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## LANDSLIDE HAZARD INDUCED BY RIVER UNDERCUTTING ALONG THE DANUBE (\*\*)

**Abstract:** LÓCZY D., BALOGH J. & RINGER Á., *Landslide hazard induced by river undercutting along the Danube.*

Since the 1964 landslide of a loess bluff affecting the iron and steel plants of Dunaújváros several papers have been written on the parameters to be considered for short-term bluff stability. The aim of the present investigation is to reveal the relationship between landslides, undercutting and other processes of bluff recession. Opinions agree that undercutting is due to the gradual westward shifting of the Danube from its Pleistocene alluvial fan on the Danube-Tisza Interfluvium to its present valley. The approximately N to S course is not directly explained by a single, major fault-line. A local subsidence S of Budapest is probably responsible for an initial change of course and the undercutting of the margin of the Mezőföld loess-mantled plain has been maintained subsequently by river mechanism and the weak Coriolis force. The most effective mechanisms of bluff retreat along undercut river bank sections are collapse of slabs detached, removal by runoff in the period of above-zero temperatures, frost shattering in winter and occasional landslides. Before flood control measures the Danube had been regularly removing part of the toes of previous landslides and thus generated renewed instability. Increased infiltration due to human settlement aggravated the landslide hazard. Archaeological evidence suggests that the previously proposed bluff retreat of 3-5 m per 100 years may be valid for periods of undercutting only, while human interference has reduced the recurrence interval of landslides and considerably accelerated recession along certain sections. By bank revetment the Danube is now prevented from undercutting the bluff and consequently groundwater conditions have become the primary control of the landslide hazard.

KEY WORDS: Landslides, River undercutting, Neotectonics, Loess bluffs, Danube.

**Riassunto:** LÓCZY D., BALOGH J. & RINGER Á., *Rischio di movimenti di massa indotti da erosione basale lungo il Danubio.*

Movimenti di massa sulle scarpate costituite da loess, che interessano alcune infrastrutture in ferro ed acciaio della città di Dunaújváros sono stati segnalati fin dal 1964. Da allora sono stati scritti molti articoli a proposito dei parametri da prendere in considerazione per garantire la stabilità a breve termine di tali scarpate. Lo scopo della presente indagine è di chiarire le relazioni intercorrenti fra movimenti di massa, erosione basale ed altri processi che influenzano l'arretramento delle scarpate. Varie opinioni concordano nel ritenere che l'erosione basale è causata dal progressivo spostamento del Danubio dal conoide alluvionale pleistocenico interposto fra il

Danubio stesso e il Tibisco (Tisza) fino al corso attuale. L'andamento approssimativamente Nord-Sud di tale corso non è spiegabile come direttamente influenzato da una singola linea principale di faglia. Una subsidenza locale a Sud di Budapest è probabilmente responsabile di uno spostamento iniziale del corso; inoltre l'erosione basale del margine della pianura coperta di loess di Mezőföld è stata successivamente mantenuta attiva da una certa dinamica fluviale e da una debole forza di Coriolis. La dinamica più attiva di arretramento della scarpata lungo tratti di sponda erosi alla base è costituita dal collasso di «porzioni» staccate, dalla loro evacuazione da parte delle acque di scorrimento superficiale nei periodi con temperature superiori allo zero, dalla frammentazione ad opera del gelo in inverno, e da frane occasionali. Prima che fossero presi provvedimenti per il controllo delle piene, il Danubio asportava la parte terminale dei corpi di frana, provocando nuove situazioni di instabilità. L'aumento dell'infiltrazione derivato dall'espansione degli insediamenti antropici ha aggravato il rischio di frana. Evidenze archeologiche suggeriscono che il già stimato arretramento delle scarpate di 3-5 m ogni cento anni può essere ritenuto valido per periodi nei quali era attiva la sola erosione basale, in condizioni naturali, mentre l'interferenza antropica ha interrotto gli intervalli di ricorrenza delle frane ed accelerato considerevolmente l'arretramento lungo determinati tratti di sponda. Tramite la protezione delle sponde con manufatti, l'erosione basale del Danubio è ora ostacolata, e di conseguenza le acque sotterranee sono divenute il principale fattore influenzante il rischio di frana.

TERMINI CHIAVE: Frane, Erosione fluviale, Neotettonica, Ripa di erosione in loess, Danubio.

### INTRODUCTION

It is striking on the map of the Danubian catchment (fig. 1) that along some stretches the largest rivers, the Danube and the Tisza follow a rather rigid N to S course. While the Lower Tisza runs in a tectonic graben, revealed by boreholes, in the case of the Danube no major tectonic control on alignment can be proved over more than 100 km distance of Budapest (At Budapest itself the river follows the marked 'Buda Thermal Line' fault).

For most of the Upper Tertiary and Quaternary periods the central part of the Carpathian basin (the Great Hungarian Plain) has been affected by general subsidence. This movement, however, has considerably varied in intensity spatially and temporally and interruptions also occurred locally. Although the overall sequence of events (intensifying

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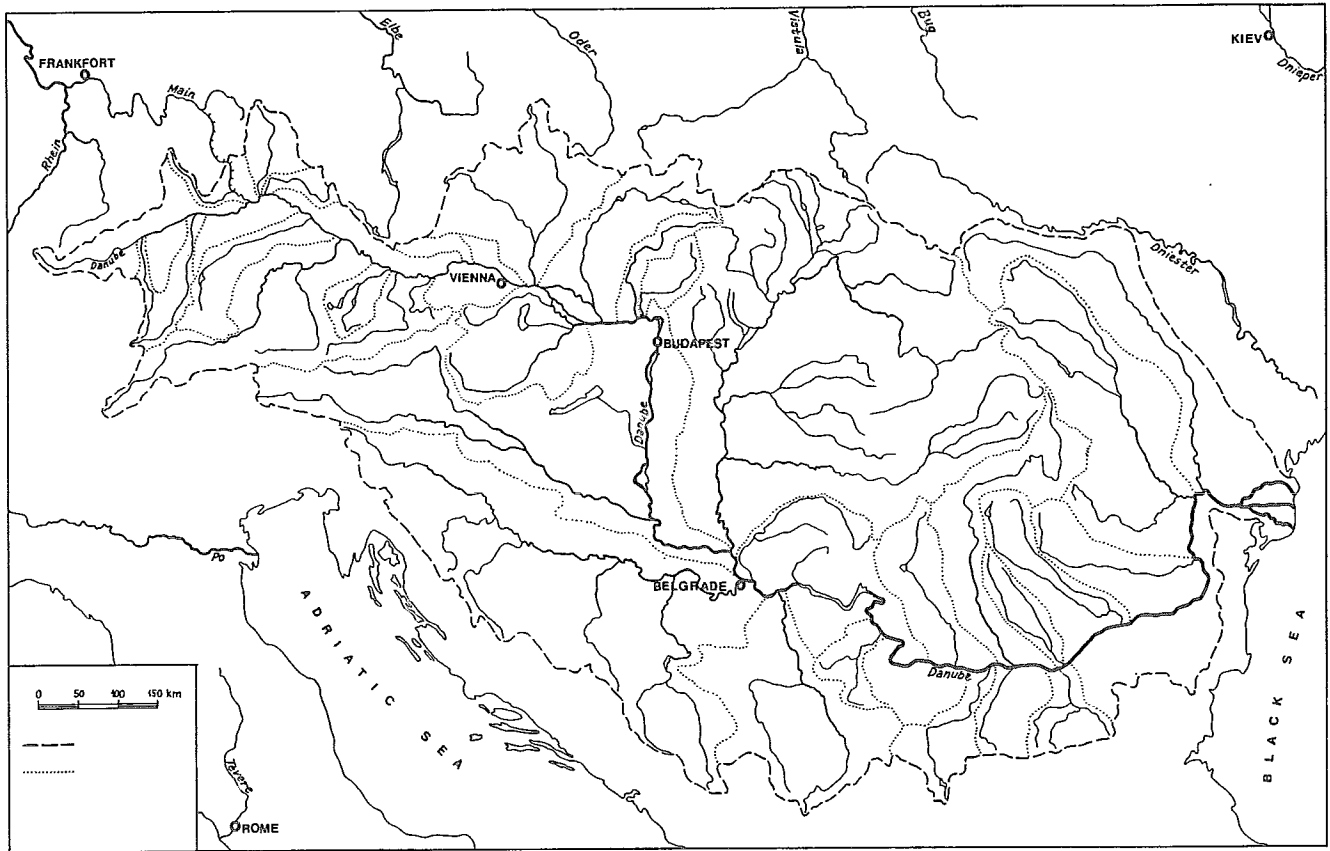


FIG. 1 - Drainage of the Danubian catchment.  
 - - - Boundary of Danubian catchment  
 ..... Boundary of catchment of first order stream

subsidence accompanied by volcanic activity from the Eocene to the Pliocene and marginal downwarping in Quaternary times) calls for a plate tectonics explanation, no detailed analysis of regional crustal dynamics has been made. However, it seems probable that, at least in outline, the adjustments of drainage have been governed by neotectonic movements ever since the infilling of the Pannonian lake (ca. 3-4 million years ago).

How the Danube channel acquired the present position running at the base of the Mezőföld loess plain margin, to what extent undercutting influences landslides and other processes contributing to the retreat of the loess bluff, these are the questions to which general (mostly hypothetical and preliminary) answers are proposed in the paper. Geological, archaeological and historical map evidence was applied for making the statements.

The landslides of 1964 at Dunaújváros, 1970 at Dunaföldvár and 1976-77 at Dunakömlőd point to the practical use of this research.

#### DRAINAGE CHANGES AND LOESS ACCUMULATION

Certain marker rock types exclusively occurring in



FIG. 2 - Early Pleistocene drainage of the Carpathian basin (after BORSY, 1987).

Danubian deposits allow the tracing of the changing course of the river. When the area of the present plain became mainland, the Proto-Danube followed a NW-SE course (PÉCSI,

1959, 1971a). Carrying a heavy and coarse sediment load from the rapidly uplifting mountains and accommodating it in a channel of high width/depth ratio with banks built of loose material (DURY, 1976), the river formed a *braided system* (fig. 2). The Pleistocene saw the accumulation of a vast alluvial fan with a rather steep slope, a gradual westward shifting of the channels and the relative strengthening of the more western branches (RÓNAL, 1985). The latter must have been characteristic of the drier interglacial times, while in the glacials, with reduced discharge, the eastern channels were unable to move their sediment load and loess accumulated on interfluvial surfaces. The western channels had recharge from waters stored in the karstifying mountains of Transdanubia and probably showed meandering mechanism. By the last third of the Pleistocene, the relative elevation of the sand interfluvium between the Danube and the Tisza had caused the shifting of the main axis of the Danubian braided system almost 20° to the W. In postglacial times increased water discharge resulted in considerable incision, the depth of which was limited by the coarse Pleistocene gravel layers (SOMOGYI, 1967). The number of anastomosing channels was reduced considerably (fig. 3).

ting (SOMOGYI, 1983). Spreading forests in the watershed reduced load and regulation even prevented the braiding of

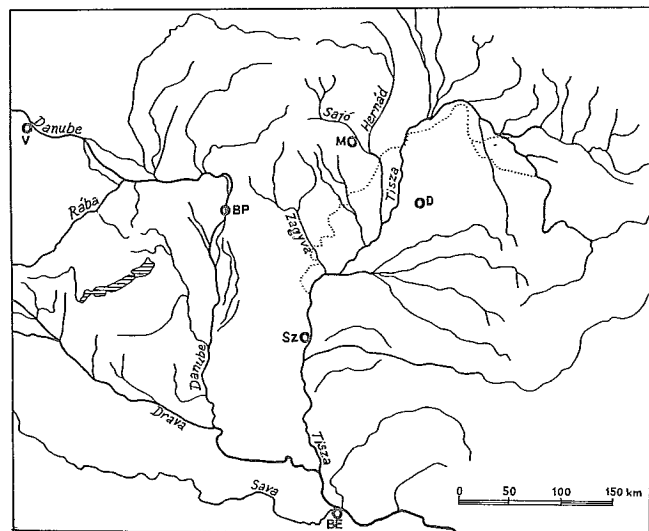


FIG. 3 - Drainage at the beginning of the Upper Pleniglacial (after BORSY, 1987).

Two sites confirm the assumption that this reduced braided system had survived to historical times: two hillocks rise from the flat alluvial surface of the Danubian plain (the Solti-halom, 124 m, and the Tétel-halom, 114 m) and on their tops remnants of the loess and fluvial mantles are preserved. Moreover, the topography and sediment fill of the embayments and of the Sárköz region testify that the river once followed even more western courses than today.

The present river mechanism of the Danube along the Mezőföld section is meandering and moderately accumula-

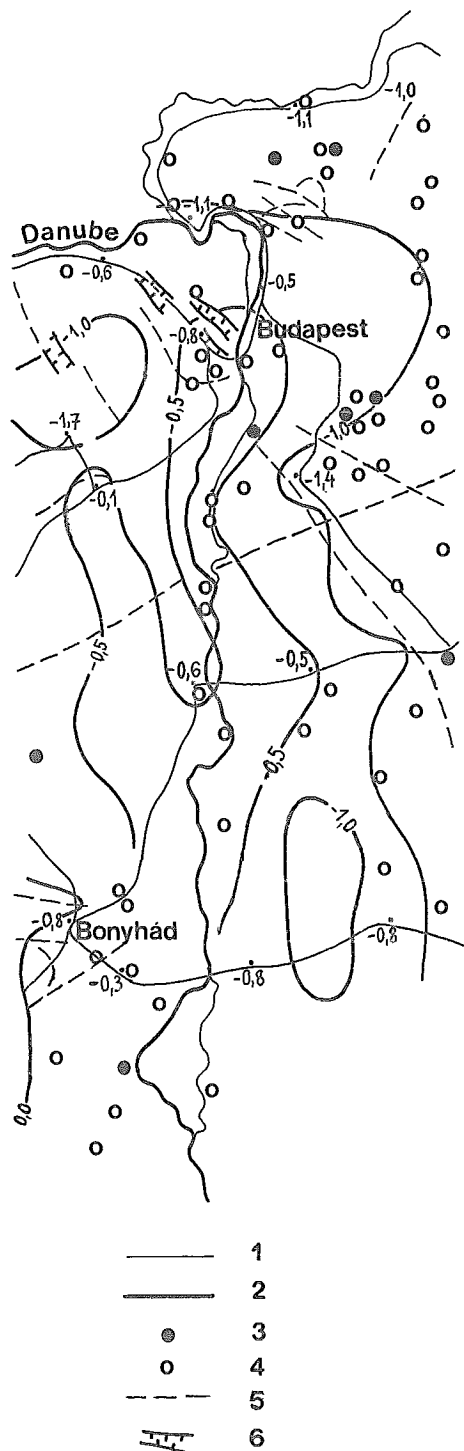


FIG. 4 - Recent vertical crustal movements along the Danube (after JOÓ, to be published in the new National Atlas of Hungary) - 1 = Lines of repeated levellings; 2 = Rate of recent vertical crustal movements, mm per year; 3 = Epicentres of major earthquakes; 4 = Epicentres of minor earthquakes; 5 = Hypothetical faults mainly in the basement; 6 = Rift valleys and steep faults.

the main channel. However, out of the collapsed and slumped bluff material numerous shoals and islands are being built and divide the channel.

Local fault-lines and depressions have played an important part in drawing the channels to the base of the Mezőföld with thick loess cover (up to 100 m thickness, cfr. ÁDÁM & *alii*, 1959). The confluence of the two branches embracing the Csepel island show the centre of one of the depressions and the epicentres of shallow earthquakes are aligned along a NNE-SSW fault-line.

The map of recent crustal movements (fig. 4) indicate 0.5 mm per year subsidence for this area, while from the thickness of the Quaternary sequence on the left bank of the Danube, only a rate of 0.1 mm per year can be inferred. (The surveying measurements may record the rate of compaction of sediments on floodplains, where after river regulation no fresh deposition takes place). An important observation is that on the right bank to the S of the Csepel island the base level of the Quaternary sequence tends to rise (FODOR & *alii*, 1981). At Paks the Danube (at 85 m above sea level) undercuts layers of littoral deposition and at least 2 million years old (min. 0.1 mm per year Quaternary uplift!).

These data point to the existence of a fault set under the Danube. As the area is not perspective for hydrocarbon exploration, these faults have not been studied by seismic surveys.

## THE CONSEQUENCES OF BANK UNDERCUTTING

On a geological time-scale, the main agent of the retreat of the 30-60 m high loess bluff had been undercutting by the river (until the last-century regulation). It is assumed that undercutting had varied spatially and temporally before groynes were employed in the channel to divert the line of maximum depth and velocity from endangered banks (fig. 5). Channel changes have been considerable even in historical times.

The site of a monastery (indicated on old maps as «Monstor Butibulas») serves as a well-identifiable point to monitor these changes. The monastery of St. Pantaleon was built in the 11th-12th centuries in the northern part of the island, lying to the N of the village Pentele, named after the saint (ÉRSZEGI, 1975). In the 17th-18th centuries the monastery, abandoned during the Ottoman Occupation, was inundated and in the last century its ruins were visible only at very low water stages. In 1902 the ruin was regarded as an obstacle in the new navigation route and was blown up and the channel dredged.

The geomorphological map (fig. 6) shows the location of the present Danube channel along the eroding margin of the Mezőföld loess plain. South of Dunaújváros (fig. 6) has been selected for the study of bluff erosion. The 28 m high loess bluff there represents the situation for undercut sections, since the Danube had been constantly removing part of the debris slope before two groynes were constructed.

The most important processes of erosion observed during field study are the following:

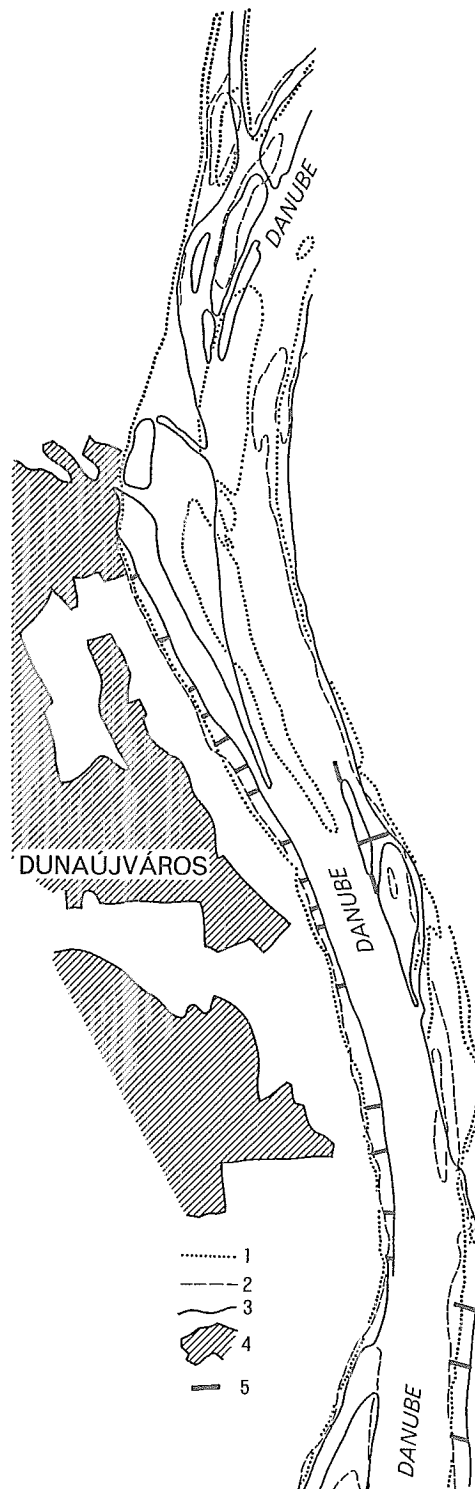


FIG. 5 - Changes in channel banks due to regulation (from the Vizrajzi Atlasz sorozat 11. Duna 2. Szob-Dunaföldvár, VITUKI, 1970) - 1 = River bank on the 1824-1829 map by HUSZÁR; 2 = River bank after the 1899-1904 survey by the Hydrographic Department of the National Water Construction Authority; 3 = Present-day river bank; 4 = Built-up area; 5 = Groyne.

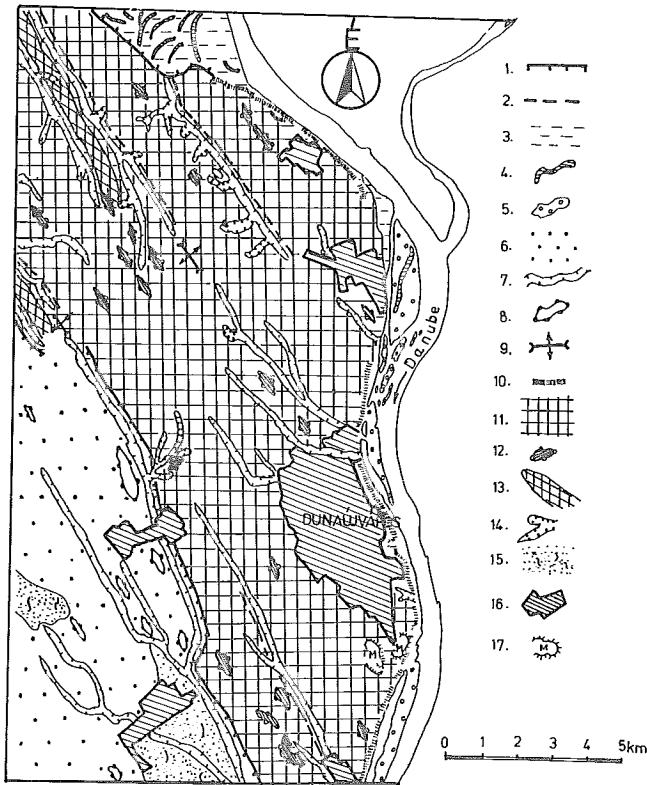


FIG. 6 - Geomorphological map of the right bank of the Danube at Dunaújváros (Redrawn by BALOGH, after ÁDÁM) - 1 = Boundary of tectonic basin; 2 = Fault-line; 3 = Flood-plain; 4 = Infilled oxbow; 5 = Shoal; 6 = Loess-mantled alluvial fan; 7 = Erosional valley; 8 = Erosional residual hill; 9 = Valley divide; 10 = Bluff; 11 = Loess-mantled plain; 12 = Residual hill; 13 = Elevated ridge; 14 = Dells and niches; 15 = Blown-sand surfaces with dunes; 16 = Built-up area; 17 = Spoil heap.

- gully incision and
- slumping.

The loess along this section has a high sand content in some horizons (PÉCSI & *alii*, 1979). Detailed studies revealed the lithological, hydrogeological, hydrological and meteorological conditions of bluff erosion (KÉZDI, 1951, 1969, 1970, 1978; GALLI, 1952; DOMJÁN, 1952; EGRI & PÁRDÁNYI, 1968; KARÁCSONYI & SCHEUER, 1969, 1972a, b; PÉCSI, 1971b; PÉCSI, JUHÁSZ & SCHWEITZER, 1976; SCHWEITZER, 1978; PÉCSI, SCHWEITZER & SCHEUER, 1979; FODOR, SCHEUER & SCHWEITZER, 1982). On the bluff surface sand grains are loosened during dry periods and removed by wind. Sheet-wash is most active when the free face is already wet or during heavy showers on the upper segment of the steep (85°) slope. It is interesting to note that splash erosion is not significant along this E slope. Rain-drop impact is very rare as frontal rains come from the W. During and after rains water flows along roots and the eroded material, arriving at the dry, hydrophobic loess surface, forms stalactite-like features similar to those seen on a candle.

During the winter frost shattering removes material in scales. The true significance of this process is difficult to estimate and, therefore, authors designed a simple measurement to find data on the amount of material removed. The method comprises the interpretation of stereopairs of colour photographs for the surface areas affected and the thickness of the scales. (The unusually mild winter of 1987-88 was not suitable for obtaining representative data).

Vertical fissures detach large slabs from the wall. After floods and during earthquakes spalling may be especially effective. Human intervention has highly increased both fissuring and surface runoff on the bluff margin and thereby given rise to intensified piping.

- granular disintegration,
- sheet-wash,
- shattering in scales,
- fissuring and spalling,

#### LANDSLIDE MECHANISM

The most disastrous events of bluff recession are the landslides. In loess compressive strength depends on the co-

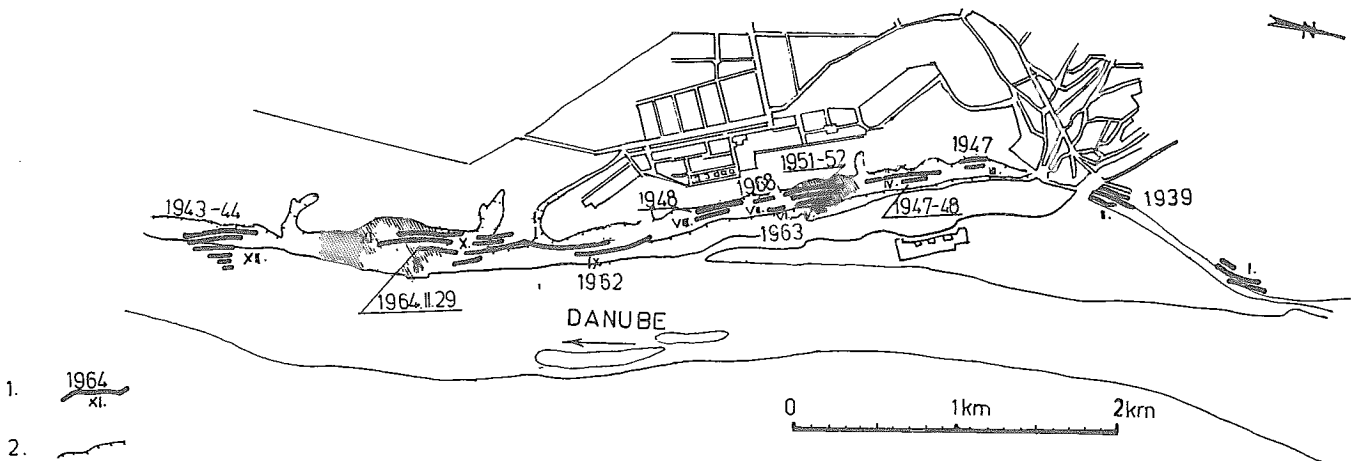


FIG. 7 - Localities and dates of recent landslides along the Dunaújváros bluff (by VARGA) - 1 = Major landslide with date; 2 = Gradual retreat (1950-1965).

herence between grains, which is a function of moisture content and void ratio. On the surfaces of subhorizontal Upper Pannonian layers the saturation of the overlying loess masses (attained in some days or weeks) increases earth pressure. The resulting slumps (fig. 7) involve the whole thickness of the Pleistocene series (as in the case of the 1964 landslide). Here the characteristics of rapid movements are demonstrated on the example of the best-studied landslide at Dunaújváros.

The causes of landsliding and the interactions involved are summarized in the following (KÉZDI, 1978):

1. As a result of rising groundwater level (communicating with the Danube) and increased hydraulic gradient, horizontal earth pressure had grown.

2. Simultaneously, the higher groundwater table led to increased neutral strength and reduced shear strength.

3. Over the horizontal critical plane the larger hydraulic gradient resulted in increased percolation pressure and, consequently, horizontal shear strength decreased.

4. Reduced shear strength along the critical plane induced deformations (dislocation of grains). This creep had a positive feedback further reducing shear strength.

5. Consequently, over a critical surface friction diminished to minimum and horizontal forces continued to act. Stress shifted and shear failure emerged. The shift of earth pressure deforms the end of the failure surface closer to the Danube, where rotational piling up is observed in the channel.

The above described mechanism worked most strikingly during the most disastrous landslide on February 29, 1964. Early morning above no 1 pumping station of the iron works, a 1300 metre section of 15-20 m width was affected by movement. The station was displaced over 33 m distance towards the Danube and the quadruple 1000 m diameter main pressure pipes were broken. Piling up in the Danube channel resulted in shoal accumulation. According to the data from the Institute for Geodesy and Geotechnics, nearly 10,000,000 m<sup>3</sup> of earth slumped down. (Fortunately, the disaster did not involve a toll in human life).

The recurrence interval of slumps has also been reduced significantly in the wake of human activities. Historical evidence (the earliest from 1092) supports that earthquakes have also functioned as triggering mechanisms for landslides (BENDEFY, 1972). The major slides are attributed to tectonic movements along SW-NE lines. The epicentres of the earthquakes are usually located in Slovenia, Croatia or S-Austria. Relying on the information from hydrological observations, expensive drainage measures were designed and implemented to produce groundwater depressions, bank revetment to stop undercutting and terracing to prevent bluff collapses.

## EVALUATION OF ARCHAEOLOGICAL EVIDENCE ON BLUFF RETREAT

Previously, it was proposed (DOMJÁN, 1952) that about 60 m was missing from the ramparts of the first-century Ro-

man *castellum* of Intercisa (today: Dunaújváros). This would have meant to 5 m recession per hundred years. A recent reconstruction (VISY, 1977), however, shows that only minor portions of the ramparts have into the Danube channel. Even if man-induced landslides are assumed to have taken place, a rate of not more than 1 to 1.5 m per 100 years seem to be acceptable. The other extreme is represented by experts of the Enterprise for Surveying and Soil Analysis, who, relying on data from this century, proposed the figure of 15 metres per 100 years as the rate of bluff recession. In our site of study the remains of a Bronze Age *tell* (circular fortified settlement) are clearly visible on the top of the bluff. Only 40 m of it is found to be missing; we are not sure, however, how close the Bronze Age settlement was originally built to the edge of the loess region, while the Roman fortress was located about 20 m away from it. The picture becomes more complicated if we also consider the losses other *castellae* along this stretch have suffered (VISY, 1977). Map evidence from the groundplan of one of these fortresses (Lussonium) suggests 5-25 m retreat since the 1778 mapping (2.5-12.5 m per 100 years). An important circumstance is that this fortress lies by an abandoned branch of the Danube in the Madocsa embayment.

Three various rates are planned to be estimated: (1) an overall rate on a geological time-scale (thousand years - ca 1-2 m per 100 years); (2) for periods of active undercutting (hundred years - ca 2-10 m per 100 years) and (3) a rate influenced by human interference (over the last 100 years - above 10 m per 100 years). In the tenfold difference between the rates, the disastrous consequences of man's activities on bluff stability are clearly reflected.

Although ample evidence exists for the intensification of bluff erosion during the last centuries, the true rates of retreat can only be calculated when the archaeological topography on this Mid-Danubian region will be collected and made available for evaluation.

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