quartz gravels on the summits of ridges were often called erroneously 'peneplain gravels' (LÁNG, S. 1955, 1967). The gravel deposits or their remnants are now interpreted as indications of pediments (PÉCSI, M. 1970, 1980).

Most of the area became again a sedimentation trough for the Oligocene and Lower Miocene (BÁLDI, T. 1983; KORPÁS, L. 1981; JÁMBOR, Á.-KORPÁS, L. 1971). The only exception from burial was the 'Pelso ridge', ie. a range following the present-day Balaton Uplands and Velence Mountains almost up to the Buda Mountains (SZALAI, T. 1970; DUDICH, E. 1977; JASKÓ, S. 1981). Thus, its strike was identical with that of the Transdanubian Mountains of today. The Pelso ridge was surrounded by basins of various width both to the northwest and to the southeast. Beyond them crystalline ranges followed. The weathering products removed from their surfaces were transported by streams into the gradually deepening and broadening troughs.

In the Oligocene and Lower Miocene the Mesozoic surfaces of planation were buried under sediments of several hundred metres' thickness (KORPÁS, L. 1981). Regression/transgression cycles deposited fluvial, deltaic, littoral, coastal and lagoonal sediments alternatingly. The source areas of deposits were predominantly the crystalline ranges and subordinately the low ridges of calcareous rock in the place of the present Transdanubian Mountains.

In the southwestern section of the sedimentation trough overwhelmingly terrestrial, while in the northeastern part both terrestrial and fluvio-marine formations developed. Their granulometric and petrographic study (KORPÁS, L. 1969, 1981) and the climatic, geomorphological and paleogeographical reconstructions of sedimentation allow the conclusion that in the basins between the ranges *bahada-playa type* sediments accumulated to the southwest and mostly *littoral* and lagoonal sediments to the northeast during the Paleogene *(Fig. 46).*

The plateaus of the Pelso ridge in the southern belt of the Transdanubian Mountains were pediplanated along with the outer crystalline ranges PÉCSI, M. 1970). In contrast, the broader northern belt of the Transdanubian Mountains was *buried on two occasions* under several hundred metres of sediment. The pre-Paleogene karstic planated surface was preserved in its dismembered state and locally further truncated.

The thick overburden eroded partially or entirely from the rapidly emerging horsts only in the Neogene (BÁLDI, T. and BÁLDI, M. 1985; JÁMBOR, Á.-KORPÁS, L. 1971; JÁMBOR, Á. 1980; KORPÁS, L. 1981; PÉCSI, M. 1986). At the same time, the basins between mountains and horsts are still filled with 200-400 m thick Oligocene to Lower Miocene molasse-like correlative sediments *(Fig. 46).*

Relief inversion in the Neogene

Vertical tectonic movements began to intensify again at the end of the Oligocene and resulted in the emergence of portions of mountains, groups of horsts above the base level of erosion (eg. Vértes, Gerecse, Eastern Bakony and part of the Buda and Pilis

Mountains). During the Miocene along the margins of the range, over lower-lying horsts and in grabens, erosion produced – with multiple interruptions – coarse debris and sands, later replaced by calcareous sediments and this was accompanied by volcanic activity .

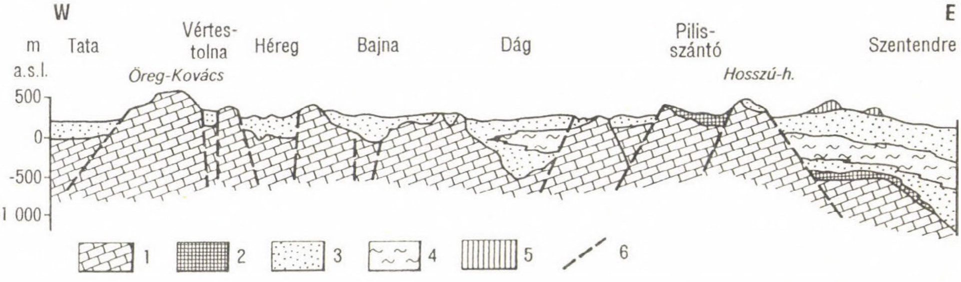



*Fig. 46.* Horst and graben character of the Transdanubian Mountains (after KORPÁS, L.). 1 = Mesozoic and Eocene limestones, dolomites undifferentiated; 2 = Hárshegy Sandstone (Lower Oligocene); 3 = Upper Oligocene sand; 4 = Kiscell Clay (Lower Oligocene); 5 = Tertiary molasse undifferentiated; 6 = major fault-lines

Parallel with renewed volcanism in the Miocene, most of the horsts of the Transdanubian Mountains gradually rose above its neighbourhood. Although they did not reach higher elevations, part of the cover sediments of horsts began to be removed. With several interruptions, this process went on in the Sarmatian and particularly in the Pannonian (Upper Miocene) and Pontian, when the Transdanubian Mountains formed a series of low islands. In the Pannonian another subsidence stage occurred and in many places the marginal horsts were buried under sands and gravels. Bays penetrated into the grabens opening to the SE and in the sides of coastal horsts *abrasional platforms* were carved.

Thus, in the Transdanubian Mountains *relief inversion* started in the Middle Miocene, but, in a geomorphological sense, the mountain range was only created by epeirogenic rise beginning in the Upper Miocene and intensifying in Pliocene and in the Quaternary. These stages of uplift increased relative relief and erosion. Along the mountain margins and on the unconsolidated deposits in basins, *foothill surfaces* formed and in the Quaternary deep valleys were carved into the uplifting mountain surface. *Intermountain basins deepened* and foothills were dissected into mountain foreland hills (see below).

### *Morphotypes of Mesozoic horsts*

The Mesozoic horsts of the Transdanubian Mountains have been referred to types according to their polygenetic evolution and orographic position. The descriptions of subtypes reveal the main features of their geomorphic history *(Fig. 47)*.

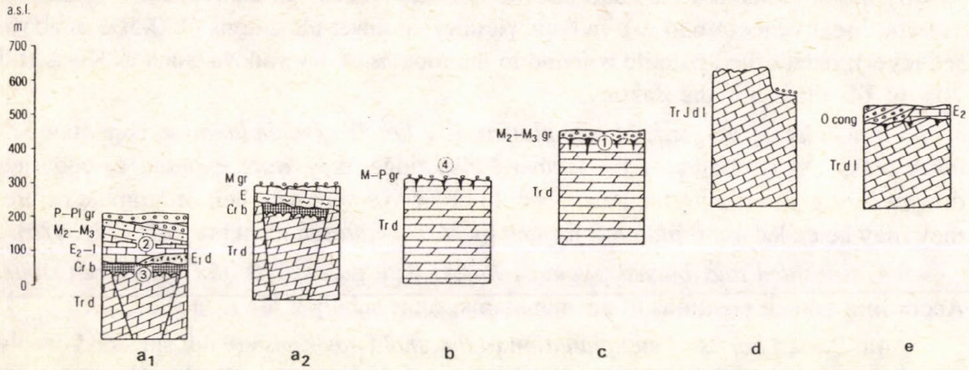



*Fig. 47.* Geomorphological positions of the dislocated and remodelled tropical etchplain remnants of the Transdanubian Mountains (after PÉCSI, M.). $a_1$, $a_2$ = buried surface of planation in a sub- or intramontane graben; b = surface of planation in threshold position, exhumed and remodelled etchplain; c = buried surface of planation in uplifted position; etchplain remnant, partly planated in the course of the deposition of Oligocene gravel sheet over it; d = exhumed surface of planation in summit position, etchplain remodelled by (peri)pedimentation; e = uplifted, buried Cretaceous etchplain remodelled by pedimentation during the Tertiary (eg. in the Oligocene) in the forelands of crystalline massifs, with conglomerate covers over their subsided portion; P-$P_1$ gr = Pliocene and Pleistocene gravel; $M_2$-$M_3$ = Miocene marl, limestone and gravel; $E_2$ l = Middle Eocene limestone; $E_1$ d = Lower Eocene dolomite debris; Cr b = Upper Cretaceous bauxite; $Tr_3$ d = M gr = Miocene gravel; $M_2$-$M_3$ gr = Middle to Upper Miocene gravel and conglomerate; Tr, J dl = Triassic and Jurassic dolomite and limestone; O cong. = Oligocene sandstone and conglomerate; 1 = remnants of tropical weathering with kaolinite and red clays; 2 = unconformity; 3 = tower karst remnants of a tropical etchplain; 4 = discontinuous gravel cover on the surface

1. *Horst uplifted into summit position, remains of etchplain with buried paleokarst.* This type includes uplifted horsts whose relict landforms of Cretaceous tropical etchplanation with tower karsts and bauxite lenses have been preserved under Eocene and Oligocene cover sediments (Buda Mountains – Type e in *Fig. 47*). Some of them were not only buried during the Paleogene but again in the late Neogene thick beds of travertine deposited on them and they were finally uplifted in the Quaternary (e.g. Szabadság Hill and Széchenyi Hill in the Buda Mountains).

2. *Uplifted and exhumed horsts of etchplanation.* The horsts buried once or twice during the Paleogene were uplifted into summit position in the Quaternary. Their Paleogene sediment cover was only preserved in traces (Buda Mountains, Western Gerecse and Vértes – Type d in *Fig. 47*).

2a. Within this group *semiexhumed horsts of etchplanation* in summit position also occur. In spite of their elevated positions, they are mantled by Miocene quartz gravel (Northern Bakony Mountains) or thicker Oligocene conglomerate (Pilis Mountains). Locally the tropical etchplain with paleokarst was remodelled by pedimentation *(Fig. 47c)*.

2b. *Entirely exhumed horst of etchplanation.* These are surfaces of erosion at 600-700 m elevation with no remnants of tower karsts or bauxitic correlative sediment. Mostly along faults, red clay and bauxite indication occur on their surfaces (Pilis-tető 700 m, Great-Gerecse 634 m). In their vicinity, at lower elevations (400-500 m above sea level), redeposited bauxite is found in the mouths of dry valleys (such as Kőris Hill 704 m, Tés Plateau in the Bakony).

3. *Moderate uplifted, locally plateau-like horsts of etchplanation* constitute another class. As remnants of the former Pelso ridge, they were exposed to enduring downwearing also during the Paleogene. In order to emphasize their orographic nature, they may be called *horst plateaus formed by karst planation* most properly *(Fig. 47b).*

4. *Subsided and buried planated horsts with paleokarst and baxite remnants.* According to their positions in the mountains, some subtypes are identified.

4a. *Buried horsts of etchplanation in threshold positions* are not subsided deeply below the present-day base level of erosion and there is no considerable Cretaceous or Tertiary sediment cover on the etchplain with bauxite and tower karst (such as the Gánt Basin in the Vértes - *Fig. 47* $a_1$).

4b. The *deeply buried etchplains* with bauxite lenses and tower karst lie below the present base level, buried under Tertiary sediments of 100 m thickness (at Halimba, Iharkút, Nyirád and Iszkaszentgyörgy in the Bakony - *Fig. 47* $a_2$).

Deeply buried etchplains occur in the basement of small intermountain basins (Nagyegyháza Basin in the Gerecse) and in mountain foreland depressions (at Fenyőfő in the Bakony). In the dolines of the paleokarst or in minor grabens bauxite reserves of workable quantity are often preserved on the subsided etchplains. These subtypes were discovered by bauxite exploration.

Some horsts subsided along faults to greater depths and otheir several hundreds of metres of Tertiary unconsolidated deposits a new structural-morphological landform, *hill region in basin* developed. Under them the Mesozoic etchplain with paleokarst is a reminder of a once extensive surface of planation in the Transdanubian Mountains.

5. *Transitional landforms.* In addition to the above types, there is a range of transitional landforms: among *horsts in threshold position,* there are a, horsts *under Tertiary mantle* (Rózsadomb in the Buda Mountains), b, *semiexhumed horsts* (Gellért-hegy) and c, *entirely exhumed horsts* (Sas-hegy). There are further opportunities for the identification of types according to their relative positions and details of their evolution, including Tertiary reshaping (PÉCSI, M. 1975).

### *Andesitic volcanoes*

In the Transdanubian Mountains older Paleogene volcanism have only left some minor traces on the surface. Some *subvolcanic andesite* bodies (necks) are found in the eastern *Velence Mountains* as isolated residual hills.

During the intense Tertiary denudation of the Velence Mountains, subvolcanic andesite was exposed. It is only in the group of the Meleg Hill that andesite lava, tuff, agglomerate and pyroclastics attest to Eocene surface volcanism. Most of these formations, however, are buried under Pannonian (Upper Miocene) marine sediments (JANTSKY, B. 1957; ÁDÁM, L. 1993). Traces of Eocene volcanics are also present in the environs of the Bakony and Buda Mountains, mostly buried under sediments.

The SW to NE main range of the Transdanubian Mountains is replaced along a marked NW to SE fault by the Neogene andesite volcanoes of the *Visegrád Mountains (Fig. 48)*. In the basement of the predominantly explosive volcanics, hundreds of metres of older, Rupelian (Oligocene) to Lower Badenian (Miocene) molasses overlie the deep-subsided Triassic calcareous pre-volcanic series. The volcanoes of the Visegrád Mountains were active for a relatively short interval (15 to 14 Ma BP) in the Middle Miocene, analogous to the Börzsöny Mountains in the North Hungarian Range. In the central part of the mountains, a huge volcano with a double caldera was produced. Its erosion started as early as the Miocene and transformed the mountains into a ruined volcano. Three major surfaces of planation took shape: at 600–700 m, 550–600 and above 800 m above sea level. It is remarkable that, in spite of considerable Pliocene and Quaternary uplift (200–300 m) the drainage pattern also reflects the former calderas.

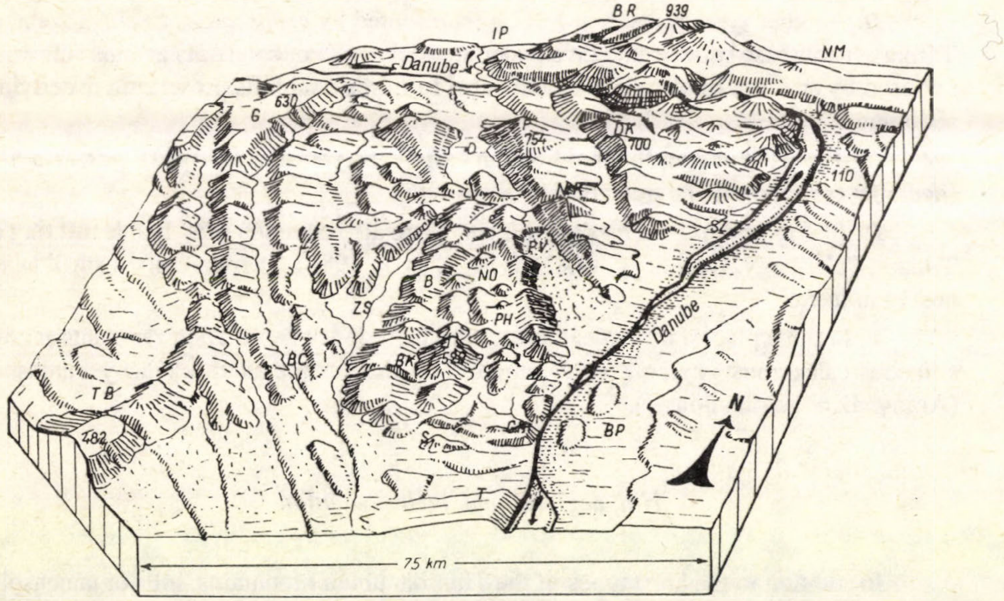



*Fig. 48.* The Danube Bend Mountains (5.4 in *Fig. 3*) (after PEJA, Gy.). G = Gerecse Mountains (630 m); P = Pilis Moutains (754 m); B, BK, J = Buda Mountains (529 m); DK = Visegrád Mountains (700 m); BR = Börzsöny Mountains. The last two of the microregions belong to the volcanic mountains. BP = Budapest; GH = Gellért Hill; BK = Budakeszi; BC = Bicske; TB = Tatabánya; Zs = Zsámbék Basin; PH = Pesthidegkút Basin; NO = Nagykovácsi Basin; PV, D = Pilisvörösvár-Dorog graben; NK = Nagykevély; IP = Ipoly river; NM = Nógrád Basin

## *Basaltic volcanoes*

In the Bakony region landforms of young volcanic origin include: isolated flat basaltic cones (composite volcanoes, Agár-tető, Kab-hegy, Bondoró, Királykő); lava-capped residual hills of double truncated cone shape (Badacsony, Szentgyörgy-hegy, Haláp, Csobánc); remnants of subvolcanic sills (Lázi-hegy, Szebike) and maar-like features *(Fig. 49)*. In the environs more than 50 occurrences of basalt have been described (LÓCZY, L. 1913; JÁMBOR, Á. *et al.* 1980; KORPÁS, L. 1981). About thirty of them can be called geomorphologically a residual hill. These features are overwhelming in the landscape of the Tapolca Basin *(Fig. 50)*.

*I.* The basaltic hills are geomorphologically and morphogenetically all of the same type. The higher-lying and larger residual hills are *composite volcanoes* produced by three or four pyroclastic and lava layers. Lava flows were generally preceded by tuff ejection. The largest of the composite volcanoes, the *Kab-hegy* overlies Upper Triassic dolomite, probably a remnant of the Cretaceous etchplain. Most of the volcanics, however, preserved the middle and upper part of the Pontian stage of the Miocene from removal (LÓCZY, L. 1913; JÁMBOR, Á. 1989 – *Fig. 49*). The composite volcanoes on Pontian formations probably extended over Pliocene foothill surfaces affected by pedimentation (KORPÁS, L. 1981).

*II.* Another type of residual hills is represented by *exposed basalt sills* (Szebike, Tátika). In this case subvolcanic lava penetrated between Pontian strata and the sills were exposed by erosion. In some places they also form residual hills preserving underlying sediments.

*III.* From the unconsolidated Pontian sediments (parasite) *lava passages, lava fills* (necks) were exposed and truncated (Hegyes-tető).

*IV.* The remnants of *maars* (or tuff rings) are also common (the double tuff ring at Tihany, Pulai-hegy, Öcsi-hegy – JÁMBOR, Á. *et al.* 1980). There are often small lakes nested in them.

*V.* In some places, postvolcanic activites included *geysers*. Their remnants are the siliceous-calcareous *geyserite vents* studded on the surface of the Tihany Peninsula (Aranyház = 'golden house').

## *Hill regions and their evolution*

In addition to the horst types of the Transdanubian Mountains, hills of unconsolidated deposits constitute about a half of the area of the geomorphological region (see the Geomorphological map of Hungary). With elevations between 200 m and 300 m, part of these hills encircle horst ranges, they are *hills in mountain forelands*. This type is transitional towards plains and small basins. In the northern foreland of the mountain range the Pápa, Súr-Bakonyalja, Bársonyos and partly the Pannonhalma Hills belong to

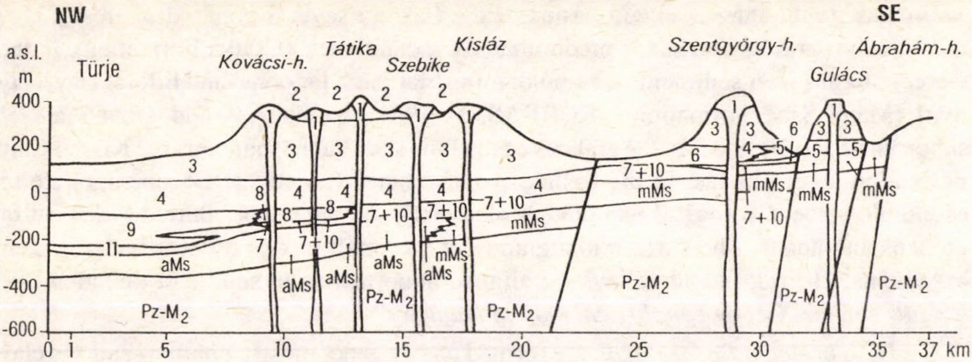



*Fig. 49.* Basalt buttes in the Tapolca Basin, NW of Lake Balaton (after JÁMBOR, Á. 1980). 1 = Tapolca Basalt (Pontian-Dacian); 2-11 = Pannonian-Pontian (Upper Miocene) marl, clay, sand, gravel deposits; mMs = Sarmatian (Middle Miocene) limestone; aMs = Lower Sarmatian clay, clayey marl; Pz-$M_2$ = Paleozoic, Mesozoic basement

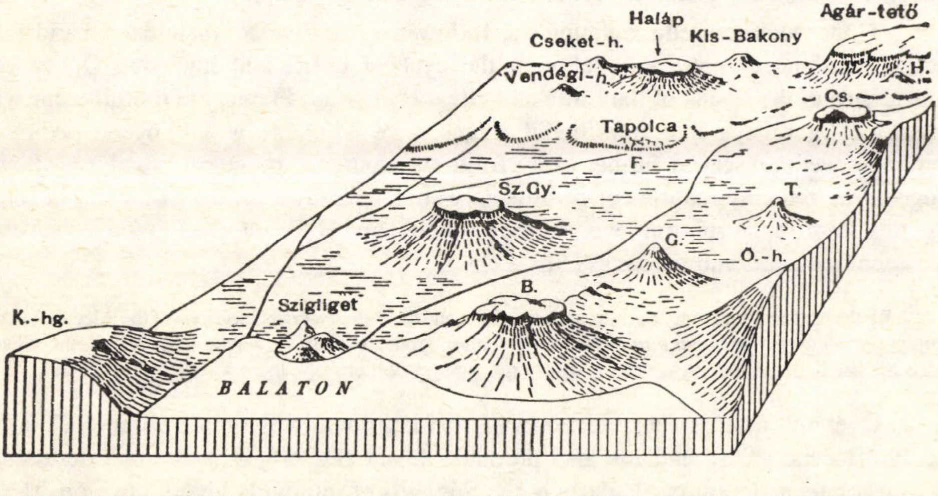



*Fig. 50.* Block diagram of the Tapolca Basin (after CHOLNOKY, J.). B = Badacsony; K.-hg. = Keszthely Mountains; G = Gulács; Ö.h. = Örs Hill; Sz.Gy. = Szentgyörgy Hill; T = Tóti Hill; Cs = Csobánc

this type. The latter has been markedly separated from the mountains by the Cuha and Sokoró Bakonyér streams and forms an independent hill region *(Fig. 51)*. In the southern foreland the Etyek Hills is also loosely connected with the Transdanubian Mountains.

*Intermountain hills* are partly found between mountain groups in basins (Western Gerecse Hills) and partly in grabens between horsts (Bakonybél, Tardosbánya basins) on Paleogene unconsolidated sediments. The tectonic grabens perpendicular to the southwest to northeast strike of the Transdanubian Mountains are mostly filled with Oligocene sediments. In the intermountain basins of the Bakony several hundred metres of clay marls, clays, gravels and sands predominantly accumulated (Csatka Formation). In the Gerecse basins finer sediments are found: terrestrial sand, lagoonal and littoral clay, clay marl (Mány Sand Formation - KORPÁS, L. 1981), sandstones and gravels are of subordinate significance. In the grabens of the Pilis and Buda Mountains the Kiscell Clay Formation predominates. In the basins, coal measures (mostly of Eocene age) are of economic value. Geological exploration also disclosed the deeply buried basement of grabens and horsts. The surface topography of the small basins reflects faults in their basements. The ridges and valleys are aligned in northwest to southeast direction (see *Fig. 46* and the '*Geomorphological map of Hungary*').

*Hills in mountain forelands* are formed on Neogene, mostly Pontian sand and clay formations, instead of Paleogene sediments. In the Neogene, particularly in the Upper Miocene, mountain forelands underwent considerable further subsidence. The sediments removed from mountain margins and accumulated in lagoons, rivers and lakes filled up an ever broadening lowland belt in the mountain foreland. During the Pliocene and particularly during the Pleistocene the water-courses arriving from the mountains built flat alluvial fans and glacis of accumulation of gravel and sand.

Upper Miocene sedimentation was followed by *pedimentation* under subarid-subhumid seasonal climate. Parallel with the cyclical uplift and intensive Quaternary subsidence of the basins of the Little and Great Hungarian Plains, the foothill zone was dissected by valleys into interfluvial ridges. Late Miocene and Pliocene pediment remnants were preserved further away from the mountain range on broad interfluvial ridges. The red clay mantles of pediments were later removed, only retained in some patches. Parts of the summit levels of the Pannonhalma Hills and the Bársonyos are also pediment remnants and yardangs *(Fig. 51)*.

By the Middle Quaternary two streams, the Cuha and the Bakony-ér and sections of the Által-ér incised deeply and *separated the mountain foreland hill region.* Protected from further stream erosion, the *summit levels* are mantled by a thin loess veneer, while on the slopes deeper slope loess with debris is found.

Over hill surfaces dense networks of dry (derasional) valleys are observed. During the Pleistocene valley incision also produced lower flat ridges with some derasional terraces on their slopes, particularly in the Súr Hills of relatively higher position. These areas are called *derasional hills (Fig. 52)*.

*Intermountain hill basins,* the name reflects that these hill areas are formed in intermountain graben-like basins and comprise valleys, basin floor flats and low flat ridges. Most of them date back to the Quaternary. Although the basins were not affected by Upper Pannonian marine sedimentation, there geomorphic evolution cannot be traced back beyond Upper Pliocene pedimentation. *Sarmatian* (Miocene) *abrasion platforms* are only found on the margins of some basins. Between most of the hill basins and the neighbouring horsts gentle to steep *pediments* of Pliocene to Lower Pleistocene age provide connection.

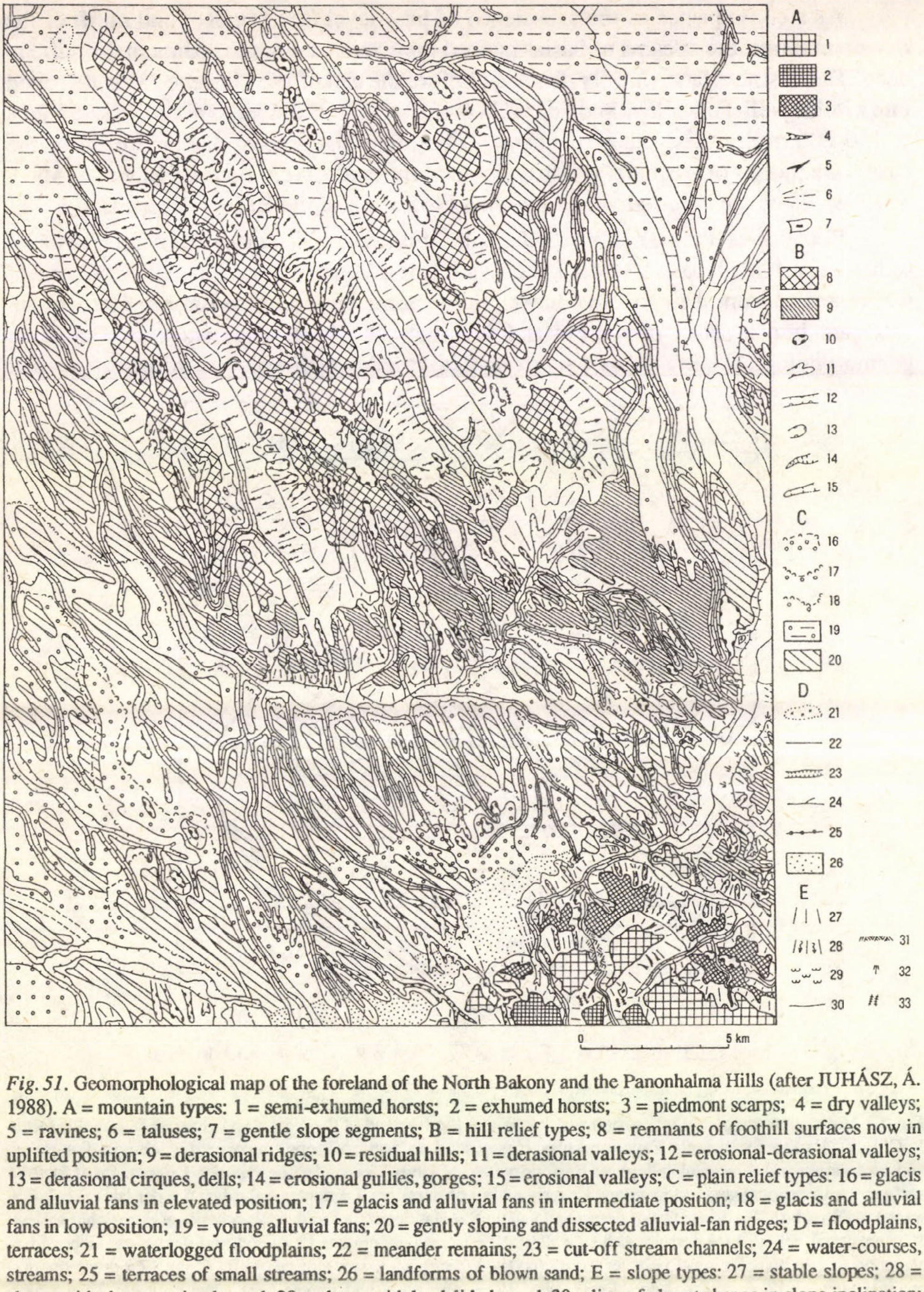



*Fig. 51.* Geomorphological map of the foreland of the North Bakony and the Panonhalma Hills (after JUHÁSZ, Á. 1988). A = mountain types: 1 = semi-exhumed horsts; 2 = exhumed horsts; 3 = piedmont scarps; 4 = dry valleys; 5 = ravines; 6 = taluses; 7 = gentle slope segments; B = hill relief types; 8 = remnants of foothill surfaces now in uplifted position; 9 = derasional ridges; 10 = residual hills; 11 = derasional valleys; 12 = erosional-derasional valleys; 13 = derasional cirques, dells; 14 = erosional gullies, gorges; 15 = erosional valleys; C = plain relief types: 16 = glacis and alluvial fans in elevated position; 17 = glacis and alluvial fans in intermediate position; 18 = glacis and alluvial fans in low position; 19 = young alluvial fans; 20 = gently sloping and dissected alluvial-fan ridges; D = floodplains, terraces; 21 = waterlogged floodplains; 22 = meander remains; 23 = cut-off stream channels; 24 = water-courses, streams; 25 = terraces of small streams; 26 = landforms of blown sand; E = slope types: 27 = stable slopes; 28 = slopes with sheet erosion hazard; 29 = slopes with landslide hazard; 30 = line of abrupt change in slope inclination; 31 = cliff; 32 = strong siltation; 33 = col

As a consequence of the subsidence of base level (the Danube) and uplift of the mountain range, the streams of basins incised their valleys into the pediment 150-200 m deep. The basin surface - hardly dissected before the end of the Pliocene - was reshaped into a rolling relief of valleys and ridges. At the same time, the streams removed sediments of 150-200 m thickness out of the basins. Therefore, the present-day landforms of the basins are mostly of erosional origin under tectonic control (eg. Budaörs Basin - LÁNG, S. 1958). They are *lithologically preformed basins,* eg. in the Balaton Uplands.

Because of their smaller catchments and greater distances from recipients of sediment, the small basins of the Bakony are less minutely dissected and less sediment was removed from their fill. In contrast, the tectonic basins of the Eastern Gerecse are dissected into a series of valleys and longitudinal ridges. They show two or three geomorphological surfaces as a result of Pleistocene uplift and, subordinately, of dif-

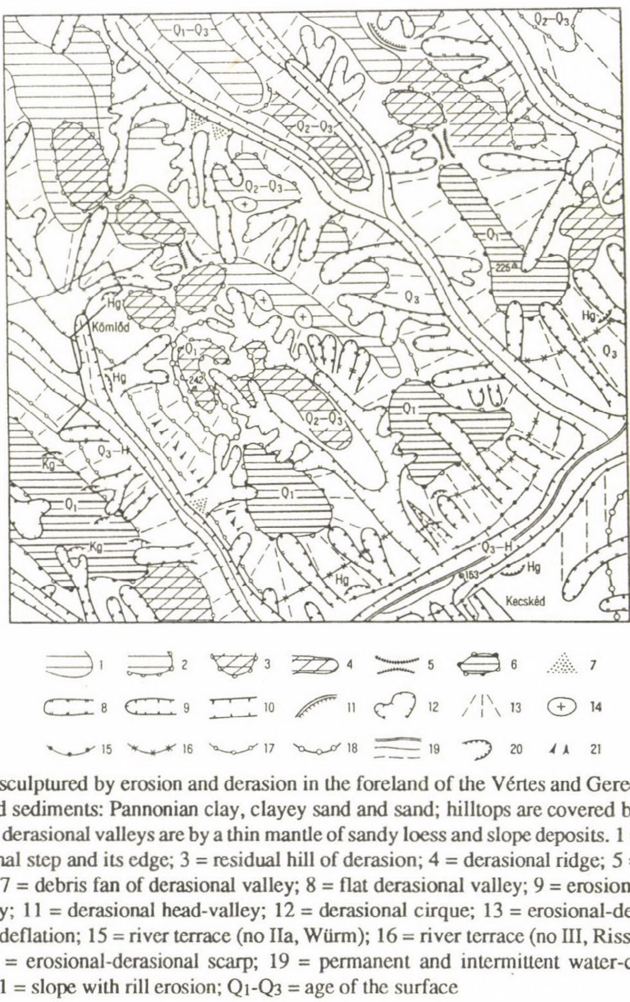



*Fig. 52.* Hill region sculptured by erosion and derasion in the foreland of the Vértes and Gerecse Mountains (after PÉCSI, M.) Exposed sediments: Pannonian clay, clayey sand and sand; hilltops are covered by alluvial-fan gravel and sand, slopes and derasional valleys are by a thin mantle of sandy loess and slope deposits. 1 = remnant of foothill surface; 2 = derasional step and its edge; 3 = residual hill of derasion; 4 = derasional ridge; 5 = derasional col; 6 = ruined residual hill; 7 = debris fan of derasional valley; 8 = flat derasional valley; 9 = erosional-derasional valley; 10 = erosional valley; 11 = derasional head-valley; 12 = derasional cirque; 13 = erosional-derasional slope; 14 = elevation shaped by deflation; 15 = river terrace (no IIa, Würm); 16 = river terrace (no III, Riss); 17 = erosional-derasional terrace; 18 = erosional-derasional scarp; 19 = permanent and intermittent water-courses; 20 = major exposure: Hg, Kg; 21 = slope with rill erosion; $Q_1$-$Q_3$ = age of the surface

ferential denudation. In some valley sides the steps of travertine levels, resistent to erosion, also attest to the stages of evolution. In karst valleys the storeys of spring caves indicate base level changes.

### *Some typical exogenic landforms*

Out of structural landforms exogenic features were carved out. They often appear in networks over the surface (such as erosional and derasional valleys). In uplifted karstic horsts *caves* developed and steep *karst valleys* incised into the surface. Their alignment was undoubtedly controlled by tectonic lines, but they are essentially of erosional origin. A similar interpretation is appropriate for the genesis of *raised beaches, fluvial terraces* and most of the travertine occurrences overlying the various geomorphological surfaces. Although marine transgressions are generally induced by tectonic movements, abrasional platforms are produced by wave action.

All landforms are composed of slopes, but sometimes slope as such should be conceived an independent exogenic landform (eg. scree slopes of horsts, foothill slopes and extensive pediment surfaces).

#### Raised beaches

Along the margins of the Transdanubian Mountains, Neogene transgressions produced abrasional platforms. Their significance was emphasized by LÓCZY, L. (1913), PRINZ, Gy. (1926), CHOLNOKY, J. (1936) and JASKÓ, S. (1988). Recent geological and geomorphological mapping projects also revealed their common occurrence (JÁMBOR, Á. 1980; LÁNG, S. 1958; PÉCSI, M. 1970; WEIN, Gy. 1978).

*Terraces of abrasion* are not easy to detect on each horst of the mountain margin. Locally, however, there are even two or more of them above each other *(Fig. 53a,b)*. A typical raised beach is overlain by limestone gravels or conglomerates of local origin (e.g. Murva-domb at Csákvár in the Vértes Mountains) or indicated by *abrasional niches* in steep cliffs (at Gyenesdiás in the Keszthely Mountains). However, morphologically well-developed abrasional terraces are common which lack any local gravels. Many Upper Miocene abrasional terraces are covered predominantly by quartz gravels (eg. along the margins of the Balaton Uplands, the Vértes and the Buda Mountains). According to JÁMBOR, Á. (1980) and KORPÁS, L. (1981), they derive from the removal of the thick Oligocene mantle of quartz gravels and sand in the Transdanubian Mountains. They were reworked along the coasts, rounded and sorted ('Pannonian pebbles').

In the forelands of horsts *deltaic gravels* accumulated by major rivers are often found. At the end of Neogene transgression stages and during regressions the rivers flowing from the Alpine-Carpathian mountain frame into the Pannonian Basin built deltas of sands and gravels along the margins of the low-lying surface of the Transdanubian Mountains. From the early stages of Middle Miocene only thin gravel deposits are known in the S foreland of the Buda Mountains (Tétény Plateau) and in the W and S margins of the Bakony. On the other hand, along the Sarmatian coastlines marked abrasion platforms developed (eg. along the W and S margins of the Bakony and the Balaton Uplands and in the S embayments of the Danube Bend mountains. The Lower Pannonian (Miocene) inland sea almost encircled the horst range of the Transdanubian Mountains *(Figs 54* and *55)*. From the evidence of deltaic gravels in the Gerecse and Buda Mountains it seems probable that the Ancient Danube appeared in the Danube Bend as early as the Lower and Middle Miocene.

In the Pontian stage (Upper Miocene) a further marine transgression affected the subsiding Transdanubian range. Particularly to the SE, the basin-like grabens (Ajka and Zirc Basins, Mór Trench) were inundated. Moreover, some horst groups of the Buda Mountains were also covered by coastal sands and gravels. In the SE forelands of the Bakony and Vértes Mountains *pebbles often show deltaic stratification* (Lesence, Billege, Kálla and Csákvár Gravels). They lack any basalt or calcareous rocks. They consists of well-rounded quartz pebbles transported long distances probably by the river system of the Ancient Danube. The deltas may have developed in several phases and expanded at the expense of the Pannonian inland sea along the mountain margins. It is remarkable that deltaic gravel beds generally dip towards the mountain range. Part of the Balaton Uplands sandy pebbles had accumulated prior to basaltic volcanism (ca 8.5 to 7 Ma) and are preserved as conglomerates cemented by geyserite/hydroquartzite (eg. on the Tihany Peninsula).

On the horst affected by vertical movements of various rates Upper Miocene transgressions allowed the formation of locally two or three abrasional platforms *(Figs. 54* and *55)*. In places Pontian raised beaches are found in one or two levels and sometimes 5 to 6 abrasion gravel bed remnants occur cemented to the cliffs of horsts (Haraszt-hegy at Csákvár).


*Fig. 53a.* Geomorphological surfaces of the western Gerecse Mountains (after PÉCSI, M.). I = Holocene floodplain; IIa = first flood-free terrace (Würm); IIb = second flood-free terrace (Riss-Würm); III = Riss terrace; IV = Mindel terrace; V = Günz terrace; VI = pre-Günz terraces; P-$Q_1$ = Pliocene to early Quaternary foothill surface; P'-P'' = Upper Miocene raised beaches; M = Oligocene-Miocene terestrial gravel (Late Mesozoic surface of planation remodelled by Oligocene-Miocene pedimentation and uplifted in the Pliocene and Pleistocene); 1 = Holocene alluvium; 2 = brown forest soil; 3-4 = gravel and sand on lower terraces; 5 = thin layer of gravel on higher terraces; 6 = travertine horizon; 7 = loess, slope loess; 8 = local debris fan mixed with red clay; 9 = Tertiary clay and sand; 10 = Triassic limestone


*Fig. 53b.* Geomorphological map of the Vértesszőlős–Tata area (PÉCSI, M. –SCHWEITZER, F. 1986) 1 = Summit level of Mesozoic horsts in the Gerecse Mountains; 2 = Mesozoic horst in threshold position at Tata; 3 = remnants of marine terraces; 4 = foothill surface and margin (locally two levels); 5 = terrace N° VI; 6 = terrace N° V; 7 = terrace N° IV; 8 = terrace N° III; 9 = terrace N° II/b; 10 = terrace N° II/a; 11 = higher flood-plain, terrace N° I; 12 = lower flood-plain; 13 = seasonally waterlogged flood-plain; 14 = terraces covered by travertine; 15 = natural and artificial lake; 16 = gully; 17 = karst erosional valley; 18 = erosional-derasional valley; 19 = derasional valley; 20 = flat and broad erosional valley; 21 = doline; 22 = col; 23 = settlement; 24 = open cast mine; 25 = steep slope; 26 = gentle slope; 27 = lapies slope; 28 = alluvial fan; 29 = Vértesszőlős Paleolithic site; 30 = Tata Paleolithic site; 31 = Kenderhegy Paleolithic site

Deposits and landforms of abrasional origin were locally repeatedly inundated and finally or temporarily buried. The latter were later exhumed or destroyed.

## Pediments and foothill alluvial fans

In the Transdanubain Mountains foothill surfaces were generally formed on Upper Miocene (Pannonian) sediments, but also on older Tertiary or Mesozoic formations during the late Miocene, Pliocene and early Pleistocene. The zone of pediments of erosion and of alluvial fans of accumulation also shifted at each other's expense, in the Pleistocene relief between the mountain range and the foreland increased and, as a consequence, first the pediment and then the alluvial fans were dissected into ridges *(Fig. 51)*.

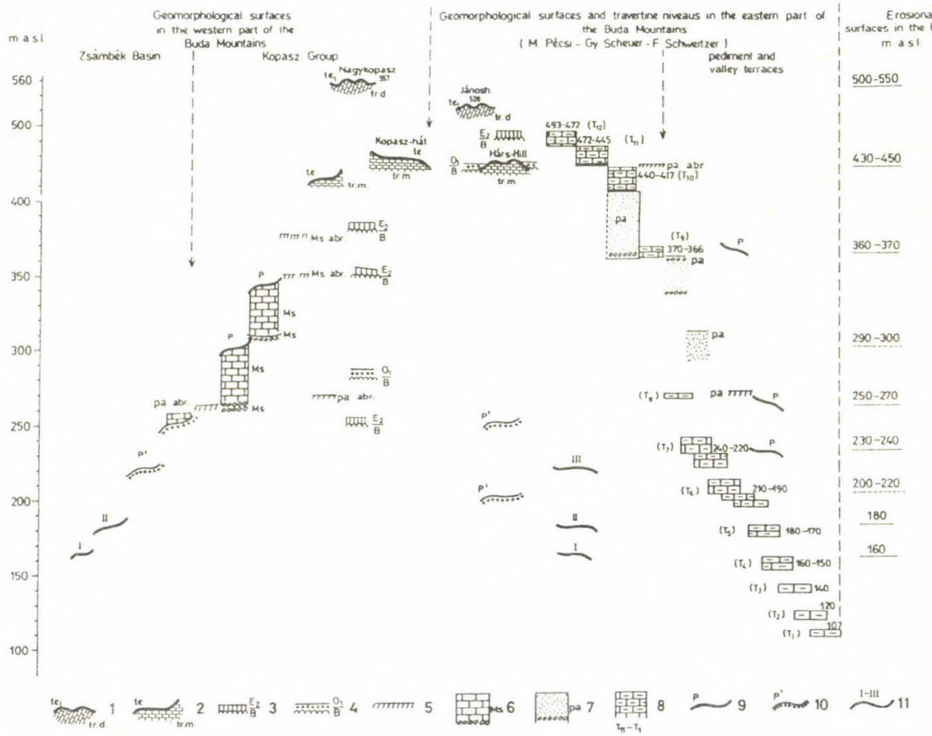



*Fig. 54.* Geomorphological surfaces in the Buda Mountains (after PÉCSI, M., SCHEUER, Gy. and SCHWEITZER, F. 1979). 1 = exhumed Mesozoic etchplain in summit position ($te_1$) on Upper Triassic dolomite (tr d); 2 = remnants of exhumed Mesozoic etchplain (te) on Upper Triassic Dachstein Limestone (tr m); 3-4 = buried Mesozoic etchplain, remnants of tropical karst and bauxite under Eocene limestone ($E_2$/B) or under Oligocene sandstone ($O_1$/B); 5 = raised beach; 6 = Miocene (Sarmatian) gravel and coarse-grained limestone (Ms); 7 = Pannonian (pa) gravel, sand and clay; 8 = travertine horizons ($T_{12}$-$T_1$); 9 = Pliocene pediment (P) on solid rock; 10 = Pliocene pediment on unconsolidated deposits (P'); 11 = Pleistocene derasional terraces, gentle slope segments on unconsolidated deposits

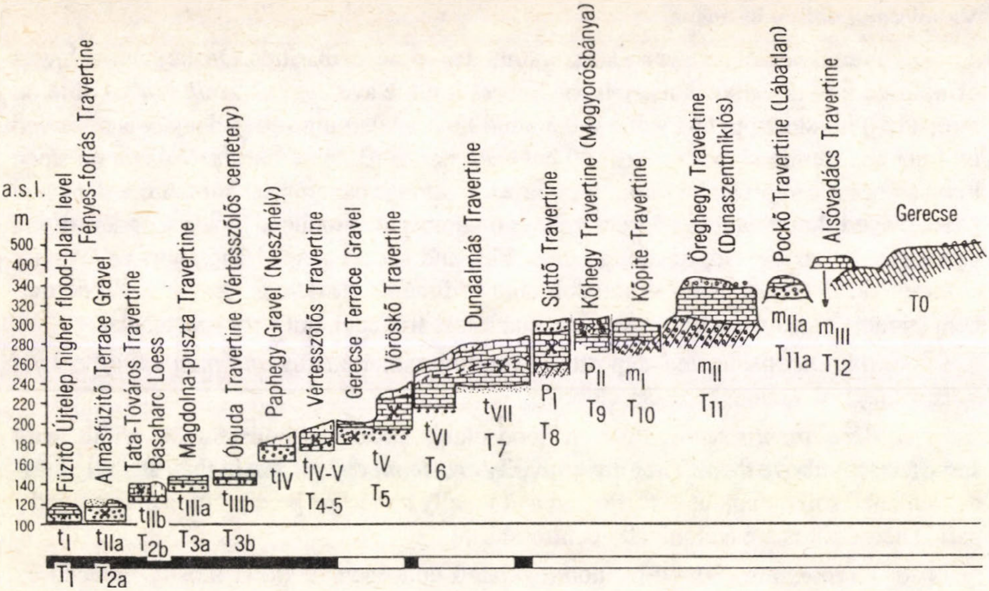



*Fig. 55.* Geomorphological surfaces and travertine horizons in the Gerecse foreland (PÉCSI, M., SCHEUER, Gy. and SCHWEITZER, F. 1988). $t_I$-$t_{VII}$ = river terraces usually covered by travertines = $T_1$-$T_7$) and loess; $P_I$-$P_{II}$ = Pliocene pediment surfaces covered by travertines ($T_8$-$T_9$); $m_I$-$m_{III}$ = Upper Pannonian (Upper Miocene) raised beaches covered by travertines ($T_{10}$-$T_{12}$); $T_0$ = Paleogene- Mesozoic surface of planation sculptured by Oligocene-Miocene pedimentation with scattered gravels

On pediment remnants Upper Pannonian sediments were also eroded and the pediments are mantled by late Upper Pannonian and Pliocene travertines and oldest river terrace beds. These facts indicate that pedimentation began at the end of the Upper Pannonian and continued into the early Pleistocene.

The regression of the Pontian inland sea from the Transdanubian Mountains region was a cyclical and enduring process. Parallel to pedimentation over land surfaces, Pontian coastal and lacustrine formations developed in zones still under sea. Pedimentation may have lasted for several million years (KRETZOI, M. *et al.* 1982). The interfluvial ridges of the foreland hills are regarded remnants of pediments and, at the same time, initial surfaces for Pleistocene valley formation.

In the Pleistocene some of the interfluvial ridges were further eroded. Locally, there are transitional sloping surfaces with scarps linking them up with the lower-lying foreland.

In addition to these landform of erosion, accumulations like the alluvial fans of the mountain foreland are also common. There are *taluses* of coarse, poorly rounded debris on the marginal slopes of horsts. The water-courses built extensive alluvial fans and terraces in the N foreland of the Bakony and the Vértes *(Fig. 51)*.

## Valleys and valley basins

The analyses of *valleys on horsts* pointed to some regularities. On the summit levels of uplifted horsts valley density is the lowest (on the average 0.1 km/4 km$^{2)}$, while on steep (15°) horst slopes this value is 0.5 km/4 km$^2$. Maximum valley density is observed on long and gentle slopes (5° to 15°) between horsts (0.7 km/4 km$^2$). Valleys on steep horst slopes are short and without tributaries. Drainage patterns are sometimes dendritic ('fan-shaped' karst valleys). Minor valleys on horsts are produced by karst or derasional processes, better developed along faults. Flat and saucer-shaped and short valleys are common on slopes of plateaus and dolomite pediments. *Karstic gorges* of small permanent streams cutting through horsts are much less frequent, but very spectacular.

In the unconsolidated deposits of *intermountain basins and mountain foreland hills, valleys* of various type developed.

a. *Permanent streams* flow on flood-plains, locally of considerable width, with some terraces above them. They are primarily *erosional valleys*, but in their shaping mass movements, soil creep, loess formation and locally travertine precipitation also played a part. Their strikes are tectonically controlled.

b. *Ravines* are formed by non-regulated concentrated flow, mostly induced by human influence. They are local landforms on loess-mantled slopes. They are destructive phenomena and, therefore, technical and drainage measures are needed to protect the surface.

c. The type of *erosional-derasional valley* is represented by broad and flat valleys of several kilometre length. They are the product of ephemeral stream and sheet erosion on valley-side slopes.

d. The *derasional* and embryonic *valleys* (dry valleys) extend over the sides of major valleys, interfluvial ridges and glacis. Their cross-sections are semicylindrical or saucer-shaped. Their lengths range from several hundred metres to several kilometres. On the hill surfaces valleys of derasion cover large areas *(Fig. 52).*

## Terraces and travertine horizons

In valleys between horsts, along narrow valley sections no traces of river terraces can be detected. The reasons are partly the lack of coarse sediment and partly subsequent erosion. Valley evolution, however, can be reconstructed from other geomorphological phenomena and landforms. In the sides of some gorges *former spring caves* mark the contemporary base levels. Thus, their evidence is similar to that of terraces.

In major valleys 2 to 4 *terraces* are observed along sections of various length. The two lower terraces can be followed over longer sections. The higher terraces are only preserved in spots, because of the erosion of tributary valleys and slope wash. They are mostly found under travertine layers.

Among all streams, the age of the Tata stream could be best dated. Dating was promoted by the fact that here travertine layers with early man sites were deposited on terrace flats *(Fig. 56)*.

In the NE corner of the Transdanubian Mountains, in the foreland of the Gerecse Mountains, the Danube formed a valley section with 6-7 terraces. Over the higher terraces thick travertine horizons present a series almost identical in each cross-section *(Fig. 55)*. In addition, they are - with the exception of the first flood-free terrace - covered by deep loess mantles. As a consequence, the terrace levels form a continuous gentle slope.

The higher flood-plain level of the Danube (numbered as I) is of early Holocene age, not older than 11 ka. The first flood-free terrace (no II) dates to the late Pleistocene, not older than 30 ka. Even terrace no VI is a Pleistocene one and the overlying travertine encloses Upper Villányium-Kislángium faunas (ca 1.4 to 1.8 Ma - KRETZOI, M. - PÉCSI, M. 1979, 1982).

It is a striking phenomenon that the Quaternary terraces of the Danube and its tributaries, older pediment surfaces and Pontian-Pannonian raised beaches are mantled by travertine series of considerable thickness. They occur on 10 to 12 geomorphological surfaces. The travertine occurrences on the terraces of the Tata river have been Th/U dated *(Fig. 54* and *56)*. The most complete Pleistocene travertine series, however, are known from the stream valleys of the Pilis and the Buda Mountains, particularly from the Ördög-árok (SCHEUER, Gy. - SCHWEITZER, F. 1988). They represent important evidence to stages of valley evolution, even if there are no other indications of terraces. The alluvial deposits on higher terraces have often been *cemented and preserved* from erosion *by travertine horizons*.

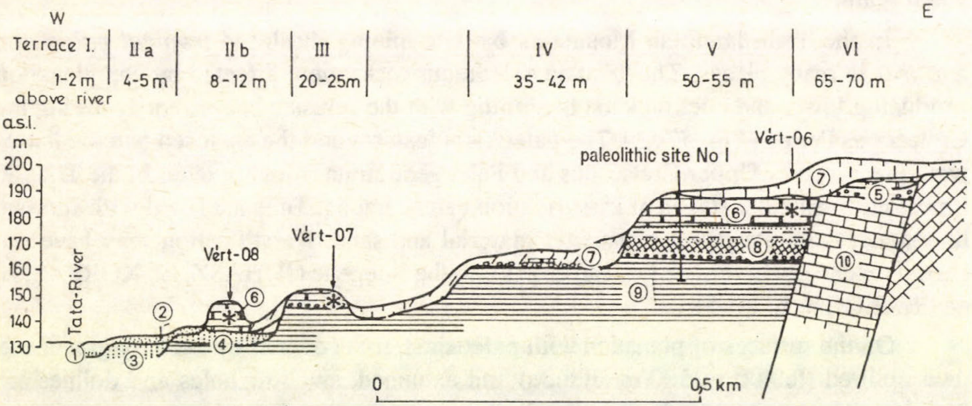



*Fig. 56.* Geological profile and absolute ages of the travertines on the terraces of the Tata River at Vértesszőlős (after PÉCSI, M., SCHEUER, Gy. and SCHWEITZER, F. 1988 and HENNIG, G.J. *et al.* 1983). 1 = floodplain; 2 = colluvium; 3 = sandy gravels on the first flood-free terrace; 4 = fluvial sand (tII/b); 5 = thin gravel beds (tII/b to VI); 6 = travertine cap on terraces nos III to VI; 7 = loess, slope loess and slope deposits; 8 = alluvial-fan and terrace series with red clay; 9 = Oligocene clay, sandy clay and gravel; 10 = Triassic limestone; ✱ = Paleolithic sites. Vért.-08 Th/U 135+12-11 ka, ESR 123±25 ka; Vért.-07 Th/U 248+00-67 ka, ESR 202±20 ka; Vért.-06 Th/U 227+56-37 ka, ESR 386±39 ka

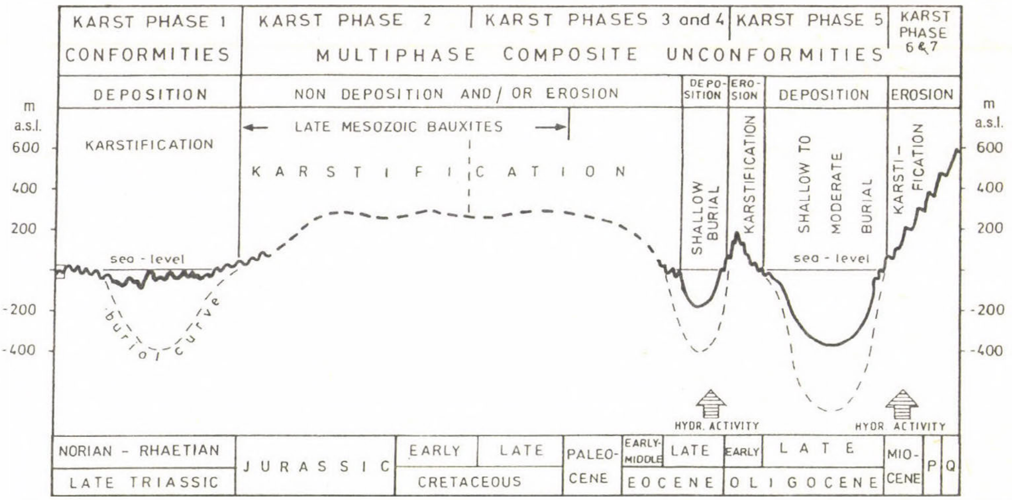



*Fig. 57a.* Estimated curve for burial history with karstification intervals indicated (after JUHÁSZ, E., KORPÁS, L. and BALOGH, A. 1995)

Concluding from the geomorphological and geological positions of travertine occurrences, the Quaternary uplift of the Transdanubian Mountains could be at least 300 m. The geomorphological mountain character developed during the last 2.5 Ma.

## Karst features

In the Transdanubian Mountains bauxite mining disclosed *tropical paleokarst features* in many places. The Triassic calcareous rocks were affected by etchplanation producing tower and cockpit karst beginning with the Jurassic but primarily during the Cretaceous Period *(Fig. 57a,b)*. The paleokarst features and the enclosed bauxite lenses were preserved by Upper Cretaceous and Paleogene strata from removal. In the Triassic limestone even older stages of karstification can be traced. They are filled with Jurassic limestone, dolomite powder, bauxitic material and sand. Karstification may have occurred repeatedly in four or five stages prior to the Neogene (JUHÁSZ, E., KORPÁS, L. and BALOGH, L. 1995).

On the surfaces of planation with paleokarst, first covered by Tertiary gravel and then uplifted (to 400 to 500 m altitude) and exhumed, swallow holes and dolines are common. The quartz gravels occurring in them support the assumption that part of them developed in buried karst (VERESS, M. 1983).

In the Transdanubian Mountains, *deep karst features* are represented by large caverns. Some of them are capable to store ten thousand cubic metres of karstwater endangering coal and bauxite mining with water bursts. In addition to dolines and lapiés fileds, there are more than 800 cold water and thermal caves. Their dimensions are

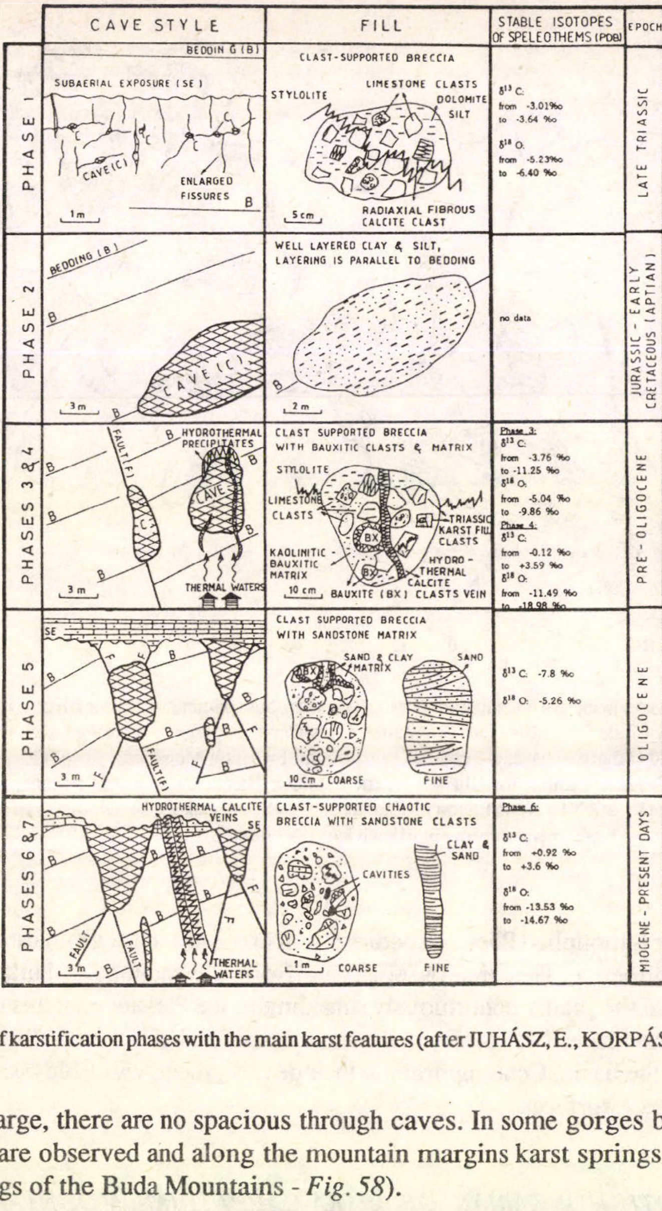



*Fig. 57b.* Sketch of karstification phases with the main karst features (after JUHÁSZ, E., KORPÁS, L. and BALOGH, A. 1995)

particularly large, there are no spacious through caves. In some gorges between horsts, spring caves are observed and along the mountain margins karst springs issue (like the thermal springs of the Buda Mountains - *Fig. 58*).

In summary, it can be claimed that in the Transdanubian Mountains there are among the surfaces of planation remnants of etchplains (ie. tropical tower karst with spots of bauxite) uplifted to various topographic positions (buried cryptoplanes or exhumed surfaces of planation in summit-level position etc.). Remnants of early Tertiary pediplains, predominantly in volcanic mountains, Miocene terraces of marine abrasion can be recognised along the margins of both mountain types. In mountain forelands, there

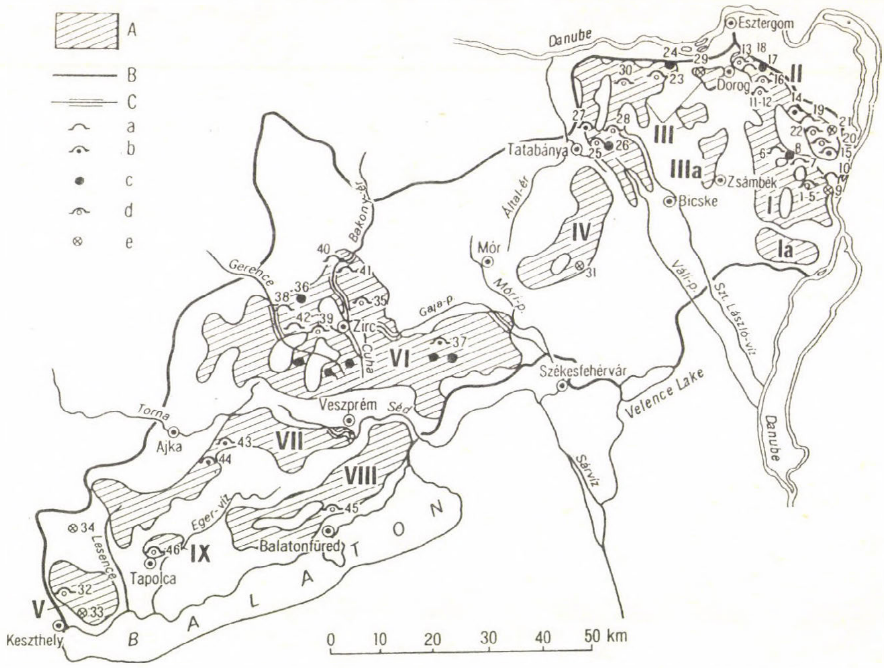



*Fig. 58.* Karst areas and principal karst features in the Transdanubian Mountains (after LEÉL-ŐSSY, S.). A = karst areas; B = boundary of the Transdanubian Mountains; C = water gap, gorge; a = spring cave; b = swallow cave; c = aven and doline; d = thermal cave; e = cave of other origin. I = Buda Mountains; Ia = Tétény Plateau; II = Pilis Mountains; III = Gerecse Mountains; IIIa = western Zsámbék Basin; IV = Vértes Mountains; V = Keszthely Mountains (dolomite karst); VI = North Bakony Mountains; VII = South Bakony Mountains; VIII = Balaton Uplands; IX = Tapolca Basin; N° 1– 46 = some more significant karstphenomena

are dissected or remodelled Pliocene pediments of erosion and accumulation, Pleistocene periglacial pediments. The streams emerging from the mountains built alluvial fans reaching far into the plains, continuously subsiding in the Pleistocene: this resulted in the formation of vast alluvial-fan plains in the central parts and of terraced alluvial fans along the margins of the basin. Contemporary to their development, wind-blow sands and loess also covered large surfaces.

## *NORTH-HUNGARIAN OR INTRA-CARPATHIAN MOUNTAINS*

### *Mesozoic and young volcanic mountain types*

This mountainous region includes two structurally and geomorphologically rather different types of mountains: *Mesozoic horsts and young volcanic mountains (Fig. 59).*

Of the Mesozoic horsts wedged in between the volcanic mountains, the *Bükk* and the *North Borsod Karst* are the most extensive (6.3 and 6.5 in *Fig. 3*). Both overlie a Paleozoic base. Their evolution much resembles that of the Transdanubian Mountains. The central karst plateau of 900 m mean altitude of the Bükk is surrounded by a lower surface of planation and by a broad but dissected foothill surface. The latter in its turn surrounded by zones of glacis of erosion and accumulation *(Fig. 60a,b* and *61)*. Whereas the North Borsod Karst is an exhumed horst of planation in threshold position, the *Mesozoic blocks of the Western Cserhát* are uplifted buried horsts covered by an Oligocene conglomerate (6.21 in *Fig. 3*) – with the exception of the *Naszály*, an exhumed planated horst (see *'Geomorphological map of Hungary'*). The Mesozoic horsts of the Cserhát region have subsided so deep they are merely scattered buttes rising above the rolling foothill surface of the Tertiary molasse deposits *(Fig. 62a,b)*.

The Bükk and the North Borsod Karst carry the most typical karst features in Hungary, the most common of them being dolines, uvalas, lapiés fields, swallow holes and spring caverns *(Fig. 63)*. In the Bükk abundant Paleolithic finds were discovered (Szeleta and Subalyuk caves). A world-famous of the numerous caverns is the 22-km long *Aggtelek Cave* with its magnificient stalactites and huge halls *(Fig. 64a,b)*. On the exhumed limestone plateaus there are numerous dolines, ponors and underground streams with large karst springs.

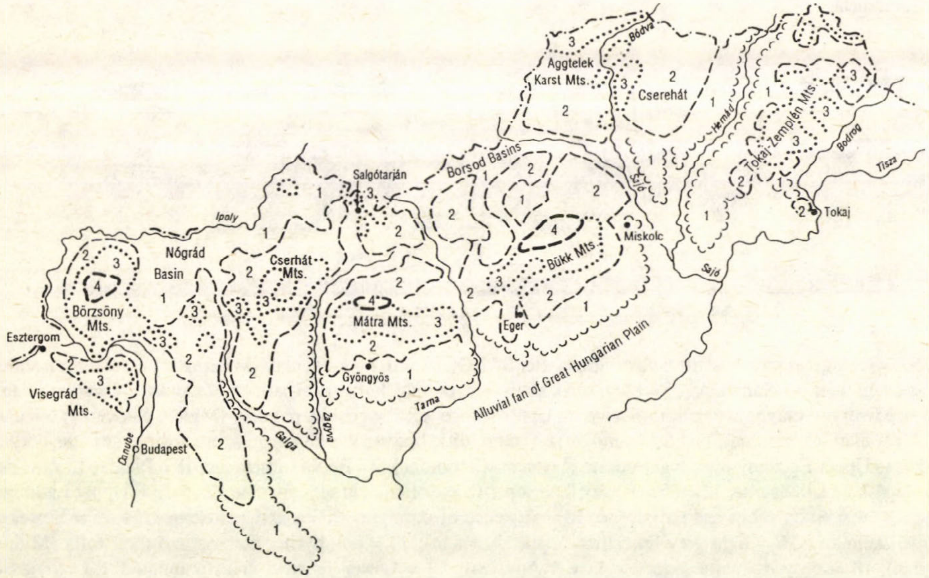



*Fig. 59.* Geomorphological distribution of the North Hungarian Mountains and Intramontane basins, and the dominant geomorphic surfaces. 1 = foothill surfaces, intramontane basins, dismembered by erosional and derasional valleys; 2 = hilly ridges, foothill surfaces of higher elevation dissected by valleys of erosion and derasion; 3 = low mountains with top level or narrow and broad ridges occasionally remnants of planation surfaces; 4 = summit level or plateau of medium hight mountains

The *Intra-Carpathian volcanic elements* of the North-Hungarian Mountains were produced by Middle to Upper Miocene volcanic activity. Early Tertiary, largely Eocene, volcanism can also be traced, but this was a relatively insignificant precursor to the large-scale Neogene events, which gaye rise to one of the most extensive volcanic chains

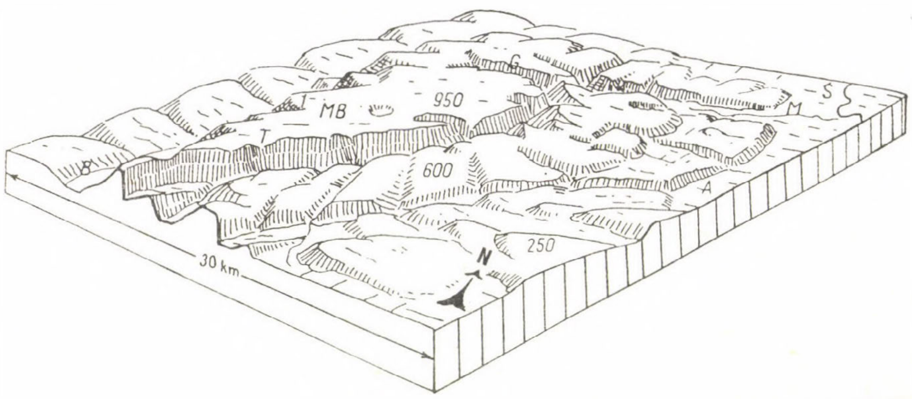



*Fig. 60a.* Block diagram of the Bükk Mountains (after PEJA, Gy.), altitudes in metres. A = Great Plain; B = Bélapátfalva village; G = Garadna valley; I = Istállóskő peak; M = Miskolc town; MB = High Bükk; S = Sajó river; T = Tarkő peak

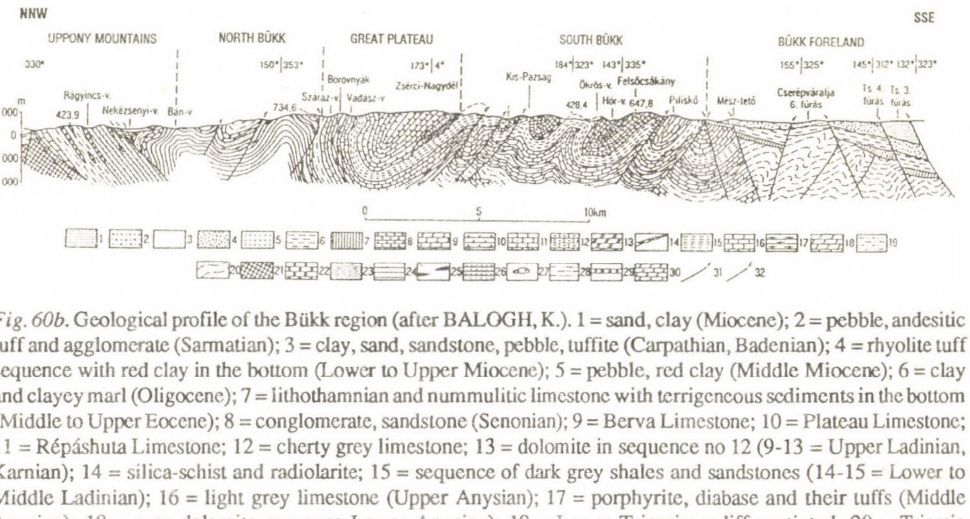
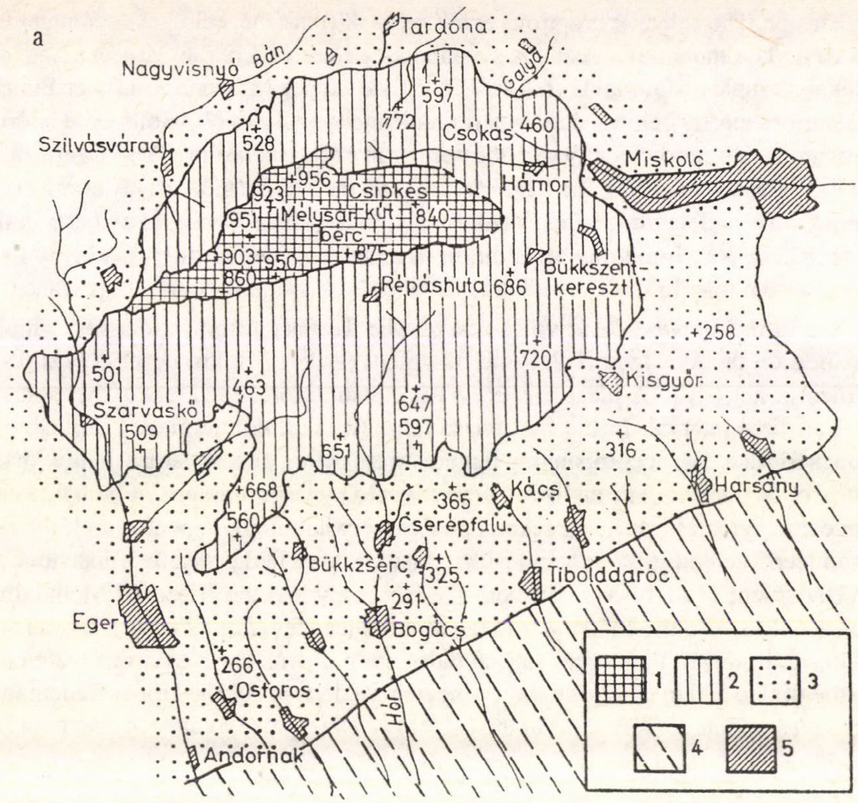



*Fig. 60b.* Geological profile of the Bükk region (after BALOGH, K.). 1 = sand, clay (Miocene); 2 = pebble, andesitic tuff and agglomerate (Sarmatian); 3 = clay, sand, sandstone, pebble, tuffite (Carpathian, Badenian); 4 = rhyolite tuff sequence with red clay in the bottom (Lower to Upper Miocene); 5 = pebble, red clay (Middle Miocene); 6 = clay and clayey marl (Oligocene); 7 = lithothamnian and nummulitic limestone with terrigeneous sediments in the bottom (Middle to Upper Eocene); 8 = conglomerate, sandstone (Senonian); 9 = Berva Limestone; 10 = Plateau Limestone; 11 = Répáshuta Limestone; 12 = cherty grey limestone; 13 = dolomite in sequence no 12 (9-13 = Upper Ladinian, Karnian); 14 = silica-schist and radiolarite; 15 = sequence of dark grey shales and sandstones (14-15 = Lower to Middle Ladinian); 16 = light grey limestone (Upper Anysian); 17 = porphyrite, diabase and their tuffs (Middle Anysian); 18 = grey dolomite sequence Lower Anysian); 19 = Lower Triassic undifferentiated; 20 = Triassic undifferentiated; 21 = Rudabánya-type Triassic sequence at Uppony; 22 = dark grey limestone sequence (Upper Permian); 23 = variegated schist and sandstone (Lower to Middle Permian); 24 = sequence of dark grey schist and sandstone (Upper Carboniferous); 25 = lenses of limestone in sequence no 24; 26 = sequence of dark grey schist and sandstone (Visean); 27 = diabase in sequence no 26; 28 = sequence of limestone and schist (Tournaisian); 29 = major limestone interbeddings in sequence no 28; 30 = semicrystallised limestone (Tournaisian); 31 = overthrust; 32 = fault plane



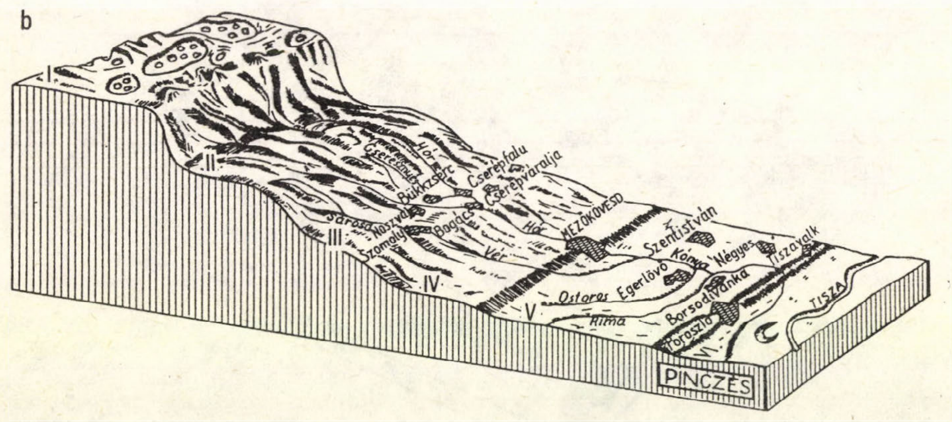




*Fig. 61*. Geomorphological surfaces of the Bükk Mountains (after PINCZÉS, Z.). a: 1 = High Bükk, upper surface of planation (Miocene); 2 = Middle Bükk, middle surface of planation (Miocene); 3 = Lower Bükk, glacis d'erosion (Upper Pliocene); 4 = Bükkalja alluvial fan (glacis d'accumulation); 5 = settlements; b: I = High Bükk; II = Middle Bükk; III = Lower Bükk; IV = Bükkalja alluvial fans ($Q_1$-$Q_2$); V = alluvial fan $Q_3$; VI = alluvial plain of the Tisza ($H_1$)

in Europe. The volcanic eruptions exhibited a shift in time, being ever younger from west to east. The mountains near the Danube Bend are of Middle Miocene age, while the Tokaj-Zemplén Mountains (6.6 in *Fig. 3*) are Upper Miocene to Lower Pliocene. The volcanoes mostly belonged to the stratovolcano type. Lava effusions were interrupted by repeated ash ejection locally with the dominance of pyroclastics. The *Visegrád Mountains* (4.4), the *Börzsöny* (6.1), the *Cserhát* (6.2) and the *Mátra* (6.3) largely consist of andesite lavas, tuffs and agglomerates. Farther east, in the *Bükk Foreland* and especially in the *Tokaj-Zemplén Mountains,* in addition to andesite, rhyolite tuffs and lavas also played an essential role. In some mountains rhyolite even gained primary importance.

In the *Danube Bend* volcanics overlie Tertiary littoral molasses, which are deposited on the Mesozoic-Paleozoic basement (at 1 to 1.5 km depth) *(Figs 65* and *66).* Volcanic activity took place in narrow littoral-sublittoral corridors of the molasse within a short time interval. In the first phase large (2 to 10 km diameter) explosive volcanic cones formed. The accompanying features were dykes, andesite intrusions with instrusive body of dacite lava. The environs were covered by large amounts of both fine and coarse andesitic pyroclastics. In the second phase overwhelmingly repeated andesite lava flows produced a central stratovolcano with parasitic cones. In the Middle Miocene (Carpathian to Badenian, 17 to 14 Ma BP) both the Börzsöny and the Visegrád Mountains and, to some extent, also the Mátra were high stratovolcanoes *(Fig 67 a,b,c).* By the end of this interval, however, they were substantially worn down. Their environs were covered up to the 400 to 500 m level of today by nearshore deposits of the Upper Badenian sea. The present summits are remnants of the caldera of a vast paleovolcano, rather than independ-

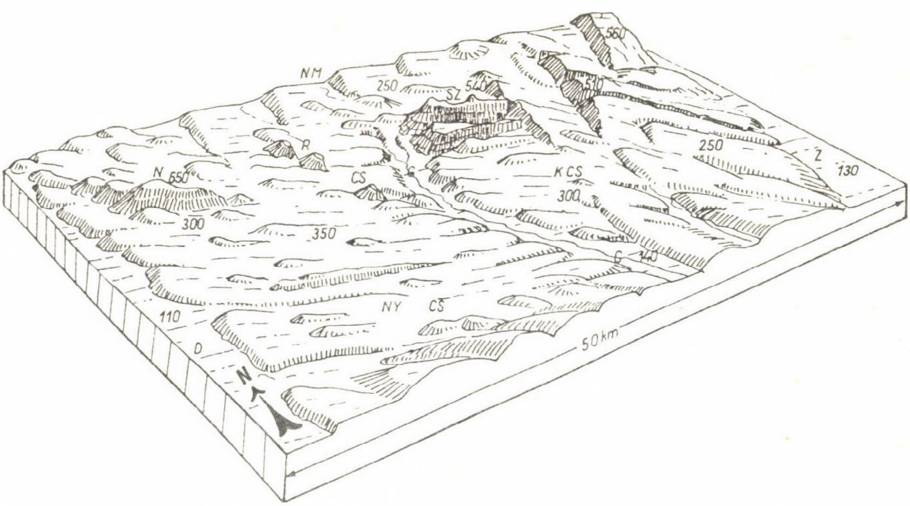



*Fig. 62a.* Block diagram of the Cserhát Hills (after PEJA, Gy.), altitudes in metres. Cs = Csővár mondanocks; D = Danube valley; G = Galga valley; KCs = Eastern Cserhát; N = Naszály; NM = Nógrád Basin; NyCs = Western Cserhát; Sz = Szanda Hill; T = Tepke Hill; Z = Zagyva valley

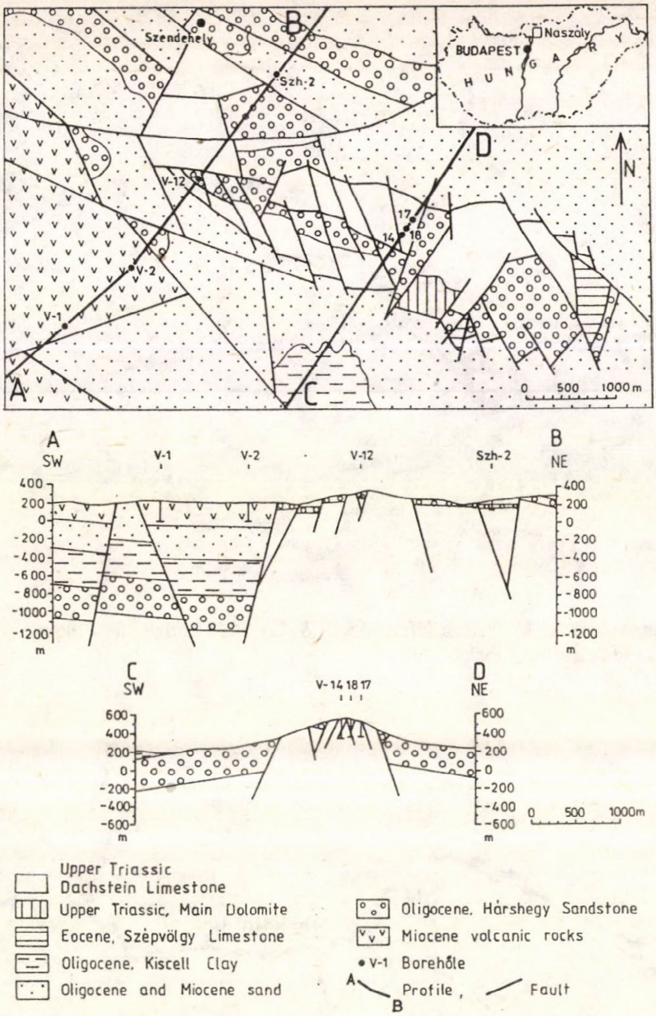



*Fig. 62b.* Geological map and profiles of the Naszály, a Mesozoic horst in the Cserhát Mountains (after BALOGH, E. *et al.* 1995).

ent centres of eruption. Some centres of eruption have undergone substantial planation (presumably pedimentation) during the Upper Badenian and also in Upper Miocene and Pliocene.

After the Badenian, the levels which today lie at 350 to 400 m altitude may have been the piedmont-type forelands of the Intra-Carpathian crystalline masses (today on Slovak territory). The streams traversing them deposited on their surface a sheet of Upper

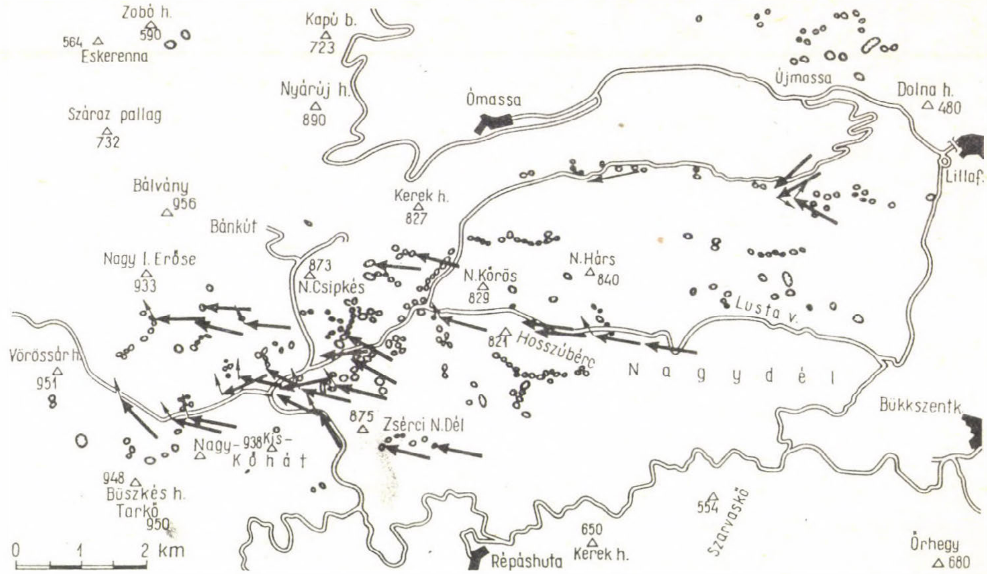



*Fig. 63.* Karst dolines on the Bükk Plateau (after JAKUCS, L.). Bold arrows show the steepest sides of dolines, while smaller arrows indicate dip of rocks

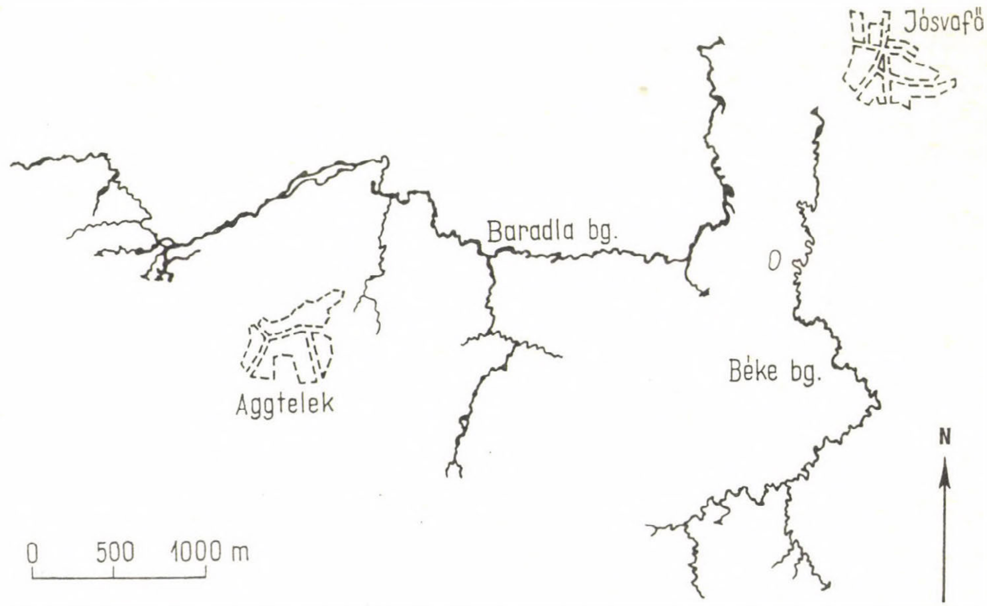



*Fig. 64a.* Ground plan of the Baradla and Béke caves, Aggtelek, reminiscent of a surface drainage pattern (after JAKUCS, L.))

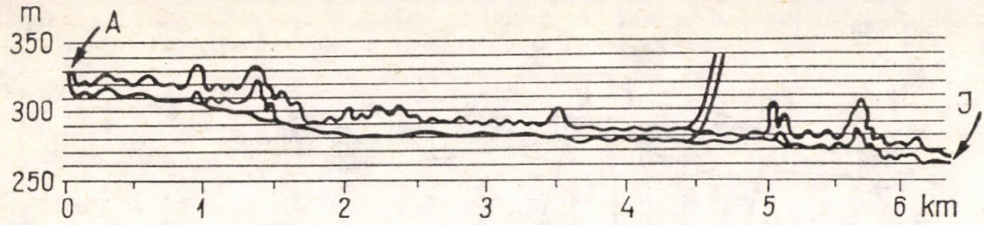



*Fig. 64b.* Longitudinal profile of the main passage of the Baradla Cave between Aggtelek (A) and Jósvafő (J)

Miocene gravel originating from pedimentation. The embayments of the Pannonian sea reached far north between the members of the mountain chain. Some of the platforms may be due to wave action.

The volcanic range of the *Tokaj-Zemplén Mountains* was formed along a deep lineament crossing the Great Hungarian Plains during the Sarmatian and Pannonian stages (Upper Miocene). In the volcanic belt there were several centres of eruption and the mountains extended over an area much larger than today. There were three main stages of volcanic activity. Rhyolite, dacite and andesite lavas and tuffs are intercalated between limnic and terrestrial sediments *(Fig. 68a,b)*. During the Uppermost Tertiary the initial composite volcano forms were heavily destructed and affected by intense pedimentation. At the end of the Miocene and mainly in the Pliocene the mountains were uplifted and simultaneously piedmont steps formed on the ridges.

The latest remodelling took place in the Quaternary through fluvial and periglacial processes, while the mountains underwent a steady rise. Crater plugs and dykes of hard lava are exposed by differential erosion. Erosional and tectonic valleys, basins colsed on all sides and embayments open towards the plain formed. The slopes were covered with a thick mantle of debris, while the foothill surfaces with slope loess and loam.

### *The North-Hungarian intramontane basins (6.7, 6.8 and 6.9 in Fig. 3)*

All the volcanic mountains are surrounded by an outward-sloping foothil surface of various width sculptured in poorly consolidated sediments beginning at altitudes of 200 to 300 m *(Figs 65)*. The foothill began to develop in the Upper Miocene. Subsequently, in the Pliocene and Pleistocene, it was strongly dissected by the rivers running off the mountains towards the subsiding Great Plains.

Since the Intra-Carpathian stratovolcanoes had been built over poorly consolidated Tertiary molasse, marine clays and sands, the thinner lava sheets and dykes surrounding the central masses of the volcanoes were deeply worn down. In the *Cserhát Hills* (6.2 in *Fig. 3*; *Fig. 59* and *62*), for instance, there are locally only traces of some dykes exposed.

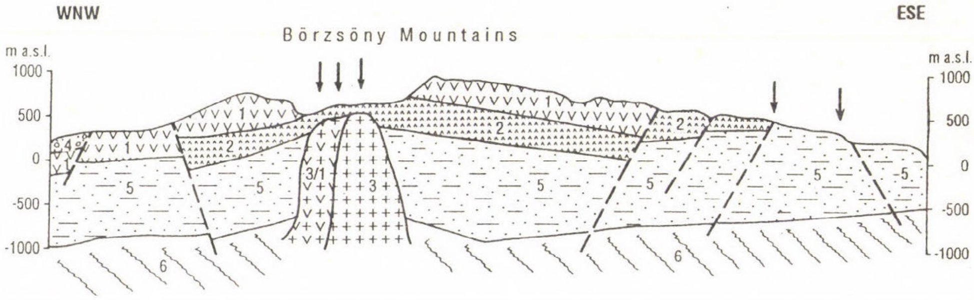



*Fig. 65.* Generalised geological cross-section of the neovolcanic Börzsöny Mountains (after KORPÁS, L. and LÁNG, B. 1993). 1 = andesite, Upper Volcanic Unit; 2 = andesite-dacite, Lower Volcanic Unit; 3 = shallow intrusive bodies, mainly related to the Upper Volcanic Unit; 3/1 = andesite, mainly related to the Lower Volcanic Unit; 4 = cover sediments; 5 = Tertiary molasse; 6 = Proterozoic-Early Paleozoic basement; 7 = main fault; the age of the volcanism is dated to ca 15.0±0.4 Ma, using K/Ar analysis

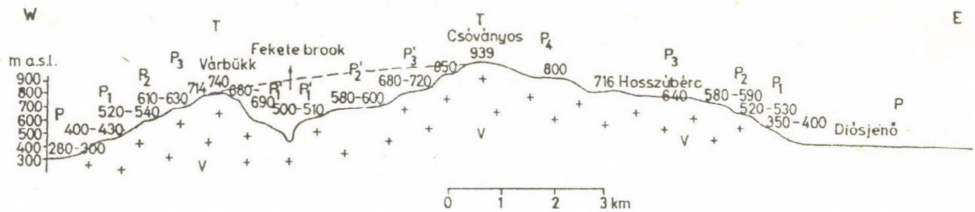



*Fig. 66.* Geomorphological cross-section of the Börzsöny Mountains (after PÉCSI, M.). T = remnant of Upper Miocene surface of planation; $P_2$-$P_4$ = inferred Uppermost Miocene steps; $P_1$ = Upper Pliocene piedmont surface; P = glacis d'erosion, remodelled in the Pleistocene; $P'_1$-$P'_3$ = intermontane piedmont steps; V = Badenian volcanics (17-15 Ma BP)

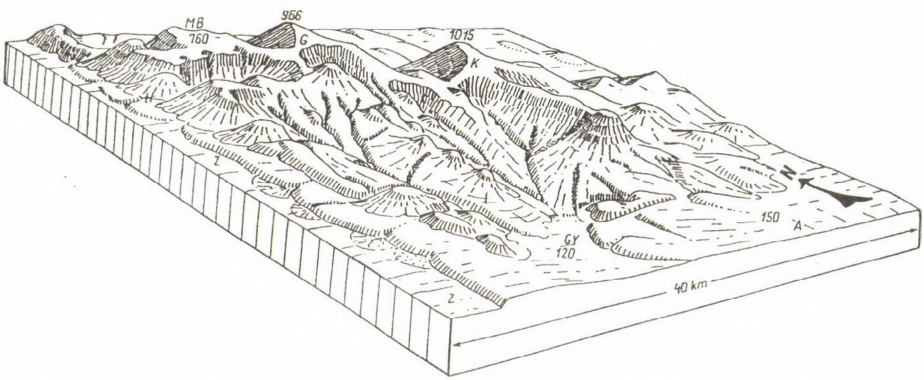



*Fig. 67a.* Block diagram of the Mátra Mountains (after PEJA, Gy.). A = Great Hungarian Plains; Gy = Gyöngyös town; Z = Zagyva valley; K = Kékes peak; G = Galyatető peak; MB = Mátrabérc crest

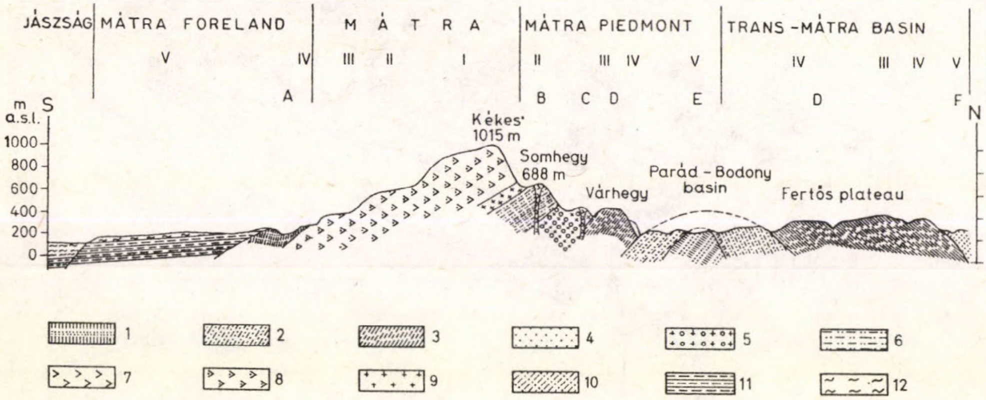



*Fig. 67b.* Cross-section of the Mátra Mountains (after SZÉKELY, A.). 1 = Middle Oligocene; 2 = Upper Oligocene (Lower Chattian) schlier; 3 = Upper Oligocene hard sandstone; 4 = Upper Oligocene (Upper Chattian), less consolidated schlier; 5 = Lower Miocene sediments (variegated clays, friable sandstone, Lower rhyolithic tuff, lignite seams); 6 = Miocene schlier; 7 = subvolcanic bodies (laccoliths, dykes) etched out by differential erosion; 8 = Badenian volcanics (andesite agglomerate, tuff, rhyolite tuff); 9 = Sarmatian sediments (clay marl and others); 10 = Upper Pannonian brackish clay and sand; 11 = Quaternary alluvial fans, slope deposits, loess; 12 = Middle Rhyolite Tuff; I = Sarmatian surface of planation, summit level; II = Lower Pannonian piedmont; III = Upper Pannonian (middle) piedmont; IV = Upper Pliocene piedmont (glacis); V = Quaternary surfaces of erosion and accumulation; A = Mátraalja structural basins; B = upper laccolith set; C = lower laccolith set; D = Upper Chattian sandstone scarp; E = erosional basins of the Mátralába; F = erosional basins of the Trans-Mátra region

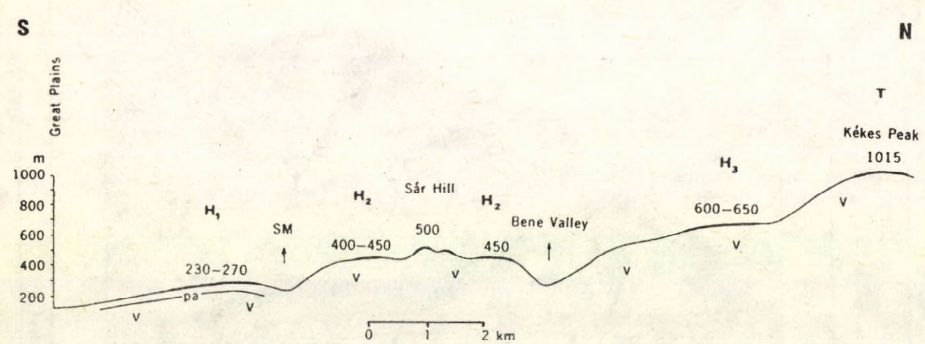



*Fig. 67c.* Sketch of surfaces of planation in the southern Mátra Mountains (after PÉCSI, M.) T = remnants of the Central Mátra surface of planation (Middle to Upper Miocene), $H_3$ = presumed Sarmatian pediment; $H_2$ = presumed Lower Pannonian pediment; $H_1$ = Upper Pliocene foothill surfaces, remodelled in the Pleistocene glacials; V = Middle Miocene igneous rocks; pa = Upper Miocene (Pannonian) sediments; SM = submontane basins

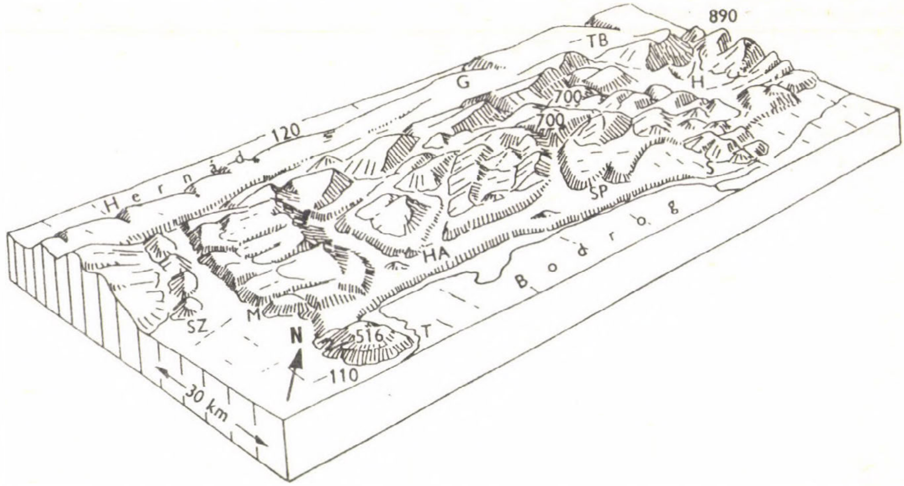



*Fig. 68a.* Diagram of the relief of the Tokaj-Zemplén Mountains (after PEJA, Gy.). Sz = Szerencs town; M = Mád village; HA = piedmont; SP = Sárospatak town, S = Sátoraljaújhely town; H = Hegyköz basin; G = Gönc village; TB = Telkibánya village T = Tokaj town

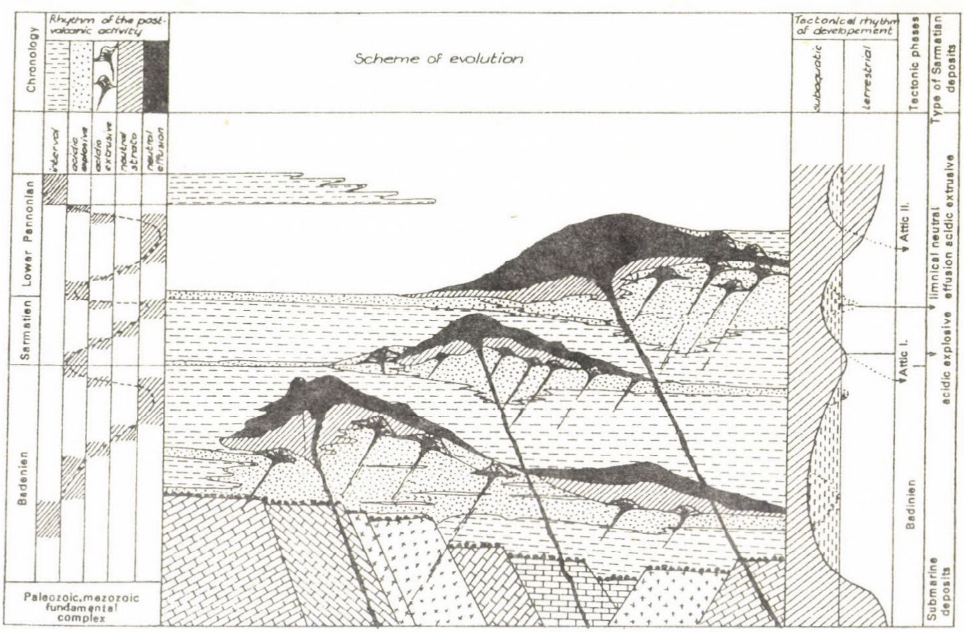



*Fig. 68b.* Neogene evolution of the Zemplén-Tokaj Mountains (after MÁTYÁS, E.)

In the northern forelands of the paleovolcanoes there is a type of intramontane basins consisting of unconsolidated sediments with a hill relief. This zone separates the Intra-Carpathian volcanic and the intercalated Mesozoic mountains from their Slovak counterparts. The slopes and flat interfluves are mantled by thick Pleistocene slope loess and loams.

The warm-humid phases of the Pleistocene induced intensified valley incision in the hills, while cold and humid phases gave rise to solifluction.

In the cold and dry phases processes like cryoplanation and deflation dominated. In the southern forelands of the mountains facing the Great Plainss there is a broad zone of fluvial alluvial fans and pediments and glacis covered with slope loess.

*Terrace formation along the uplifting and the subsiding valley sections*

Below their mountain sections, most Hungarian rivers traverse basins or extensive plains. Morphogenetically, there are three fundamental types of valley section:

a, multiterraced valley sections in predominantly uplifting mountains and hills *(Fig. 13)*;

b, valley sections with some alluvial-fan terrraces in mountain forelands and on basin margins;

c, valley sections in submerging basins, with no or only one or two terraces of accumulation.

Terraces in mountainous regions

The best-developed terraced valley in Hungary is that of the Danube where it traverses the Transdanubian Mountains. Here six to seven terraces can be distinguished in certain valley profiles. The highest and oldest terrace (marked VII) is of Pliocene age and lies ca 150 m above the actual flood-plain level. The lower terraces (nos VI to II) have been placed into the Pleistocene. There are even higher geomorphological surfaces which were foremd by marine abrasion. Terrace no VIII consists of the delta gravel of the Danube, while the surfaces nos IX and X are marine terrraes covered by Upper Miocene travertine *(Fig. 55)*.

No other section with seven terraces, except a short one along the Rába valley where it enters Hungary from Austria. The terraces pass there into the Lower Kemeneshát alluvial-fan terrace of the Rába (2.24). The Pliocene terraces no VII of both the Danube and the Rába are sculptured in or merge into the margin of a pediment of accumulation or a pediment of erosion. The latter are attributed to planation under Pliocene subhumid to semiarid climate.

In the *valley sections through the Transdanubian Mountains* and hill regions, two to four terraces can usually be traced *(Fig. 55)*. Most valley slopes are asymmetric, partly for structural reasons, and partly due to different exposure. Southerly slopes are extensive flat surfaces. Terraces of cryoplanation are common on both valley flanks. Valley floors are rather broad in most cases.

The rivers traversing the North Hungarian Mountains emerge through broad gates to the Great Plains. Along these river sections, a plain type relief penetrates far to the north. The broad valleys are mostly independent geomorphological microregions, dividing the mountain range into individual units. On the gentle valley slopes, three to five Pleistocene terraces can be traced, but over rather short lengths *(Fig. 69)*.

Terraces in mountain forelands

The rivers emerging from the mountains and hills incising into their Pleistocene alluvial fans, have sculptured broad valleys with *alluvial-fan terraces*. The alluvial fan of the Danube on the Great Plain margin is subdivided into three or four terraces *(Figs 17* and *25)*, while in the alluvial fans of smaller streams there is a smaller number of terraces and their altitude decreases as the basin is approached.

There are particular cases where the low terraces converge with the flood-plain and sink below it and continue under the surface in a normal stratigraphic succession. In such cases the *lowland streams form no valleys*. Locally, even their channels may be uncertain and regularly shifting, e.g. the Szamos and Tisza in the Great Plains *(Fig. 70)*.

Predominantly tectonic controlled terrace formation

As opposed to other megaregions in Europe, fluvial accumulation and erosion in the Carpathian Basin was not affected either by the damming effect of the continental ice-cap or by eustatic sea-level fluctuations. A feature peculiar to the Carpathian Basin is the intensive and cyclical subsidence of the basin and the parallel uplift of the mountain frame. The *evolution of erosional terraces and basin infilling were controlled* – in space and time – *predominantly by tectonic movements*, only modified by climatic change during the Pliocene and the Quaternary *(Fig. 71* and *72)*.

The closed basin had a profound, although areally restricted, influence upon the overall climatic conditions of Quaternary Europe. As a result, a periglacial province distinct from the neighbouring regions developed in each period of glaciation. This is proved by a set of characteristic periglacial features *(Fig. 42)*.

For structural reasons, there could be and was indeed a continuous accumulation in some of the interglacials, in the plains and margins of the basin. It also influenced the river valleys emerging onto the plains from mountains or hills. Conversely, in episodes of rapid and intense basin subsidence, erosional valley incision could have taken place also during the periods of glaciation. However, the latter possibly existed in the case of streams with abundant discharges, even under a glacial climate.

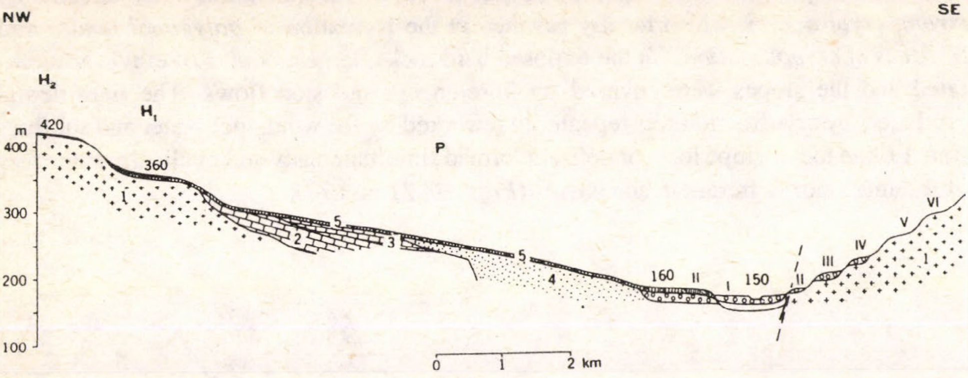



*Fig. 69.* Terraces and foothill surfaces along the Zagyva valley between the western Mátra and the Cserhát Mountains (after PÉCSI, M.). $H_2$ = Sarmatian to Lower Pannonian (Miocene) pediment; $H_1$ = Upper Pliocene pediment; P = pediment modelled during the Pleistocene; I-VI = Holocene-Pleistocene terraces; 1 = Badenian rocks; 2 = Badenian limestones; 3 = Sarmatian limestones; 4 = Upper Pannonian and Upper Pliocene sandy sediments; 5 = Pleistocene slope loess mixed with rock debris. During the glaciations the Pleistocene deposits sank to ever lower levels due to river downcutting and valley formation

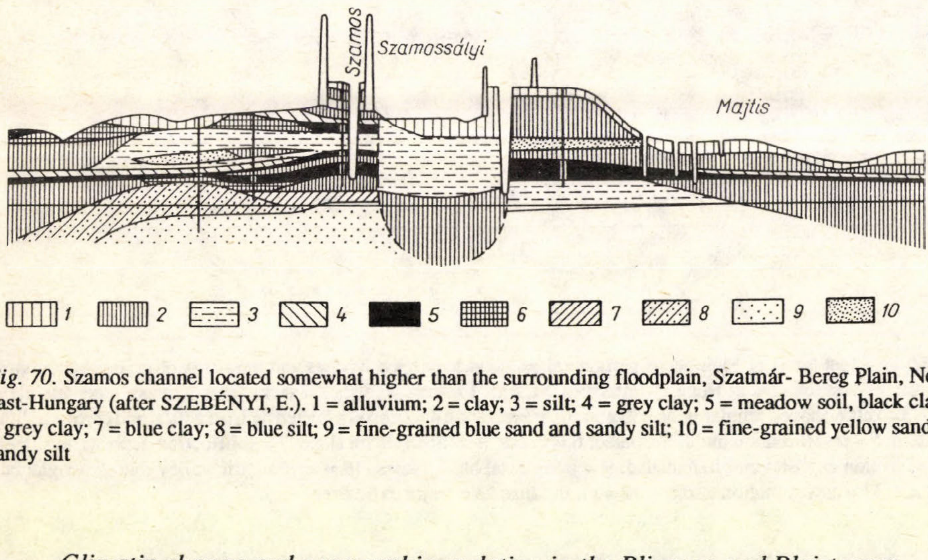



*Fig. 70.* Szamos channel located somewhat higher than the surrounding floodplain, Szatmár- Bereg Plain, North-east-Hungary (after SZEBÉNYI, E.). 1 = alluvium; 2 = clay; 3 = silt; 4 = grey clay; 5 = meadow soil, black clay; 6 = grey clay; 7 = blue clay; 8 = blue silt; 9 = fine-grained blue sand and sandy silt; 10 = fine-grained yellow sand and sandy silt

### *Climatic change and geomorphic evolution in the Pliocene and Pleistocene*

In the North Hungarian Mountains and in the Transdanubian Mountains, periglacial pediments are among the most conspicuous landforms. Their evolution was closely connected with the cold semiarid climatic intervals of the Pleistocene. Their remodelling was, on the other hand, due to Pleistocene valley evolution. In general, the mountains of Hungary were areas of degradation during the Pleistocene.

Under periglacial climate, the higher levels of the *mountains were affected by strong cryofraction*, which locally resulted in the formation of *polygonal tundra* and *terraces of cryoplanation*. On the exposed hard rocks, large amounts of eluvia accumulated and the slopes were covered by felsenmeers and stoneflows. The finer debris produced by cryofraction was repeatedly reworked by the wind, meltwater and solifluction. Eolian loess, slope loess or deluvia formed simultaneously and cyclically at the feet of mountains or in intramontane basins *(Figs. 10, 71* and *72)*.

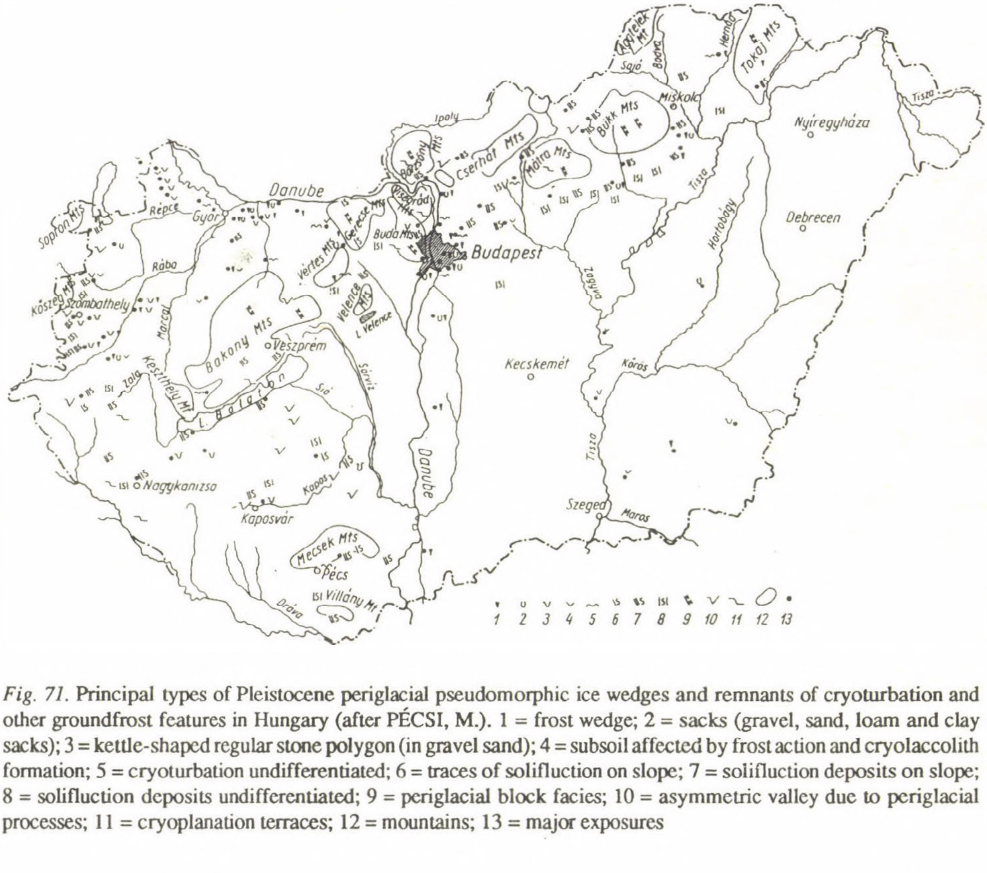



*Fig. 71.* Principal types of Pleistocene periglacial pseudomorphic ice wedges and remnants of cryoturbation and other groundfrost features in Hungary (after PÉCSI, M.). 1 = frost wedge; 2 = sacks (gravel, sand, loam and clay sacks); 3 = kettle-shaped regular stone polygon (in gravel sand); 4 = subsoil affected by frost action and cryolaccolith formation; 5 = cryoturbation undifferentiated; 6 = traces of solifluction on slope; 7 = solifluction deposits on slope; 8 = solifluction deposits undifferentiated; 9 = periglacial block facies; 10 = asymmetric valley due to periglacial processes; 11 = cryoplanation terraces; 12 = mountains; 13 = major exposures

During the Pleistocene glaciations in the Pannonian Basin, surrounded on all sides by mountain ranges, an alternation of dry and cold continental and cool and humid climatic conditions can be shown. In the interglacials, on the other hand, there was a similar alternation between temperate continental climate with more abundant precipitation than the average today and, particularly in the southern part of the basin, a

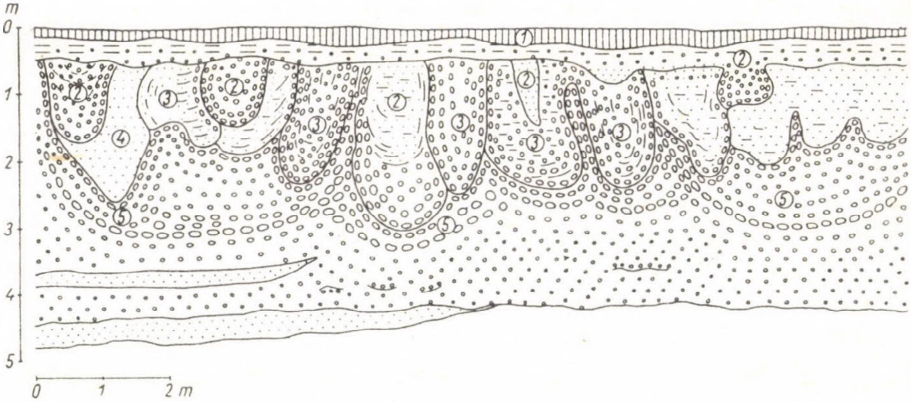
Mediterranean influence. This is clear in loess profiles and slope deposits by various paleosols, climatic indicator sediments and solifluction features *(Table 2)*. The impacts and cycles of Plio-Pleistocene climatic changes could be reconstructed through the analyses of a number of loess-paleosol sequences and the underlying Pliocene subaerial deposits. In the subaerial series of hills, old alluvial fans and foothills there are sedimentation gaps *(Figs 37b)*. Pleistocene loess and paleosol horizons are repeated ca 10 to 15 times and the number of paleogeographical changes is similar in the subaerial sequence below the loess. In contrast, below the surface of the Great Plains, in a subsided basin position, subaerial sequences of ca 1000 m, which overlie Upper Miocene deposits of the Pannonian sea, more than a hundred paleosol horizons occur *(Fig. 9)*. In these sequences 45 to 55 paleosols formed during the 2.4 Ma of the Pleistocene and 40 to 60 during the Pliocene (5.4 to 2.4 Ma BP). In the lower part of the latter locally ca 10 red clay soils occur (RÓNAI, A. 1985; PÉCSI, M. – SCHWEITZER, F. 1991). This information and reconstruction allow two summarizing remarks:

a. The Pliocene climatic cycles resemble the Quaternary ones, but in the Pliocene (5.4 to 2.4 Ma BP) soil formation under warm steppe or subarid to subhumid and warm climate (red clay soils) was typical.

b. Red clay soils also occur on pediments. From their lithostratigraphic position it can be concluded that they begin to form as early as the Miocene. A long interval (2 to 3 Ma) can be assumed for the accumulation of red and variegated clays and intercalated sand layers. This subaerial sequence promotes the reconstruction of warm semiarid and warm subhumid cycles in the Pannonian Basin. Climatic conditions respectively favoured the formation and preservation of pediments and in the subsiding basin their dissection into interfluvial ridges. Compared to the Pleistocene, the knowledge on the geomorphic evolution in the Pliocene is still imperfect.

Although the Hungarian mountains within the Carpathian Basin are of rather small areal extension on a continental scale, through their particular geomorphological and geological conditions they are key examples to several fundamental problems of geomorphology. For instance, periglacial landscape remodelling and sedimentation in the Pleistocene took place in a characteristic manner in the Carpathian Basin. It is to be regarded a specific province within the Eurasian Pleistocene periglacial zone.

A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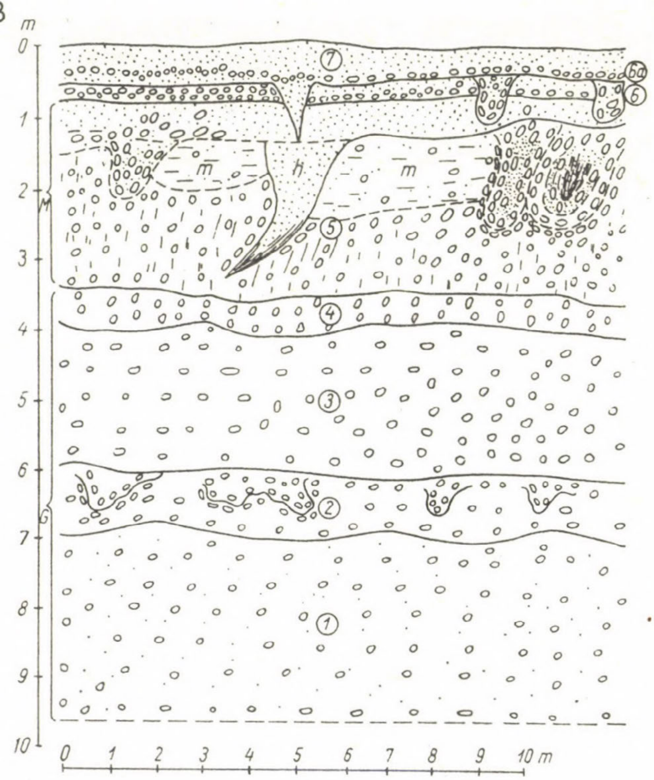
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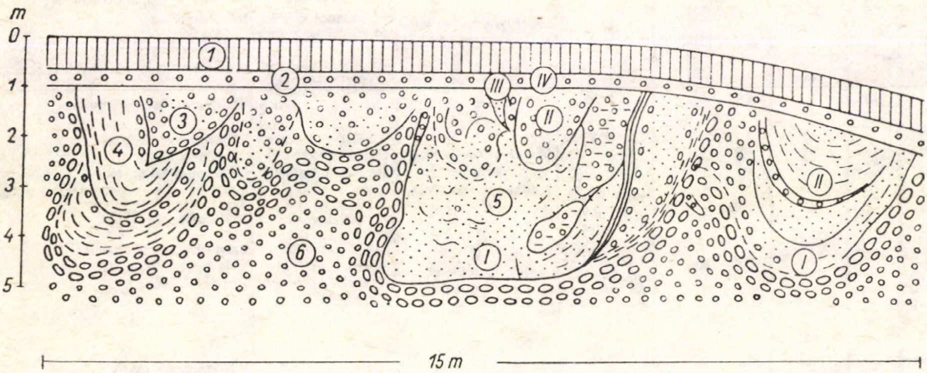


*Fig. 72.* Pleistocene periglacial phenomena on old alluvial-fan surfaces in Hungary (after PÉCSI, M.).

A. Stone polygons produced by frost pressure (profile of the Pestlőrinc gravel pit, Budapest).
1 = sandy chernozem soil; 2 = gravelly sand core mixed with red-brown forest soil, coated with a gravel mantle; 3 = sand rich in carbonates, sandy dolomite powder with scattered irregular gravel pockets; 4 = calcrete with scattered gravels; 5 = pebbles arcuately bedded in sandy calcareous silt and, outwards, in yellowish-brown sandy clay and loam. Stones (10 to 15 cm diameter) form separate bands. An onion structure is characteristic: there are smaller gravels in the centre of the core (3, 4), growing gradually coarser outwards. The polygons in the profile represent inner parts of some major stone polygons;

B. Types of subsequent periglacial groundfrost phaeses in th oldest alluvial-fan terrace, south of Budapest.
1 = horizontally bedded, greyish-yellow sandy gravel; 2 = red-brown gravel, slightly affected by cryoturbation; 3 = horizontally bedded, yellow sandy gravel; 4 = red-brown gravel with unconformity; 5 = gravels embedded in red-brown loam, with ice wedges and gravel sacks; 6 = smaller gravel sacks (stone polygons) and ice wedges in sand; 6a = gravel pavement produced by solifluction; 7 = recent blown sand; G = Günz gravel; M = Mindel gravel; m = sandy dolomite powder; h = calcareous sand filling ice wedges;
C. Multiphasal permafrost phenomena (Győr-Sashegypuszta gravel pit, older alluvial fan of the Danube, Little Plain).

I = old, large stone polygons; II = smaller polygons penetrating into the larger ones; III = groups of ice wedges; IV = gravel bed affected by solifluction; 1 = chernozem soil; 2 = gravel pavement produced by solifluction; 3 = gravel fill of ice wedges; 4 = calcareous sand and silt fill of ice sacks (stone polygons); 5 = sand fill of sacks; 6 = terrace gravels affected by frost phenomena. The stone polygons of generations I and II are coated by red soil remnants

*Table 2. Late cenozoic geomorphological surfaces (Compiled by PÉCSI, M. 1985.)*

| Polarity epoch | Stratigraphy | | Travertine | Terraces | Pediment, foothill surface | Loess, paleosols fluvial, lacustr. sed. | Localities and notes |
|---|---|---|---|---|---|---|---|
| | Holocene | | Nº1 | Nº1 | | flood plain sed. | |
| Brunhes | Upp. | PLEISTOCENE | Nº2 | NºIIa<br>NºIIb | | Young loess with 5 paleosols | Paleosol: Mende F. 29 000 y. (1)<br>Nº2 Tata: 101 000 y. (2)<br>Paleosol: Mende B.~120 000 y. (3) |
| | Middle | | Nº3 | NºIII | | Upper Old loess of Paks<br>2-3 paleosols | Nº3 Buda, Kiscell: 190 000 y. (4)<br>alluvial sand in old loess Paks: ~240 000 y. (3) |
| | | | Nº4 ⊕ | NºIV ⊕ | | Lower part of old loess of Paks, 2 paleosols | Nº4 Vértesszőlős: >350 000 y. (2)<br>Paleosol: Paks $PD_1$, $PD_2$ both ⊕ ⊞ |
| −0,7 My− Matuyama | Lower | | Nº5 ⊟⊞⊟ | NºV | glacis formation of the mountains foreland | Lowermost part of old loess of Paks<br>Pink colored sand | Oldest loess and paleosol (PDk) at Paks ⊖⊟⊖, at Dunaföldvár ⊕⊟ |
| | | | Nº6 ⊟⊖ | NºVI | Lower lying foothill surface formation NºB | Red paleosol in Nº6<br>Old alluvial fan of Kisláng | Nº6 Dunaalmás<br>Kisláng △ |
| | | | Nº7 ⊟⊞ | | | | Nº7 Dunaalmás ⊟⊞ |
| −2,4 My− Gauss | Upper | PLIOCENE | | | | Mottled clay; sand and red clay formation of Dunaföldvár: paleosol ($Df_1$ – $Df_6$) | Upper Dunaföldvár Complex ($Df_1$-$Df_4$) ⊖⊕⊕ |
| | | | Nº8 ⊟ | NºVII | | | NºVII Kemeneshát; Nº8 Dunaalmás ⊟ |
| | | | | NºVIII | | Correlative sediment of pedimentation of the Mátra foothill | NºVIII Kemeneshát gravel |
| −3,3 My− | | | Nº9 ⊕ | | Climax of the pediment formation | | Nº9 Kőpite-hill ⊕<br>Pediment of Mátra Mts |
| Gilbert | Lower | | Nº10a ⊟⊞⊟ | Oldest alluvial fan of the Danube | foreland of Mátra, Villány and other mountains NºA | Optimum of the red clay formation, bentonite formation, sand formation | Oldest red clays: Dunaföldvár ⊕⊖, Kulcs ⊕, Bag, Hatvan, Gyöngyösvisonta ⊞<br>Nº10a Újhegy ⊟⊞⊟<br>sand formation of Gödöllő ⊖ |
| −5,4 My− 5 | Upper | MIOCENE | Nº10 △ | in the foreland of mountains beginning of the formations of river system | Beginning of the pediment formation | fluvio-lacustrine sand, delta, dune sand formation | Nº10 Gerecse-Kőhegy, Várpalota<br>Bérbaltavár sand ⊕△ |
| 6 | | | | | | | |
| 7 ? | | | Nº11 △ | Marine terrace nº1 | | | Nº11 Széchenyi-hill △<br>nº1 Széchenyi-hill |
| | | | Nº12 △ | Marine terrace nº2 | | delta gravel<br>delta gravel | Nº12 Szabadság-hill △<br>Travertine of Kapolcs<br>nº2 Vértes-hill at Csákvár<br>Szabadság-hill (Buda Mts) |
| | | | | Marine terrace nº3 | | delta gravel and sand | nº3 Balaton – Upland (Balatonfüred)<br>Buda Mts: Diósd, Kálla, Billege |

Paleomagn. analysis made by:
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# GEOMORPHOLOGICAL MAPS OF HUNGARY

## 1. Introduction

A traditional geomorphological or morphogenetical study of a region requires several years of work, while the results often are summarised in voluminous monographs. However, it is impossible to describe all aspects of a landform in written form.

This fact lead to a fast development of complex geomorphological mapping. The scopes and methods of such mappings had lately widened considerably. Data gathered during large-scale geomorphological studies may be documented in spatial systems referring to landforms. Geomorphological maps completed this way can be exact and easy to use data bases for scientific and practical goals, in contrast to descriptions.

Hungarian workers during the late fifties prepared maps based on principles and using methods of representation different from those used recently. After overcoming some initial difficulties, in the early sixties an active team of Hungarian geomorphologists was organised led by the author of this paper. This group developed the methods and legends for detailed and the small scale geomorphological maps of Hungary (PÉCSI M. et al. 1963, 1976). Research and mapping went on in a fast pace and enthusiasm, resulting in small scale (1:100000 and 1:25000) maps for areas of various types of relief. Some of the detailed maps were published both in colour and black and white versions (DM L. 1972, BORSY Z. 1962, PÉCSI M. 1967) with explanations.

## 2. Outline (small scale) geomorphological maps of Hungary

More than twenty workers were involved in the past decades in geomorphological mapping of Hungary, using methods and legends previously developed. As a result, methods of survey and ways of cartographic representation were much improved during the work. Simultaneously the scope of the data set was enlarged for theoretical and practical reasons.

This way sensible differences in content and in the way of representation occurred between maps of different dates. Relying on the results and experiences of two decades of geomorphological mapping in Hungary and abroad the author prepared a small scale geomorphological outline map of Hungary. This map was published in 1:1000000 scale as a part of the Hungarian National Atlas (1967, 1989), subsequently as an independent edition in scale 1:500000 (PÉCSI M. 1972) completed according to new principles.

The geomorphological map of Hungary represents a new class of thematical maps in Earth sciences. It may be regarded as a pioneering work of Hungarian and international significance.

The complex geomorphological map of Hungary depicts five different but intimately interrelated relief patterns and groups of processes, using hundred and fifty symbols and marks. These were represented in a way enabling the user to read the information in the order of the relative importance of the data (PÉCSI M. 1976).

Depending on the scale, in concrete or in generalised form, these maps give a summary of the relief forms, their evolution in space and time, making it equally useful for scientific, engineering or educational purposes.

## 3. Explanations to the geomorphological maps of Hungary

### *Types and classes of reliefs*

Colours and shades provide twofold information about the relief. Colours display the orographic classes of the relief (mountains, hills, plains) and indicate the genesis of the relief types (e.g. alluvial plain, terraced plain, wind blown sand plain, volcanic mountain, folded mountain).

*The mountains* were classified on the highest rank according to their structural-morphological type. Volcanic mountains, Mesozoic and/or Palaeozoic faulted and folded mountains were indicated by different colours. Low and high ranges were distinguished by shades. The afore mentioned morphological types were assigned to the category of highlands even if they belonged to the hill category by their height (250–350 m).

Based on their *morphogenetical characteristics* the mountains were further classified using additional symbols and marks. *Within the category faulted and folded mountains five geomorphological subtypes were recognised:*

– *Horsts in summit position with remnants of etchplains* were indicated by the index $t_1$. These were etchplanated mainly during the Cretaceous, this process was accompanied by tropical weathering, lateritisation and bauxite formation. The letter in the symbol (T for Tertiary, $T_1$ for Paleogene) is to indicate the probable time of uplift.

– *Uplifted etchplanated horsts covered* with Tertiary sediments are indexed with $t_2$. The time of the burial is indicated by a capital letter (e.g. $T_1$ for Paleogene, M for Miocene).

– *Exhumed horsts of etchplanation* with some remnants of Tertiary sedimentary cover (index $t_3$) were similarly parts of the Cretaceous etchplain. They were buried twice, in the Eocene and Oligocene, and were not uplifted until Neogene or Quaternary to summit position. Their Paleogene sedimentary cover was partly or completely removed by erosion.

– *Subsided and buried horsts of etchplanation subsided into bench or threshold position* and pedimented during the Neogene are assigned as $t_k$.

– *Deeply buried etchplain in graben position* (index $t_e$) includes those Cretaceous karst-planation remnants which, subsided into intramontane or piedmont basins (Gánt, Iszkaszentgyörgy, Fenyőfő, Halimba, etc.), carry even bauxite deposits covered by thin layers of Cretaceous, Eocene or younger Tertiary sediments.

On the ruined and eroded remnants of *Neogene stratovolcanic mountain structures* three geomorphological surfaces of erosion have been revealed:

– summit level or top surface (index $vp_1$);

– upper level of lateral ridges ($vp_2$);

– lower level of lateral ridges or pediment dissected into intra-valley ridges ($vp_3$).

The development of these morphological surfaces was greatly influenced, in addition to denudation processes, by their tectonic setting and by the peculiarities of their rock structure. The basaltic lava-sheet structures, however, have been mostly preserved as mesa-buttes that have escaped denudation almost entirely (Badacsony, Somló, Medves, etc.).

The *hilly regions* of Hungary may be called, in structural-morphological terms, intrabasinal hill-countries for the entire surface of this category was shaped out of unconsolidated molasse type basin sediments.

– Orographically, hill ridges (ochre) and hill slopes (light ochre) have been distinguished on the maps.

– Minor basins within intramontane hilly regions (e.g. Zirc-, Zsámbék, Héreg-Tarján basins, etc.) have been coloured in dark yellow.

– The evolution of the hilly regions and the variation of the types of landforms were considerably influenced by the type of the neighbouring relief of each particular hill group. On this basis, independent hilly regions (Zala, Somogy and Tolna hilly regions) and piedmont hills were distinguished. The first type is in contact with lowland plains.

– The *surface of independent hilly* regions has been split into two categories of geomorphological surfaces:

*Higher hill* ridges dissected by erosional-derasional valleys. These represent the surface of origin of Quaternary valley formation in the Somogy Hilly Region and partly in the Tolna-Baranya one as well. On the other hand, the broad intra-valley ridges of the Vas-West-Zala Hilly Region bear remnants of old alluvial fans of Alpine rivers, too.

– The lower level of geomorphological surfaces is represented by *less elevated hill-ridges* (indicated by green and brown vertical hachures) which extend over considerable length between the erosional-derasional valleys. Their surfaces are dissected by minor derasional valleys and benches.

– The ridges of the piedmont hills were interpreted geographically as foothills (glacis formed by erosion in unconsolidated, loose sediments). The following categories were recognised:

– higher foothill remnants dissected by valleys ($P_3$, $Q_1$, brown cross hachure);

– and elevated foothills or piedmont slopes ($Q_1$, $Q_2$).

This latter type was subdivided into valley-ridges extending from a considerable length towards the plains, becoming gradually lower (brown oblique hachure).

*The lowland type* forms occur on more than half of Hungary's area. *Geomorphologically, four subtypes may be distinguished:*

– *Interfluvial alluvial fan plains* (e.g. Danube valley, Tisza floodplain), these are the so-called perfect plain surfaces. Within this subtype the *high floodplain levels* were indicated by light blue, the less elevated ones in a darker blue shade. Since the rivers have been regulated and flood-control measures have been undertaken, these surfaces can only called flood-plains with reserve, as the dams protect even against catastrophic floods both the higher and *lower levels of the former floodplain.* The high floodplain levels are particularly large on the Körös-Maros Interfluve. Here and on the Körös Interfluve Area it is the groundwater swelling up from the alluvial fans which causes damages rather than true floods. The alluvial fans of the major rivers surround swampy depressions with peat bogs of poor drainage (Little Sárrét, Great Sárrét, Ecsed Swamp, Hanság, etc.). Countless small depressions and oxbow ponds occur throughout these flood-plains. The banks of the present-day and ancient river channels are flanked by so-called riverside ridges, i.e. low natural levees. These surround smaller or greater depressions covered with meadow clay and flats with solodised soils.

– Within the *alluvial terraced plains* category (green) vast alluvial fan terraces were indicated lying higher than the flood-plains. Their surface is covered with fluvial sediments (e.g. the Sopron-, Vas-, and North-Alföld Alluvial Fan Plains, the Marcal Basin, etc.).

– *Wind-blown sand plains* were indicated by a pale yellow colour (e.g. Nyírség, Danube-Tisza Interfluve Sand Ridge, Inner Somogy). Within this category the following types were distinguished: heavily dissected, rugged areas with dunes, dune-sands blanketed with sandy loess or chernozem, and almost perfectly flat sand surfaces.

– *Loess-covered plains* (bright yellow) are generally situated on alluvial fans. Loess flats alternate with densely spaced windblown sand plains (e.g. Nyírség, Hajdúhát, Danube-Tisza Interfluve Ridge, Mezőföld). *Low-lying loess plains* are not dissected, perfectly flat surfaces (Hajdúhát Loess Plain, and an essential part of the Bácska Loess Ridge). The surface of the *slightly higher loess plains* is dissected by flat derasional valleys. On the Mezőföld this type of plains are bordered with steep slopes or loess bluffs at the boundaries of flood-plains, where the scarps are often cut with collapse ravines, gullies and, locally with slumps.

### 4. Individual forms and form-groups

The second group of symbols, using linear and areal colour symbols, and marks indicate peculiar individual forms occurring within the above mentioned relief types. Cinnabar colour indicates landforms produced by volcanism or tectonics, green denotes fluvial erosion, dotted black pattern means aeolian forms, black hachure signifies karstic denudation, while brown symbols represent planational-derasional surfaces.

Black patterns and symbols denote major settlements and other anthropogenic forms (refuse mounds, dumps, dams, replenished quarries, etc.).

The number of the symbols used is quite high compared to the scale of the map, but a great part of them denote individual structures (e.g. horst, meander, terrace edge, scarp, flood-control dam, etc.). A *smaller part of them indicate frequent occurrence of individual forms over a given area, rather than their exact position.*

Even single landforms may have genetical significance, they may indicate the dynamics of relief evolution or the grade of its stability. On surfaces represented by an alternating brown and green colour network, the relief was and still is shaped by combined erosional and planation processes. *Some of the simple symbols indicate the age of the formation of the given landform* (e.g. in the case of terraces and alluvial fans).

In mountains and hilly regions of Hungary the most frequent discrete landforms are the erosional valleys and, especially *in hilly regions, the derasional valleys.* These two types of valleys constitute the valley system of the entire country. On alluvial plains and especially on the spatial flood-plains the most common individual forms are the oxbow ponds and other types of abandoned meanders. The shape of the ancient meanders, replenished to various extent, (on the Danube Valley, Körös-Maros Interfluve, Körös riversides, Hortobágy, Taktaköz, Bodrogköz, Szamosköz, etc.) may only be recognised on aerial photos.

### 5. Lithology of sediments covering the surface

The third group of data, dealt with by the outline geomorphological map, are about the lithology of accumulation forms of the relief and those of the weathering products covering the bedrocks, which generally give the basis for soil formation. Lithological indication is given by a grey network of dots.

*The lithological content of the geomorphological map differs in several aspects from that of a geological map.* Our map shows genetically specified lithological features (eluvial, deluvial-solifluctional, aeolian, fluvial, lacustrine-fluvial, lacustrine-paludal sediments), emphasise the dynamics of morphogenesis and surface evolution. This is illustrated by the emphasised representation of slope sediments of solifluction and gravitational origin, which frequently occur on the forelands of hills and mountains or by the illustration of the detrital-loamy covers on mountain bedrocks. Another important genetical trait is that of the so-called Alföld infusion loesses which we regard as flood-deposited silts, i.e. as fluvial sediments.

## 6. The age of the surface and the relief-forms

The next group of information contained in the complex geoomorphological maps are *represented by signs with letter symbols expressing the age of the relief.* The letters are those used by geologists since a long time (H, Holocene, Q, Quaternary, P, Pliocene, T, Tertiary).

*The code system for the age of the surface* aims to give information about the *geohistorical dynamics of relief formation,* about the pace of evolution. The relationship between the age of the rocks on the surface and that of the morphogenesis may be summarised as follows:

– The formation of accumulation surfaces or *single accumulation forms* may coincide with the age of sedimentation (sand dunes and flood-plains, as landforms, were formed together with the sedimentation of the constituting matter).

– If an *accumulation surface was formed during a relatively long period* or in several phases, or, in the case of major valley floors, such as detrital cones covered with wind-blown sands, the formation of the relief as a whole dates back the deposition of the thin covering sediment. *In such cases a special code is used to denote the time span of morphogenesis.* E.g. code $Q_3$+H means a latest Pleistocene valley floor had been covered by thin Holocene sediments while the morphology have hardly changed.

– In the case of an *erosional relief* the age of the relief and that of its singular forms *is generally younger than that of the sediments forming them.* In mountains the relief, carved out of Palaeozoic, Mesozoic or Paleogene rocks, generally is much younger, than the rocks, the relief itself being formed during the Neogene or Quaternary. Only minor surfaces have been preserved from the Cretaceous, even these are usually buried by Tertiary sediments (code $t_e$) and eventually subsequently exhumed ($t_3$).

– If a surface was eroded during long geological periods, the most effective periods of morphogenesis are indicated by letter combinations. E.g. $P_3$-$Q_1$ *indicates a pediment formed during the period symbolised by the letters.* The numerator of the code $vp_2$/M-P indicates the upper level of surface of erosion on the side ridges of a Neogene startovolcano, while the nominator refers to the period of morphogenesis, Miocene and Pliocene. Additionally, the age of a relief form may also be indicated by symbols of the terraces (II–VII) and by those of the alluvial fans (Holocene, Upper Pleistocene, etc.). Furthermore, there are several lithological formations of precisely known geological age (e.g. Holocene: flood-deposited silts, peat, bog-clay, longshore dune, dune sands; upper Pleistocene: loess, loessy sand, slope sediments, etc.).

## 7. Hydrographic and hydrometeorological data, specification of natural resources

The outline (small scale) geomorphological maps of Hungary depicts all permanent watercourses and the most important ephemeral ones as well as the major canals.

*In addition*, the following data are given: the length of the major streams and rivers the in km, the elevations of characteristic points of their beds and mouth, the width of the rivers and the water depth in m, the flow velocity in m/s, the quantity of suspended and rolled load in kg/s, all for mean discharge. The map gives data on the water regime of rivers based on multiannual mean values, on the seasonal variations of discharge at low, medium and high levels in $m^3/s$. All these values are indicated by red numerals (PÉCSI M. 1976).

Standing water bodies, lakes, reservoirs, fishponds are shown areally and by their depth. *In addition*, data of the groundwater table are indicated at representative points, shown its maximum and probable variation in time. The most important hydrogeological parameters are also included (January, July, and annual mean temperatures, multiannual mean value of runoff, precipitation and difference between potential evaporation and precipitation). By some calculations based on these data one may get information about water budget and other related topics. (The information indicated by the words "*in addition*" are given only for the "Geomorphological map of Hungary", scale 1:500000; PÉCSI M. 1976).

## 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 Kőpite 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 Kőpite-hill at Süttő in the Gerecse Mts)

4. Upper Pliocene (Ruscinian – Csarnótian – Lower Villányian) old alluvial fans andtravertine 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, Vértesszőlős 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

## CONCLUSION

The complex geomorphological maps use five different symbol groups expressing the quality of the types, formations and lithology of the relief, their origin, history and actual development. Furthermore, the maps provide a hydrometeorological data set as well. These data give a synthesised picture of the available results of geomorphological survey on the area in a uniform way. Geomorphological characteristics are combined with other relevant data, in a detail corresponding to the scale of the map.

It is to be emphasised that this sheet is the first outline (small scale) geomorphological map prepared for Hungary. Thus, it was impossible to completely include results of all detailed studies. There are considerable differences between the amount and details of knowledge about various regions of Hungary causing inevitable unevenness in the contents of the map.

Nevertheless, this map provides a basis for further geomorphological studies now and in the future, stimulating comparisons and more detailed researches on areas not sufficiently studied yet. Moreover, it may call attention to the major problems of general geomorphological research and cartography.

The map in question will be revised and complemented repeatedly on the basis of new results of geomorphologists and geologists and, especially, taking into consideration of comments and requirements of its users, scientists and engineers.

Recently the "Geomorphological Map of Hungary" (1972, scale 1:500000) has been revised and renewed by the members of the working teams of Hungarian geomorphologists and newly published as a part of the second edition of the "National Atlas of Hungary 1989".

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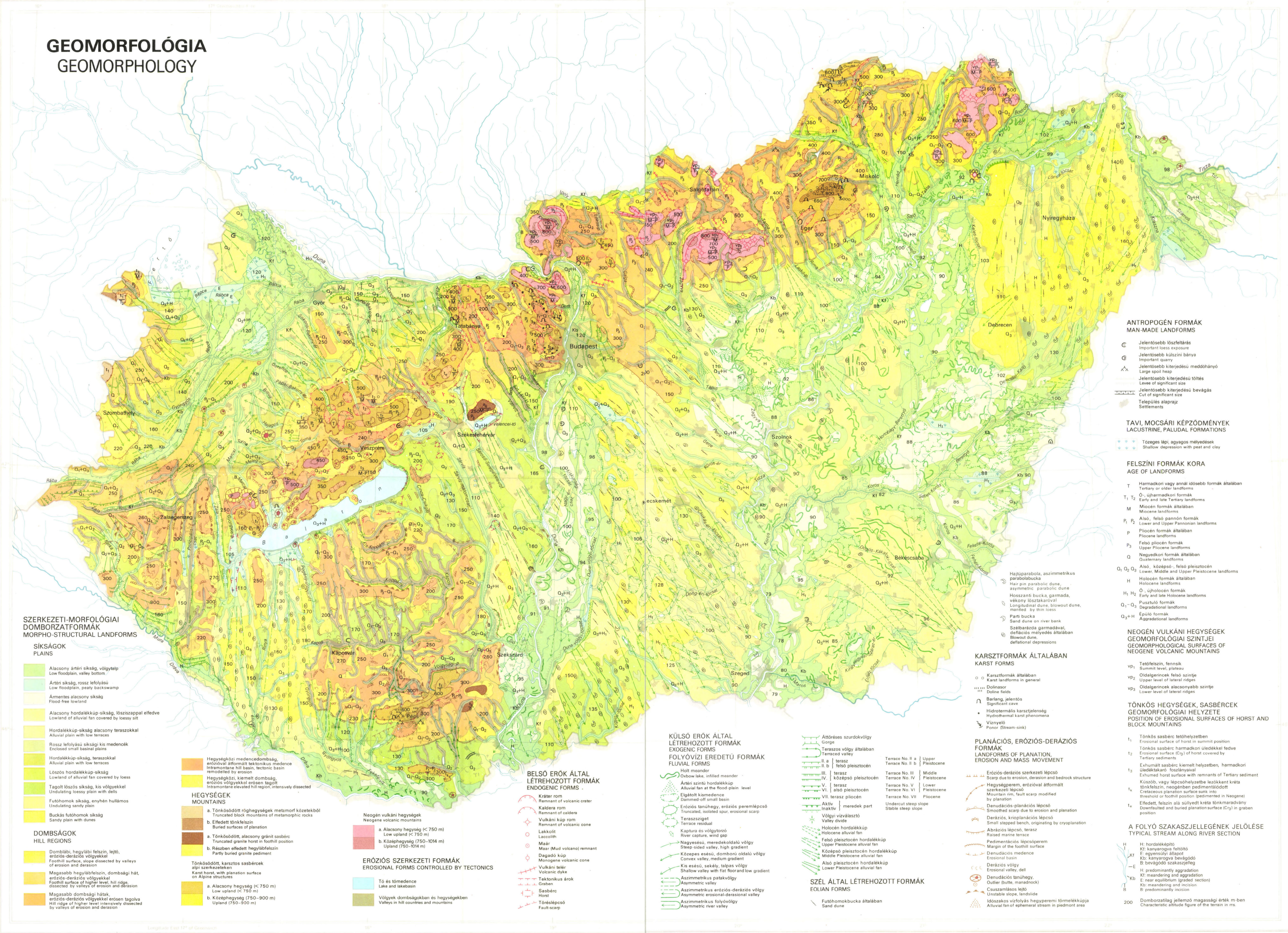
# GEOMORFOLÓGIA
## GEOMORPHOLOGY



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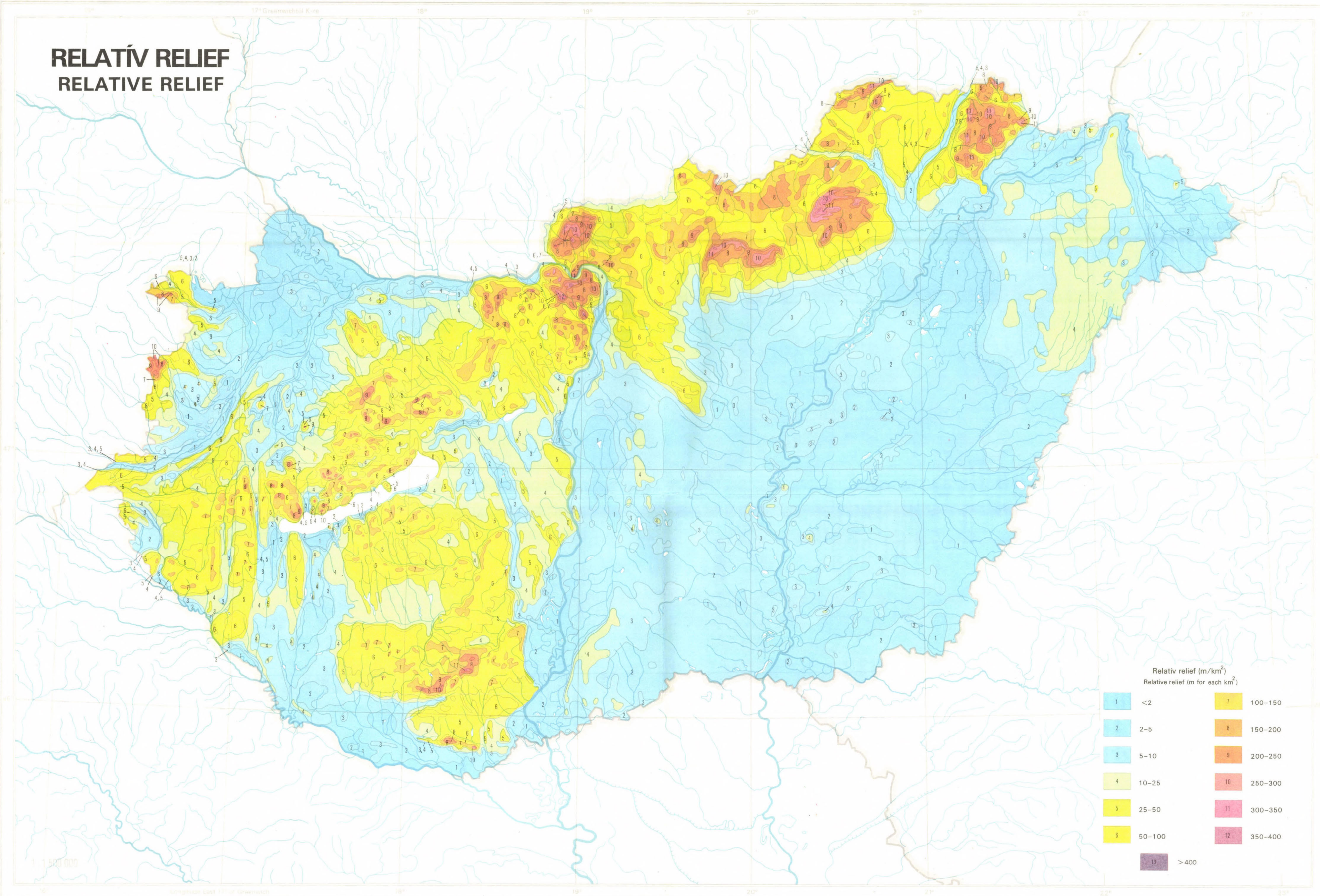

# BUDAPEST GEOMORFOLÓGIAI TÉRKÉPE (RÉSZLET)

## GEOMORPHOLOGICAL MAP OF BUDAPEST (DETAIL)


### I. LEJTŐKATEGÓRIÁK
CATEGORIES OF SLOPES

1 a, b — 0–2,5°
1/a Alacsony árterek (30, 31, 48, 49) és völgytalp (52)
Low flood plains (30, 31, 48, 49) and valley floors (52)
1/b Egyéb felszíni formák
Other landforms

2 — 2,5–5,0°

3 — 5,0–15°

4 — 15–35°

5 — >35°

### II. A LEJTŐK ÁLLAGA
STATE OF SLOPES

6 Stabil lejtő
Stable slope

7 Instabil lejtő általában
Unstable slope

8 Labilis, jelenleg is mozgásban lévő csuszamlásos lejtő
Unstable slope with slides presently active

9 Csuszamlásveszélyes lejtő
Slope with sliding hazard

10 Barázdás eróziós lejtő
Rill erosion slope

11 Törmelékmozgásos lejtő
Slope with debris movement

12 Határozott lejtőszög változás
Abrupt change in slope angle

### II. ÁLTALÁNOS DOMBORZATI FORMÁK
GENERAL RELIEF FORMS

13 Fennsík (tönkfennsík, táblás fennsík 250 m tszf.felett; szélessége >100 m)
Plateau (peneplain, tableland, above 250 m a. s. l.; wider than 100 m)

14 Alacsony fennsík (150–250 m tszf.)
Low plateau (150–250 m a. s. l.)

15 Sasbérc
a. egyenetlen, domború felszínű sasbérctető
b. sasbérclejtő szilárd kőzeten
c. sasbércláb lejtőtörés
Horst
a. convex top of horst with uneven surface
b. horst slope on consolidated rock
c. angularity at foot of horst slope

16 Hegygerinc (300 m tszf. felett; szélessége <100 m)
Rounded ridge (above 300 m a.s.l.; narrower than 100 m)

17 Alacsony gerinc (150 m tszf.-nél magasabb, szélessége <100 m)
Low ridge (above 150 m a.s.l.; narrower than 100 m)

18 Hegyhát (300 m tszf. felett, szélessége >100 m)
Broad ridge (above 300 m a.s.l.; wider than 100 m)

19 Alacsony hát, völgyközi hát (150 m tszf., szélessége >100 m)
Broad ridge, interfluvial ridge (above 150 m a.s.l.; wider than 100 m)

20 Lejtőpihenő
Gentle segment of slope

21 Hegylábfelszín, hegylábléjtő
Piedmont surface, piedmont slope

22 Hegylábléöcső és felszíne
Piedmont step and its surface

23 Természetes tereplépcső
Natural step

24 Kőbörc
Monadnock

25 Tanúhegy (eróziós, deráziós)
Residual hill (erosional, derasional)

26 Dombtető
Flat hilltop

27 Erodált síkok enyhén hullámos felszíne
Slightly undulating erosional surface (glacis)

28 Nyereg
Saddle

29 Sziklafal
Cliff

### IV. AKKUMULÁCIÓS FORMÁK ÁLTALÁBAN
(Árterek, teraszok és hordalékkúpsíkságok, törmelékkúpok)
DEPOSITIONAL FORMS
(Floodplains, terraces and alluvial fans, talus cones)

30 Ártéri sík (általában)
Floodplain

31 Vizenyős területek (laposok)
Waterlogged areas (flats)

32 Ártérnél magasabb síksági felszín
Plain above floodplain

33 Alacsony teraszok
Low terraces

34 II/a sz. terasz
Terrace II/a

35 II/b sz. terasz
Terrace II/b

36 III. sz. terasz
Terrace III

Magas teraszok maradványfelszíne
Residual surfaces of higher terraces

37 a. 125–160 m tszf.
125–160 m a.s.l.

38 b. 160–180 m tszf.
160–180 m a.s.l.

39 c. >180 m tszf.
more than 180 m a.s.l.

40 Patakmenti teraszok, terepszintek maradványai
Remnants of terraces along streams

41 Lejtőalji törmelékkúp
Footslope alluvial fan

42 Medencetalpi hordalékkúp
Alluvial fan on basin bottom

43 Lejtőoldali törmelékkúp
Talus cone on slope side

### V. MEDREK, VÖLGYEK
RIVER BEDS, SMALL VALLEYS

44 Eróziós vízmosások (<2 m)
Rills (shallower than 2 m)

45 Eróziós árkok (<2 m)
Erosion gullies (deeper than 2 m)

46 Meredek partú patakmeder
Stream-bed with steep banks

47 Kisebb vízfolyások elhagyott medrei
Abandoned channels of smaller watercourses

48 Jelenkori holt Dunaág
Recent cut-off Danube channel

49 Meander (nyomvonal) maradvány
Remnants of traces of meander

50 Mély eróziós völgy (>20 m)
Erosion valley (deeper than 20 m)

51 Közepes mélységű eróziós völgy (<20 m)
Erosion valley of intermediate depth (shallower than 20 m)

52 Lapos, széles eróziós völgy (szélesebb 50 m-nél)
Flat erosion valley (wider than 50 m)

53 Medencetalp pereme
Margin of basin floor

54 Eróziós-deráziós völgy
Erosion-derasion valley

55 Deráziós völgy
Derasional valley

56 Deráziós fülke, deráziós függővölgy
Derasional niche, derasional hanging valley

### VI. KARSZTOS FORMÁK
KARST FORMS

57 Szárazvölgy, aszóvölgy
Dry valley

58 Szurdokvölgy
Gorge

59 Korráziós mélyedés
Solutional depression (doline)

60 Völgytorzó
Wind-gap

### VII. HOMOKFORMÁK
EOLIAN FORMS

61 Futóhomok buckák
Blown-sand dunes

62 Hosszanti buckák
Longitudinal dunes

63 Széles, lapos deflációs mélyedés
Wide flat depression

64 Szélbarázda
Wind furrow

65 Széllyuk
Blow outs

66 Futóhomokkal fedett (terasz-) felszínek
(Terrace) Surfaces covered with wind-blown sand

### VIII. ANTROPOGÉN FORMÁK
ANTHROPOGENIC FORMS

67 Mélyút
Sunken roads cut in loess

68 Álteraszok
Pseudoterraces

69 Külszíni bánya művelés alatt
Active quarry

70 Időszakosan művelt bánya
Intermittently active quarry

71 Külszíni bánya, felhagyott
Abandoned quarry

72 Feltöltött bányák
Infilled quarry

I – XXII Kerületek
Districts