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Relationships between geomorphology, neotectonics and earthquakes in the Danube Plain between Ercsi and Madocsa and on the Danube–Tisza Interfluve

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Abstract

Investigations into interrelationships between geomorphology, neotectonics and seismicity in the Danube Plain and in the northern part of the Danube–Tisza Interfluve bear importance due to the socio-economic significance of these landscapes. Studies on geomorphology and neotectonics are aimed at getting knowledge about the landform evolution of the actual surface, seismic events and at collecting evidence of the latter. The results have been represented in thematic maps, where landscape boundaries based on genetic notions coincided with neotectonic fault lines in several places. In order to make geomorphological and tectonic models correct the geological sediments of the high bluff of the Danube were analyzed palaeogeomorphologically, lithostratigraphically, chronologically and sedimentologically. The most important fault lines and areas of subsidence were singled out according to geomorphological and seismological features.

Keywords: geomorphology, neotectonics, fault lines, areas of subsidence

Introduction

Neogene history of evolution of the Carpathian Basin has played an essential part in geomorphic position, extension of micro-landscapes, and shaping landforms in the Danube Flat and on the Danube–Tisza Interfluve. After the regression of the Pannonian inland sea structural movements, i.e. uplift and subsidence of various degree, occurred. Intense movements during the late Pliocene and early Pleistocene accompanied by red clay formation have been responsible for the emergence of macro landforms, whereas crustal movements having resulted in microforms continued into the Holocene.

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An antecedent of the present-day drainage system was a consequence of these structural movements plus that of the erosion by water and sedimentation during the post-Pannonian, i.e. late Pliocene Csarnotanum.

Pliocene and Quaternary deposits, Pleistocene alluvial cones, landforms initially built of wind blown sand during Pleistocene and subsequently rejuvenated by sand motions in early Holocene, flood plains and channel configuration of water courses are typical of micro-landscapes to be studied below. In some places boundaries drawn according to genetic notions coincide with fault lines of neotectonism.

Sketch of the Neogene evolution in the Carpathian Basin

In the early Miocene most of the land what is now Hungary was part of a continent with landform evolution characteristic of subtropical areas. This terrestrial period terminated in the Carpatian phase, when crustal movements triggered marine transgression in two narrow strips from the south-west. Transgression kept on in the Badenian phase so the land had become smaller than the areas inundated by sea.

Provoked by tectonic movements that occurred at the end of the Sarmatian an intense subsidence of the present territory of Hungary and the larger Pannonian Basin started. At the same time due to the uplift of the Carpathians and Dinarides the inland sea having existed at the end of the Sarmatian became separated from the remains of the Paratethys and turned into a lake. It had a single connection with the Wallachian Lake across the present-day Iron Gate (Wein, Gy. 1969).

Resulting from an intense subsidence of the basin the Pannonian Lake had covered a substantially larger area than the Sarmatian inland sea used to occupy. An overwhelming part of the Hungarian Middle Mountains, however, remained uncovered. Moreover, in the lower Pannonian stage a few islands existed in both Transdanubia and Great Plain (Alföld). Most of them were affected by marine transgression only later, during the upper Pannonian.

All the lakes as a rule become filled up by sediments sooner or later, especially those surrounded by a high mountain frame such as the wreath of Alps, Carpathians and Dinarides. Sedimentation of the Pannonian Lake had taken a relatively long time, because its bottom level, and that of the Great Plain in particular, had been in a permanent subsidence. The sedimentation took place through deltas. Lake currents transported the very fine grains (mud, silt) that did not deposit in the deltas, so they had reached the deeper parts of the basin and spread over there.

In the ultimate phase of sedimentation during the upper Pannonian (i.e. Pontian) stage the lake became very shallow. In the peripheries of the

Pannonian Basin formation of alluvial plains started and the rivers transported abundant sediment inside the basin. So the lake transport of an utmost importance previously had become subordinate steadily. Gradually the whole sedimentary basin turned into a fluvial-lacustric system. The rivers of this specific drainage network deposited a huge amount of sand. Cross-bedded sand with a thickness of 30–100 m had extended almost all over Transdanubia.

Within a relatively short period, by the end of the Pliocene the gradually shrinking lake had become filled up with a large amount of sediments brought by its tributaries; thus the Great Plain became an alluvial flat. At that time however Transdanubia was situated somewhat higher than the Great Plain which kept on subsiding. Coevally with the regression of the Pannonian Lake a new drainage network emerged in the basin. Nevertheless, that pattern of hydrography differed from the present-day one to a considerable extent.

Relation between recent crustal movements and geomorphology

Geomorphological investigations and studies on neotectonism are aimed at gaining knowledge about history of geomorphic evolution, analysis and provision of evidence about earthquakes.

A differentiated accumulation of Pleistocene–Holocene deposits refers to crustal movements extending over the entire area of Hungary even nowadays. Regional pattern of persistent subsidence is indicated by the thickness of Quaternary sediments over the lowlands. On the other hand an overall spread of an overall strong denudation testifies to an uplift character in the Middle Mountains. These trends, however, are liable to changes. For example in the western part of the Transdanubian Hills the subsidence of Zala Hills has turned into uplift so that Pannonian sediments are to be found up to 300 m a.s.l. (Kandikó, 301 m). Quaternary fluvial deposits only survived in patches owing to the denudation in the course of the elevation (Pécsi, M. 1959).

Three focus areas of the ongoing subsidence in the Great Plain are South Tisza, Jászság and Körös depressions, where the Pliocene sediment have sunk to a depth of 600 m below surface, depicted in the maps of deposits underlying Quaternary sediments by Urbancsek, J. 1961, 1965. *(Figures 1* and *2*).

Relationship between rivers and depressions is explained by a constant striving of water of liquid state to move along the slope in a shortest way to reach the local base line represented by the nearby depressions. This is the cause of the strong impact of crustal movements upon the drainage network; this is why all recent depressions had turned into focuses of drainage and remained so until present, though water regulation measures diminished this relationship considerably. Extensive flood plains, channels of uncertain direction in the Little Plain and Drava Valley, at Maros mouth, Körös rivers and

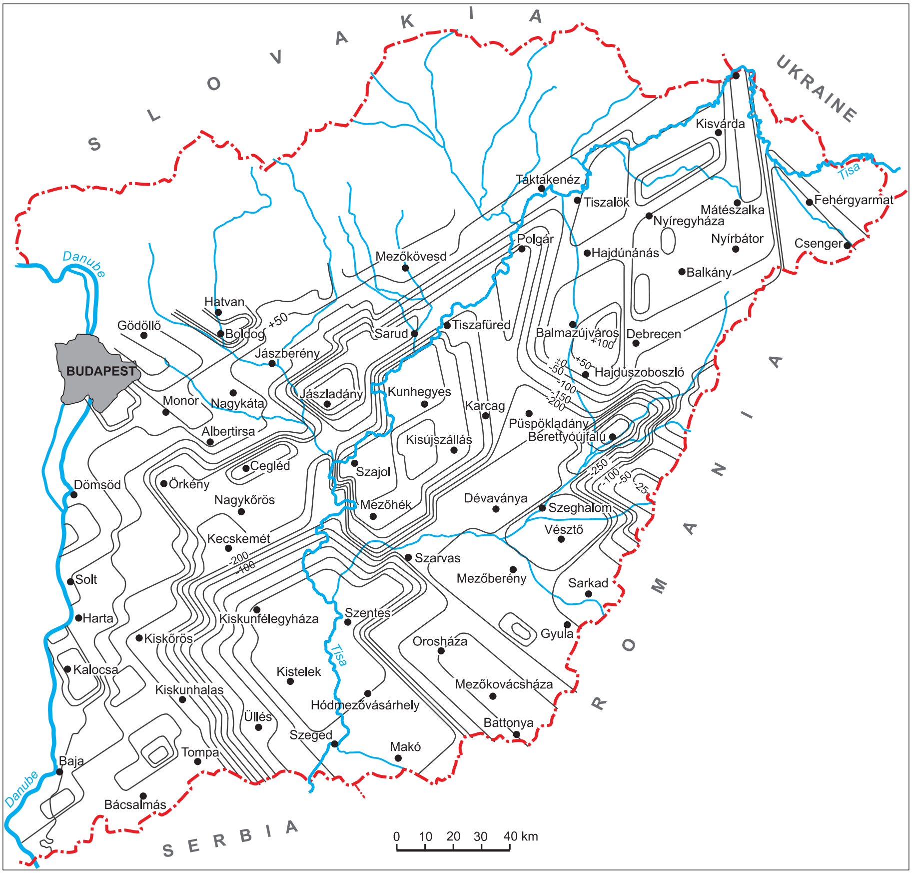


Fig. 1. Altitude of Quaternary deposits of the Great Plain relative to the Adriatic Sea level (by Urbancsek, J.)

Sajó delta are enough evidence. There are examples from the atlas by Ptolemey (2nd century A.D.) that can be referred to. In its 1901 edition (Paris) the sheets IV, V, and IX show Marcal River to have joined Rába at Marcaltő, the Sió and Sárvíz flowed together near to Simontornya; the former reached the Danube at its bend at Bogyiszló. Hármas-Körös had large active curves, and Maros had a double channel to access the Tisza River, partly via its southern branch (Aranka) (Somogyi, S. 1974).

Differences between the altitudes of terraces formed at the very end of Pleistocene and of the present surface or the thickness of recent sediments provide ample evidence about the intensity of uplift or subsidence having taken place during the past ten thousand years. The current channel of the Danube is quasi-perpendicular to this direction.

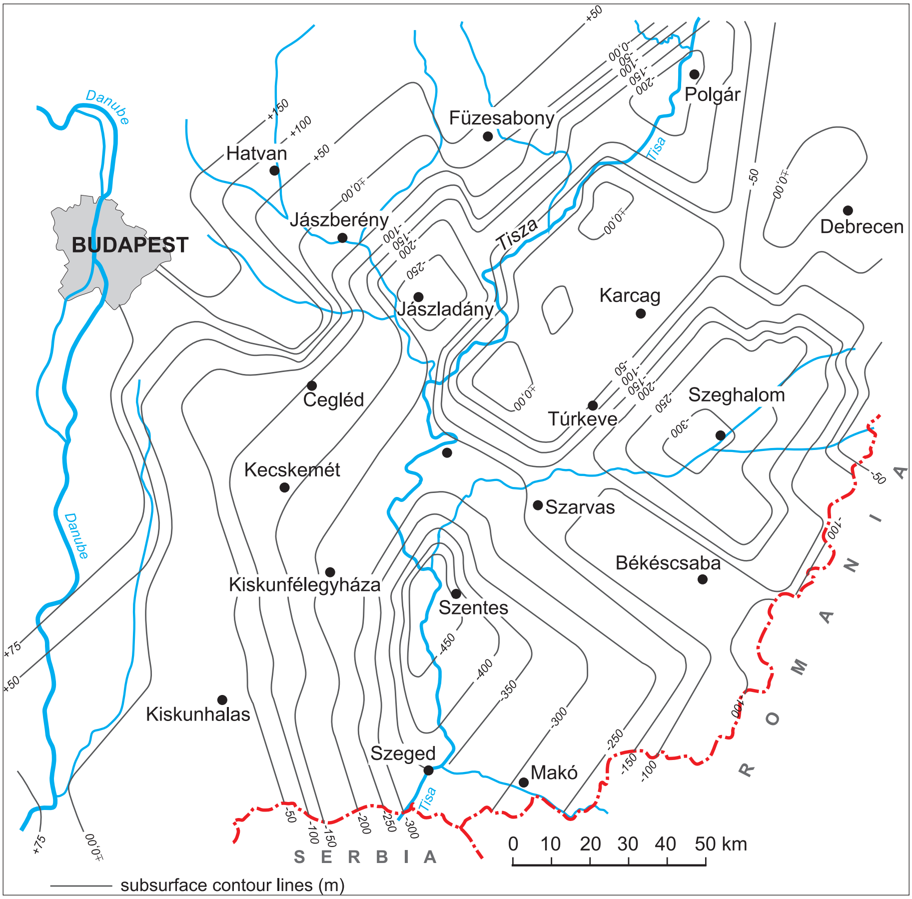


Fig. 2. Layers underlying Pleistocene sediments in the Great Plain (by Urbancsek, J.)

A gradual increase in the thickness of the Quaternary sequence from the margins inwards the Pannonian Basin testify to the subsidence lasting from the Badenian up to the present. The Fertő Lake, Hanság, and the middle and lower Rába Valley belong to this area.

Sinking accelerated in the southern part of the Jászság in the mid-Wurm as this area represented the base line attracting water courses flowing from the Cserhát and Mátra mountains. The lower reaches of the Zagyva shifted eastward continuously and the Tarna with its minor tributaries turned into south-west and abandoned the area of Nagykunság.

Subsidence and uplift have not spread all over the plains and mountains. These movements of contrary direction occurred in larger blocs (Mezőföld, Baranya, Somogy, Nyírség etc.) or have taken place in depressions

(Jászság, Little Plain, South Tisza Basin, Körös Basin, alluvial cone of Sajó filling up a hole-like depression).

Vertical movements are known fairly well from absolute chronological investigations, so Pleistocene sediments can be dated and the rate of subsidence determined. Based on paleomagnetic studies carried out in the Körös Basin the latter has been 0.2 mm per annum for the last 2.5 million years by Rónai, A. (1964). Evidence of horizontal displacements however is scanty and ambiguous.

In places where tectonic phenomena were missing, only indirect conclusions were made (based e.g. on travertine occurrences, orographic and stratigraphic position of cave horizons, deformations of fluvial terraces, thickness of young deposits).

On foothills, hills and plains tectonic lines could be drawn geomorphologically with the support of the intense formation of river valleys during the Holocene, their incision, asymmetry and downcutting of recent river valleys, the extension of depressions in mountain foreland and the rate of sedimentation within them, captures, and last but not least of the variability in the topography.

The present study was aimed at identification and mapping of seismotectonic zones and fault lines active during the Pleistocene, Holocene and in historic times. Quakes in the Carpathian Basin were analysed on the basis of the map depicting the earthquakes between 456 and 2007 (Tóth, L. *et al.* 2006; Réthly, A. 1952). Place of occurrence, focus and magnitude of quakes were verified. Young seismotectonic lines, depressions and zones, supported by data and also inferred and ambiguous fracture structural elements were identified and signified in the map (Tóth, L. *et al.* 1989).

Landscapes, geomorphology, Pleistocene fault lines and depressions in the Danube Plain and Danube–Tisza Interfluve

Micro-landscapes within the studied area have been demarcated according to characteristic landforms, natural endowments and to features of flat topography. The boundaries of micro-landscapes are running along structurally labelled lines. Micro-landscapes were indicated below with codes as of the Inventory of Natural Micro-landscapes:

1\. 1. 21. Csepel Flat, 1. 1. 22. Solt Flat, 1. 2. 11. Gerje–Perje Flat, 1. 2. 12. Pilis–Alpár Sand Ridge, 1. 2. 13. Kiskunság Sand Ridge, 1. 2. 16. Kiskunság Loess Ridge, 1. 4. 1. North Mezőföld, 1. 4. 21. Middle Mezőföld (Ádám, L., *et al.* 1959).

Indicating orographic relief types, platforms planated by fluvial erosion and covered by Pleistocene terrestrial deposits (typical and sandy loess, fluvial and wind blown sands) were analyzed by region (e.g. Mezőföld).

Pleistocene alluvial cones covered by Pleistocene–early Holocene wind blown and fluvial sand, and loessy sediments of various extension were surveyed on the interfluvial surface between the Danube and Tisza.

On the territory of Pest Flat (half-basin) built of Pliocene–Pleistocene–Holocene alluvial fans and dissected by fluvial valleys paleogeographic studies on the Danube Flat and within the Danube–Tisza Interfluve meso-landscape also prove to have been productive. A geomorphological map (*Figure 3*) at 1: 200 000 scale shows landscape boundaries and lithological buildup of the high bluff along the Danube at the Mezőföld from Ercsi and Bölcske down to Madocsa and over the Great Plain eastward up to Cegléd and Kecskemét with the landforms and conditions of neotectonism.

Major fault lines formed during the Pleistocene in the Carpathian Basin on the present territory of Hungary can be classified into three groups:

1. Established faults;
2. Faults with some evidence;
3. Inferred fault lines.

A fourth group of zones are represented by depressions.

Fault lines were separated according to geomorphological criteria, such as valley asymmetry; change in water flow direction and captures; asymmetry of sediment layers of identical age and of the same buildup; sharp turns of water courses and their relation to thermal springs and quakes. The fault lines visualized are listed in territorial order, their types can be identified by map representation and numbering in textual listing.

Depressions

1. Adony Depression: this embayment was also shaped by the lateral erosion of the Danube at the end of the Pleistocene and in the early Holocene. Changes in channel configuration and amplification of erosional activity have resulted from late Pleistocene movements as well (Fodor, T. *et a*l. 1981; Hertelendi, E. *et a*l. 1989; Marosi, S. and Schweitzer, F. 1991).

2. Kalocsa Depression: also related to the Danube structural zone. The river had reached its base line in the depression of South Great Plain.

3. Kecskemét Trench: stretches between two fault lines running in north-west to south-east direction. It is a well identifiable area on the basis of map of sediment thickness compiled from the borehole data of the Alföld.

4. Cegléd Depression: its existence is made probable by a quake focus at Cegléd and a considerable thickness of Pleistocene deposits established from the borehole data. Its oval shaped boundaries trend towards the Jászság Depression.

5. Adony–Kecskemét Depression: is probably bounded by the continuation of the fault line with the Benta Stream flowing towards the Adony

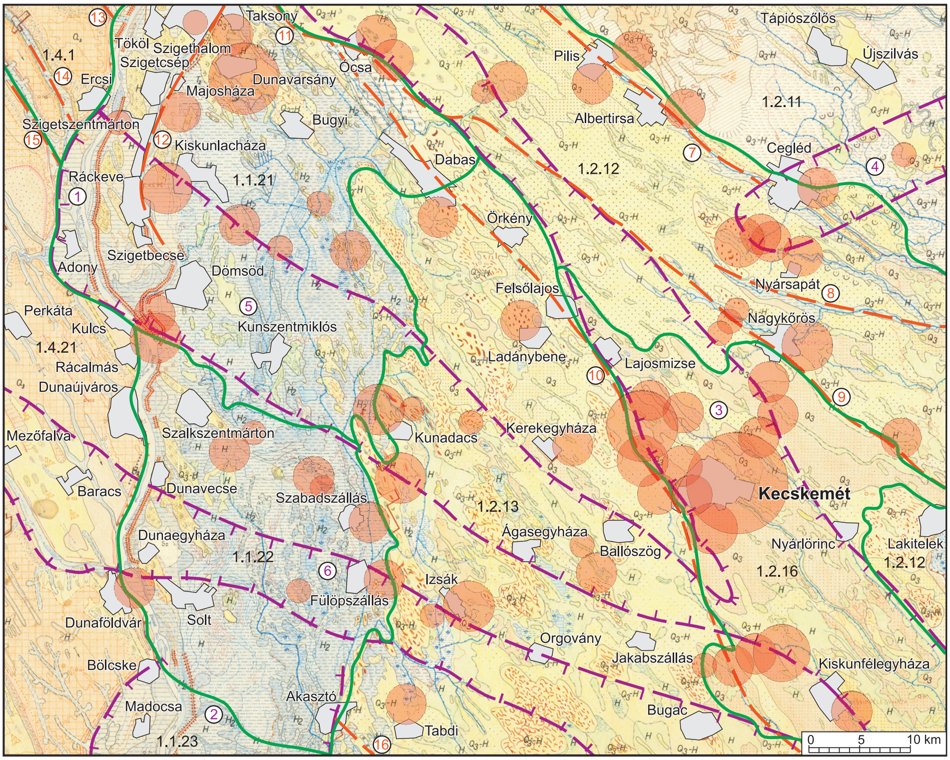


Fig. 3. Geomorphological map of the Danube Flat and of the northern part of the Danube–Tisza Interfluve (by Balogh, J. and Schweitzer, F. 2008)

embayment, of the Zsámbék–Perbál fault and of the Váli-víz fault, and includes Kecskemét quake focus and Pleistocene underlying sediments. Danube was flowing on this surface during the Pleistocene.

6. Dunaföldvár–Kiskunfélegyháza Trench: is positioned by sedimentological differences between the Danube bluff north and south of the Dunaföldvár bridge, Kiskunfélegyháza quake focus and by Pleistocene sediment thickness map constructed from borehole data.

Fault lines

7. Gerje–Perje fault line: proved between Cegléd and the stream mouth by quake focus at Cegléd and inflexibility of the valley.

8. Körös-ér fault: is a probable line seemed to be proven by a large bend of the Tisza at Vezseny.

9. Csukás-ér fault: a section between Kecskemét and the mouth, proven by quake focus at Kecskemét and inflexibility of the valley.

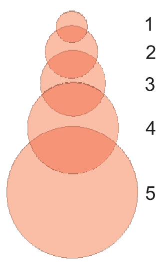
LEGEND

- Alluvial sand in flood plain
- Alluvial mud
- Alluvial clay
- Alluvial silty sand
- Alluvial sandy silt
- Flood plain sediment undistinguished
- Peat, peat mud
- Boggy clay, meadow clay
- Loess, loessy sand, sandy loess
- Wind blown sand
- Sand blanket
- Stratified derasional solifluctional slope loess
- Building up slopes shaped by derasional processes
- Deteriorating slopes shaped by derasional processes
- Low flood plain
- High flood plain
- Oxbows and meandersin flood plain
- Terrace island
- Alluvial fan
- Gravel terrace
- Blown sand dune undistinguished
- Point bar
- Coastal dune
- Longitudinal dunes mantled by loess
- Dammed minor basins filled with loose sediment
- Alkali flats
- Minor depressions on accumulated surface
- Minor elevations on accumulated surface
- Derasional valleys
- Erosional gully (dry valley)
- Minor stream valley
- Terraced valley undistinguished

- Inactive steep high bluff
- Inactive steep low bluff
- Blow-out and deflation hollow
- Erosional-derasional ridges, gentle slope segment
- Derasional terrace surface, derasional ridges
- Platform, plateau
- Major dykes, embankments
- Tumulus, artificial mound
- Contour line (by 50 m)
- Major heights
- Permanent stream
- Intermittent stream
- Canal 1st class
- Canal 2nd class
- Canal 3rd class
- Lake (permanent)
- Lake (intermittent)
- Intermittently waterlogged area
- Swamp (intermittent)
- Q Quaternary landforms and surface undistinguished
- Q_1 Lower (Early) Pleistocene
- Q_2 Middle Pleistocene
- Q_3 Upper (Late) Pleistocene
- H Holocene landforms and surface undistinguished
- H_1 Early Holocene
- H_2 Late Holocene
- H_3 Recent
- Settlement
- 1.2.21 Landscape subdivision
- Landscape boundary
- Depression
- Fault line

1. Adony Depression
2. Kalocsa Depression
3. Kecskemét Trench
4. Cegléd (quake focus) Depression
5. Adony–Kecskemét Depression
6. Dunaföldvár–Kiskunfélegyháza Trench
7. Gerje–Perje fault line
8. Körös-ér fault line (hypothetic)
9. Csukás-ér fault line
10. Budapest (Ördög-árok Valley)–Soroksár–Alsónémedi–Kecskemét fault line
11. Ördög-árok fault line
12. Dunaharaszti–Ráckeve fault line
13. Benta Stream fault line
14. Zsámbék–Perbál fault line
15. Váli-víz fault line
16. North Bácska fault line

MAGNITUDE



Source: Earthquakes in the Carpathian Basin (456–2007) eds. Tóth, L. and Mónus, P.

10. Budapest (Ördög-árok Valley)–Soroksár–Alsónémedi–Kecskemét fault: is a line still active at present, along which the quake of 1956 occurred with focus at Dunaharaszti *(Photo 1–2)*. At the mountain section (Ördög-árok) evidence of the fault provided by orographic positions of the terrace valleys, superimposing travertines and cave horizons. In the plain section (Pest Flat, northern part of the Danube–Tisza Interfluve) deformed shape of late Pleistocene–Holocene Danube channels (terraces II/a and II/b) and a former south-east direction of flow turning into south and then south-west and a sharp turn of Dong-ér Stream add to the morphological features to confirm its existence.

11. Ördög-árok fault: connecting a row of intramontane basins in the Buda Hills; orographic position of travertines and deformed terraces testify to movements during the Pleistocene and Holocene. Its continuation is the chan-

Photo 1. Earthquake aftermath in Dunaharaszti in 1956 (M 5.6; I0 8). Some 3,144 buildings were damaged out of the 3,500 in the epicentral area. Fall of gable walls as shown in the picture were typical building damage in an area of about 37 km radius. *Source:* Geodetic and Geophysical Research Institute of HAS

Photo 2. The 1956 earthquake had the strongest effects in the epicentral area Dunaharaszti, Taksony and Szigetszentmiklós. The picture was taken at the cemetery of Taksony. *Source:* Geodetic and Geophysical Research Institute of HAS

nel of the Soroksár Danube branching south-eastward with quake focuses at Dunaharaszti and Alsónémedi.

12. Dunaharaszti–Ráckeve fault: indicated by the differences in geological-geomorphological buildup between the opposite banks of the Danube.

13. Benta Stream fault from Zsámbék up to the mouth: proven by the escarpment of Tétény Plateau and quake focus at Zsámbék.

14. Zsámbék–Perbál fault: having been formed since the end of the Mesozoic until recently in the western foreland of the Buda Hills horst-graben structure that has sunk to 1,500 m depth in some places. Fractures of the Mesozoic range are reflected in the surface landforms characterized by elongated asymmetric ridges, tilted plateaus, V-shaped stream valleys. The graben fault is bounded by the Zsámbék fault from the west. It should be a repeatedly rejuvenated fault line accompanied by earthquakes mentioned in historical documents (ruins of the church in Zsámbék).

15. Váli-víz fault: stretches along the total length of the water course. The different elevation of limestones of similar age on two sides of the trench between the Vértes and Gerecse mountains and the asymmetry of the valley are its indications. The quake focus at Alcsút is an additional evidence.

16. North Bácska fault: Kalocsa–Kőrösér principal canal. Geological buildup and subsurface geological structure strongly differing from that of the northern part of the Danube–Tisza Interfluve are the proof of its existence.

Geomorphological investigations in the study of neotectonic events

In order to make the geomorphologic and tectonic models more precise it is proposed to conduct paleogeomorphic, litostratigraphic, chronological and sedimentological investigations of the geological sediments of the Danube bluff flanking the Mezőföld.

In the course of profile construction for the exposures and their stratigraphic analysis attention will be drawn to heretofore unknown features of geomorphological asymmetry showing close relationship with neotectonics (e.g. inversion of relief).

Thematic paleogeomorphological maps are to be compiled on areas with a higher frequency of earthquakes such as those having occurred at Fülöpszállás, Izsák, Jakabszállás etc.

Surface dynamics are to be studied in sections along the Danube bluff and loess covered parts of the Great Plain. In loess sequences along with the typical loesses a cyclic occurrence of paleosols will be tackled and paleorelief is to be unfolded. Spatial and temporal analyses of fossil soil horizons might explain geologic and recent processes of landform evolution that might be important for quality assurance.

Besides the description of Quaternary sequences the research of seismites is essential. Palaeoquakes are to be studied in the environs of the medieval edifices of Dunakömlőd, Dunaföldvár and a Roman castrum, limes settlements and fortifications at Dunaújváros, where the rim of high bluff retreated by 50–250 metres over the past 1,000 years. Correlation of sediments, and survey of soil deformations needs a detailed geologic and geomorphologic profiling. Semipedolite is a type of cryoturbation that can be described in boreholes; it is an outcome of a solifluction phenomenon and probably is a proof of a neotectonic event.

Paleogeographic conditions are to be mapped according to the geologic and hydrogeological borehole cadasters and the former Pliocene–upper Pannonian surface is reconstructed on the basis of the data. There will be investigated the relationship between the surface of underlying sediments and that of the actual topographic features in relation to the frequency of the recent earthquakes and change in chloride contents in relation to the movement of the basement in the Tengelic Depression, Sárköz etc.

A survey is to be conducted on the triggers, and rate of subsidence of the buildings in relation to the subsurface paleotopography. There is a well-known connection between landforms (terraces, terrace-like forms) and neotectonic movements. Correlation analysis of terrace gravels, their spatial and temporal subdivision, and the determination of position of the terraces together with neotectonism establish links between changes in paleohydrography and landform evolution.

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Ukraine in Maps

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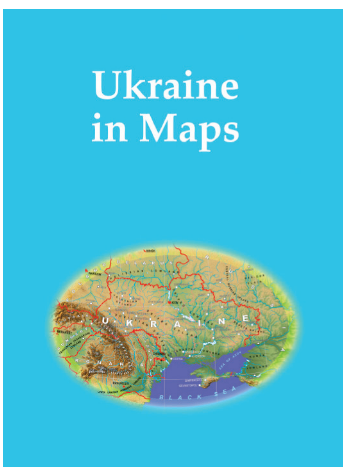
Since the disintegration of the USSR, the Western world has shown an ever-growing interest in Ukraine, its people and its economy. As the second-largest country in Europe, Ukraine has a strategic geographical position at the crossroads between Europe and Asia. It is a key country for the transit of energy resources from Russia and Central Asia to the European Union, which is one reason why Ukraine has become a priority partner in the neighbourhood policy of the EU. Ukraine has pursued a path towards the democratic consolidation of statehood, which encompasses vigorous economic changes, the development of institutions and integration into European and global political and economic structures. In a complex and controversial world, Ukraine is building collaboration with other countries upon the principles of mutual understanding and trust, and is establishing initiatives aimed at the creation of a system that bestows international security.

This recognition has prompted the Institute of Geography of the National Academy of Sciences of Ukraine (Kyiv) and the Geographical Research Institute of the Hungarian Academy of Sciences (Budapest) to initiate cooperation, and the volume entitled "Ukraine in Maps" is the outcome of their joint effort. The intention of this publication is to make available the results of research conducted by Ukrainian and Hungarian geographers, to the English-speaking public. This atlas follows in the footsteps of previous publications from the Geographical Research Institute of the Hungarian Academy of Sciences. Similar to the work entitled South Eastern Europe in Maps (2005, 2007), it includes 64 maps, dozens of figures and tables accompanied by an explanatory text, written in a popular, scientific manner. The book is an attempt to outline the geographical setting and geopolitical context of Ukraine, as well as its history, natural environment, population, settlements and economy. The authors greatly hope that this joint venture will bring Ukraine closer to the reader and make this neighbouring country to the European Union more familiar, and consequently, more appealing.



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