ENVIRONMENTAL AND DYNAMIC GEOMORPHOLOGY

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ENVIRONMENTAL AND DYNAMIC GEOMORPHOLOGY

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Edited by

MÁRTON PÉCSI

This collection of papers is dedicated to the First International Conference on Geomorphology which was held in Manchester, September 1985.

Environmental geomorphology in recent years has started to play an increasing role in the technical design of establishments and in present-day agriculture as well as in regional and physical planning and rational land use management. Comprehensive research into landforms has undergone rapid changes during the last decade as far as fields of interest and objectives are concerned and this has involved a basic revision of concepts and methods of investigation.

An important objective of present geomorphological research lies in the assessment of various dynamic processes and landform equilibria to include not only the origin of landforms but the consideration and evaluation of the interactions between relief configuration and land use.

The papers are concerned with issues in conceptual geomorphology,

ENVIRONMENTAL AND DYNAMIC GEOMORPHOLOGY

CASE STUDIES IN HUNGARY

STUDIES IN GEOGRAPHY IN HUNGARY, 17

Research Institute of Geography
Hungarian Academy of Sciences, Budapest

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Contribution to the First International Geomorphological Conference

Manchester, September 1985

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MÁRTON PÉCSI

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PREFACE

This collection of papers is the contribution of Hungarian geomorphologists and physical geographers to the First International Geomorphological Conference in Manchester (September 1985) to promote the achievement of its ends.

Both the authors and the editorial board consider it timely to exhange experience about the resolved conceptual and practical tasks and future trends in the discipline between the geomorphologists of the world. On this occasion too, tribute is expressed to the initiators of the organization of the geomorphological congress and the organizing committee for their persevering efforts. The comprehensive research and assessment of relief has undergone rapid changes particularly in the last decade as far as the topics and purposes are concerned and this involves the revision of opinions on approaches as well as on the methods of investigation.

The applied trend which is recently called environmental geomorphology has aroused much attention and has achieved much recognition. The goal of this trend is to serve the purposes of regional planning, spatial organization and rational land use.

In the near future it will be possible that relief analysis for nature conservation and environmental protection purposes accelerates in global, regional and topological dimensions alike. The interpretation facilities of aerial and space images suitable for the observation of numerous phenomena and processes on the Earth surface will soon provide the conditions for the detection of changes in the physical and chemical states of relief and even of the geographical environment. This is promoted, among other factors, by the spreading of the application of systems theory and cybernetic approaches in the practice of relief analysis through remote sensing. Relief acquires an ever increasing role both in the technical design of establishments and in agriculture based on up-to-date agrotechnics. In Hungary environmental geomorphology has been developed to satisfy the practical demands from the above and from residences and production plants.

The relief is regarded as an organic part of the total geographical environment. Besides bearing natural objects and processes, the relief provides a setting for highly dynamic anthropogenic activity too and man-made terrain is more and more important in the function of the social environment.

An important objective of present geomorphological research is seen in the assessment of various dynamic deformations or lasting or temporary equilibria of the relief not only from the viewpoint of origin of forms. It is a primary task to consider and evaluate the interrelationship between the relief configuration and land use. To achieve this end, a change in attitude as well as the introduction of quantitative methods and the application of more efficient research tools has become inevitable.

The twenty-two papers prepared by Hungarian geomorphologists for the First International Geomorphological Conference reflect the results of traditional geomorphological research, of relief evolution, but the majority of themes is related to environmental and dynamic geomorphological research of practical purpose, its achievements and new methods applied as well as the new ways of geomorphological mapping - with information helpful, in addition to geomorphologists, for geologists, engineering geologists, environmental pedologists and regional and settlement planners.

Finally, acknowledgements are expressed to the authors, translators, and editors of this volume and to all who participated and assisted at publication and, last but not least, to the laboratories and experts both at home and abroad who helped our team of authors with analyses, comments or in any other way.

Budapest, July 17th, 1985

Márton Pécsi

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ENVIRONMENTAL GEOMOPRHOLOGY IN HUNGARY

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ABSTRACT

The applied geomorphological research in Hungary has been of double aim:
1. The role and significance of geomorphology have been studied in its impact on the main factors of the physical environment on the one hand, and the geomorphological effects have been assessed from the point of view of land use, on the other. This approach has been introduced in the monographic description of the individual regions and in applied geomorphological mapping.
2. The study of the effect of instability and dynamic disequilibria on human activity has also come to the fore in geomorphology. Recently, the technical-economic activity as well as the existing technical establishments provoke local geomorphological disequilibria which cause enormous and long-lasting damage. In other cases to preserve the geomorphological equilibrium in order to maintain the safe operation of the establishment needs increased costs. The geomorphological analysis and assessment satisfying the requirements of rational land utilization and planning produced several varieties of environmental geomorphological maps. The maps and methods of this type and approach are discussed.

* * *

CONCEPTS AND METHODS OF RELIEF EVALUATION

Relief is a fundamental factor the geographical environment and of landscape. A major proportion of social activity takes place on the relief, it bears the settlements, roads, surface waters, soils and vegetation and numerous other arguments for its significance could be listed.

Due to the sudden acceleration of social activity in our days the evaluation of landforms and state of relief is needed from an increasing number of viewpoints. In the practice of modern land utilization the differences in relief quality are expressed in monetary terms, in surplus amount of work, in increasing energy utilization and in differential rent. Thus, especially in the past (two) decades claims have been set up to assess relief for scientific and various practical purposes and this demand has made it necessary to elaborate several procedures for the assessment of relief quality.

Table 1 Assesment of landforms through coding for agriculture and forestry (example of the Transdanubian Mountains and marginal areas)

Relief forms and elements	Factor scores as estimated (ranging from 1 to 100)	Classes of assessment (0-9)	Value reducing properties	Value subtracted from factor score
A) LOWLANDS				
1. Flat lower section of alluvial fan, to 160 m a.s.l.	80-50	7-4	surface ruggedness	20
2. Higher section of alluvial fan, to 200 m a.s.l.	70-50	6-4	rugged sloping surface	15
3. Foothill slope on loose deposits, 160-200 m a.s.l.	70-40	6-3	dissected by dry erosion or derasion valleys	
			less than 25 per cent of area	10
			more than 25 per cent of area	20
B) LANDFORMS IN MOUNTAINS				
4. Valley floor wider than 200 m, to 250 m a.s.l.	60-40	5-3	seasonally wet valley floors	
			< 10 per cent	5
			10-25 per cent	10
5. Valley floor narrower than 200 m	50-30	4-2	25-50 per cent	20
			> 50 per cent	30
6. Karst valley narrower than 100 m	20-10	1-0		
7. Pediment on loose deposits in mountains, 200-300 m a.s.l.	60-40	5-3	dissected by dry erosion or derasion valleys	
			less than 25 per cent of area	30
			more than 25 per cent of area	20
8. Intervalley ridges 250-360 m a.s.l.	50-30	4-2	width of ridge	
			300-200 m	10
			200-100 m	20
9. Horst ridges 400-450 m a.s.l.	40-20	3-1	width 300-150 m	5
			less than 150 m	10
			N to S strike	5
			W to E strike (exposed to N wind)	10
10. Horst plateau				
a) 360-400 m a.s.l.	50-30	4-2	above 400 m	10
b) 300-360 m a.s.l.				
c) 250-300 m a.s.l. wider than 250 m	60-30	5-3	loose deposit mantle less than 50 cm deep	10
11. Horst spurs 250-300 m a.s.l. 200-250 m a.s.l.	30-20	3-1	N to S strike	5
			W to E strike (exposed to N wind)	10

12. <u>Intramonatane basin</u>				
200-250 m a.s.l.	60-30	5-3	a. slopes angle:	
			5-12 per cent	5
			12-17 per cent	10
			above 17 per cent	15
13. <u>Steep horst slopes</u>				
r.relief less than 100 m	30-1	2-0	Covered by loose deposits	
r.relief more than 100 m			less than 17 per cent	5
			17-25 per cent	10
			25-40 per cent	20
			more than 40 per cent	29
14. <u>Slopes in general</u>	50-10	4-0	Steep rock slope	10
			- unstable	20
			- mobile	10
			dissection by valleys	
			more than 25 per cent	30
			less than 25 per cent	10
			slope angle	
			5-12 per cent	20
			12-25 per'cent	30
			25-40 per cent	40
			more than 40 per cent	49
15. Exposures	60-20	5-1	E or W exposure, slope length more than 100 m	10
			N exposed slope segment of more than 25 per cent inclination	20

This type of *morphographic relief evaluation* may serve as a basis both for scientific and practical utilization since it gives exact information on the spatial distribution of landforms.

RELIEF EVALUATION FOR LAND UTILIZATION

Certain morphographic parameters of relief may have rather different values from the point of view of different economic uses. Consequently, the role and value of relief can be concretely assessed from the viewpoint of one specified land utilization. Such a procedure has been developed e.g. for the agriculural use of land.

1. Taking this fact into account, the morphographic forms were listed first according to their height positions.

2. Subsequently, on empirical basis the landform categories were rated with scores (from 0 to 100) with regard to the possible utilization of the surfaces. Highest scores were given to the undissected and flood-free plain surfaces (PÉCSI, M.

Fig. 1 Relief assessment map of the Pannonhalma Hills and vicinity (by BALOGH, J.-JUHÁSZ, Á. 1983)
The scores from 1 to 8 represent quality classes of the relief from the viewpoint af agricultural (or forestry) land use: Higher quality classes present more favourable endowments for land use. For the procedure of assessment morphographic parameters and slope category and exposure maps have to be applied (Table 1). In the area assessed above, the most advantageous forms - for agricultural purposes - were low terraces and flood-free alluvial fans (they present quality classes 7 and 8).

1980). The hilly and mountainous landforms received lower and lower scores with their increasing height, dissection and angle of slope.

3. The scores can be further reduced where relief is damaged, eroded or slope exposure is less favourable. To evaluate relief from this point of view, it is undoubtedly necessary to prepare the *morphograpic relief exposure* and *slope category maps*.

The relative rating of relief by scores (within ten categories) may be suitable to provide more exact bases to site or land evaluation with other factors also included *(Fig. 1, Table 1)*.

EVALUATION OF RELIEF EQUILIBRIUM AND STABILITY

Relief is subject to changes, thus the morphograpic evaluation of static aspect is not always satisfactory. The morphological changes are locally of very low rate and can be measured only on the geological time-scale. Nevertheless, there are types of landform (e.g. blown sand plain, flood-plain, piedmont surfaces etc.) that show rapid changes. Especially the microforms may display diurnal, seasonal and periodical changes. It is an important practical task to evaluate the stability as well as the instability and/or mobility of certain relief constituents. Taking into consideration the requirements of land utilization it seems to be expedient to classify and assess the temporal changes of relief according to their quality and dimensions.

1. The landforms which develop over long geological periods in a imperceptible way are in *dynamic equilibrium* or in prolonged *steady state*. For theoretical and didactic purposes the stages in the terminology of DAVIS' erosion cycle (senile, mature and juvenile) may be valid of and can be used for only this type of relief.

2. The parts and forms of relief which are preserved or change in dynamic equilibrium during a relatively short period are *landforms of temporary steady state*. Their changes or transformations are through single or repeated upsets of equilibrium. During this latter phase the landform acquires a *mobile state* for a certain period. Subsequently, this state of movement hazard of the landform turns into either *temporarily unstable* or ultimately stabilized.

3. There are forms or relief parts which show repeated upsets of equilibrium, thus their *temporal dynamic equilibrium* is of cyclic character (e.g. meander development).

Undoubtedly, this type of evaluation and mapping equilibrium state of relief provides significant information to forecast possible relief utilization and change to be expected (PÉCSI, M. 1975).

The applied geomorphological maps prepared for the engineering practice serve this aim, the maps evaluating and typifying the relief with slides and surface movements hazard *(Fig. 2)*.

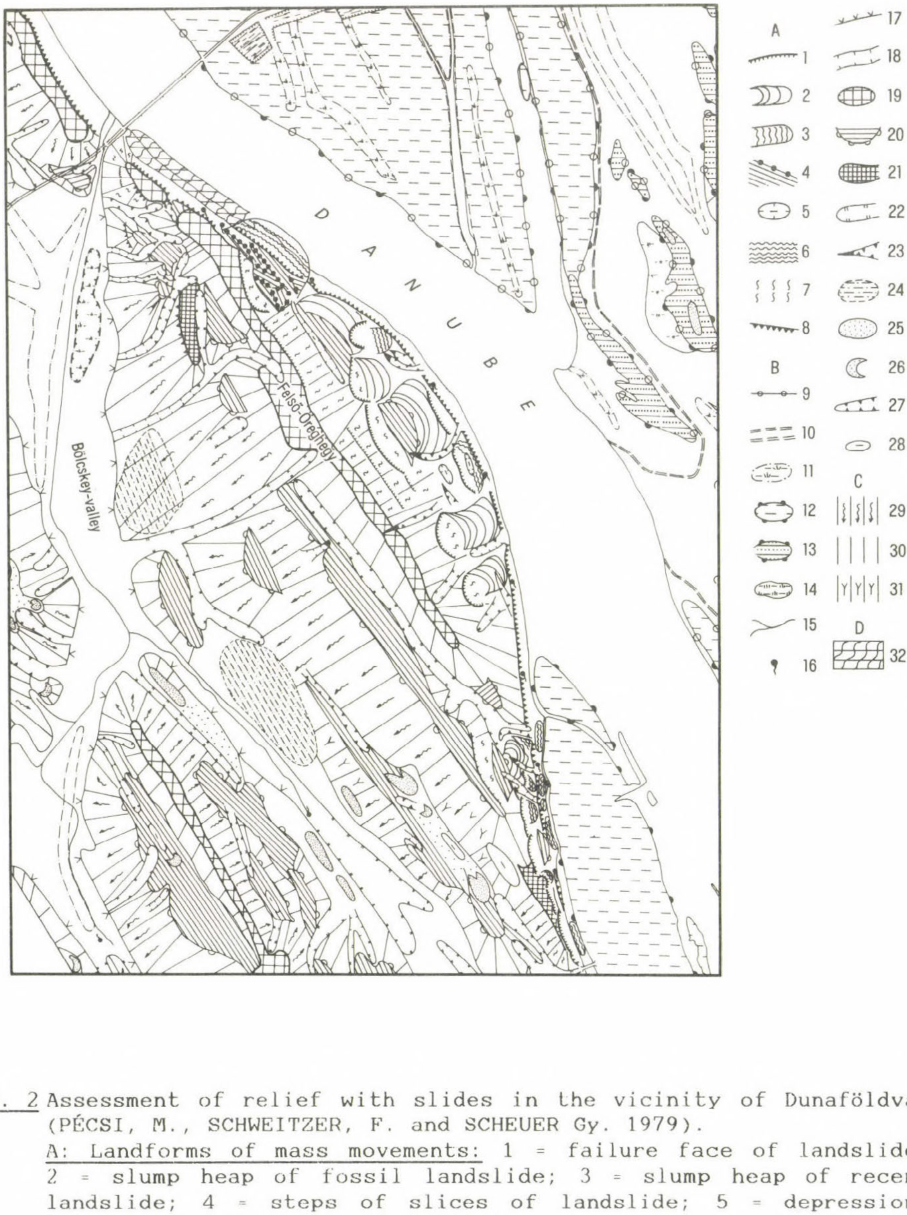

Fig. 2 Assessment of relief with slides in the vicinity of Dunaföldvár (PÉCSI, M., SCHWEITZER, F. and SCHEUER Gy. 1979).
A: Landforms of mass movements: 1 = failure face of landslide; 2 = slump heap of fossil landslide; 3 = slump heap of recent landslide; 4 = steps of slices of landslide; 5 = depressions enclosed by slump heaps of landslides; 6 = active mobile slopes with landslides; 7 = slopes with landslides, temporarily stable; 8 = high bluffs prone to collapse, bank collapses. B: Genetic landforms: 9 = high flood-plain, terrace N° I/b; 10 = Early Holocene Danube channel; 11 = channels of minor water-courses; 12 = Early Holocene meander spurs (terraces) covered by alluvial silt and clay; 13 = Early Holocene meander spurs (terraces)

EVALUATION OF THE RATE OF RELIEF EVOLUTION

Both scientific and practical purposes require the assessment of the age and change of landforms. The morphological elements, usually the microforms show changes of much shorter duration, than the whole and macroforms of the relief. The practical demands urge the evaluation of the short-term or cyclic disequilibria and the young landforms. The surfaces developing over long geological periods can be considered stable from the practical point of view.

The evaluate the date of origin and changes of microforms the categories below have been suggested (PÉCSI, M. 1975).

Microforms, morphological elements:

1. Frost-heaving forms, ripplemarks developing in a diurnal cycle with dimensions of less than a square metre.
2. Forms developing seasonally: snow forms, sand dunes, bank collapse, with dimensions more than a square metre.
3. Episodic microforms forming in about ten years' time: rockslide, landslide, with dimensions less than a square kilometre.
4. Forms developed through periodical upsets of equilibrium in about 10^2 years' time: meander cut-off; the dimensions are about 10 square kilometres.
5. Secular (cyclically periodical) forms: river flood-plain, cirque etc. Time of development: 10^3 to 10^4 years; dimensions: 10^2 to 10^3 km^2.
6. Terrace (step-like) landforms: multi-terraced river valleys, raised beaches; time of development: about 10^6 years; dimensions: 10^3 to 10^4 km^2. Within this category: local relief individual terrace formation within 10^4 to 10^5 years; dimensions: 10^2 to 10^3 km^2.

The categories above do not cover all the orders of magnitude of relief formation.

GENETIC EVALUATION OF MORPHOGRAPHIC TYPES OF THE RELIEF

When evaluating the morphographic classes and types of relief (high mountains, low mountains, hills, erosional plain, de-

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covered by alluvial and partly by blown sand; 14 = boggy, waterlogged terrains with meadow clay; 15 = water-courses; 16 = springs; 17 = lower boundary of valley floor; 18 = erosion valley; 19 = flat loess ridges; 20 = derasion step; 21 = erosion-derasion interfluvial ridge; 22 = derasion valley; 23 = erosion stream; 24 = depth of loessy-silty slope deposits; 25 = stabilized blown sand surface; 26 = blown sand dunes; 27 = wind furrows; 28 = deflation depressions; C: Slopes: 29 = slopes endangered by sheet erosion; 30 = slopes endangered by rill or gully erosion; 31 = stable slopes; D: Man-made forms: 32 = artificial landfill positional plain, large erosion valley and basin etc.) according to their tectonic setting and to the geomorphological effects of exogenous forces, relief is classified at the same time morphographically and genetically. The evaluation should be clear and unambiguous in order to reflect the most up-to-date knowledge on relief and its evolution. Usually these types of evaluation are required by the general geomorphological maps. Such maps are prepared first of all for educational and academic purposes.

APPLIED GEOMORPHOLOGICAL MAPPING

The representation of relief on geomorphological maps was required first of all by the planning and implementation works of engineering practice in order to select the safest locations for buildings.

Consequently, the need for applied geomorphological mapping arose and the means to satisfy it were developed in the practice.

When planning large-scale technical establischments (barrages, highways, residential districts etc.) it has recently become indispensable to study the impacts of the technical establishments on its environment. The expected impacts of large-scale technical establishments on the physical environment a produced a new research trend. Environmental impact statement naturally requires the detailed local and regional investigation of numerous environmental factors. The environmental impact statement is used in engineering geology on an ever wider scale, which needs again the joint evaluation of geomorphological or the entire physical geographical situation and endowments as well as of the geomorphic processes, also taking into account antrophogenic activity.

On the topographic base map the geomorphologist, relying on his research, evaluates the forms of relief according to the required aims, i.e. according to

- the lithology of the forms,
- to the stability or rate of change of landforms,
- the processes generating the forms,
- the slope conditions in the required categories.

Consequently, the applied geomorphological maps necessarily contain the state, structure and trend of change of relief.

When evaluating relief it is of primary interest that due to the joint effects of natural surficial processes (soil erosion, fluvial erosion, landslide etc.) and of social activity (building operations, canalization, water storing etc.) what changes are and will be in progress or can be expected in the landforms.

The *goal-oriented applied geomorpnological map* differs from the complex geomorphological maps both in its contents and representation. On these maps not all the information of the latter is represented. Its content is somewhat simpler on the one hand, but in harmony with the aims of the map it provides more exact information on the dynamics and states of forms than the general or complex geomorphological maps, on the other.

Applied geomorphological maps show mainly data of practical aspects that serve as a basis for the practice of planning, e.g. for agricultural soil conservation and amelioration planning, for preparing ground mechanics maps for engineering geology, and further more, for prearrangements of town and industry development and road network planning. In addition to these, the maps can be used in irrigation, flood control or afforestation planning.

The Hungarian school of geomorphological mapping ÁDÁM L.-PÈCSI, M. 1985., PÉCSI, M.-JUHÁSZ, Á. 1978., PÉCSI, M.-JUHÁSZ Á.-SCHWEITZER, F. 1978., SZILÁRD, J. 1978 developed first of all engineering geomorphological maps out of applied geomorphological maps.

ENGINEERING-GEOMOPRHOLOGICAL EVALUATION OF RELIEF ON MAPS

In order to safeguard the long-term operation of technical establishments, in engineering geology too the evaluation of the physical environment and within it that of relief potentials has been gaining increasing importance. In this manner, geomorphology and the results achieved have become either directly or indirectly a decisive part of engineering geological planning.

Thus, the subject of engineering geomorphological mapping is the evaluation of erosion processes shaping relief and of the forms generated by them from the aspect of the optimal arrangement of the technical-economic establishment and of their safe operation (PÉCSI, M. 1975).

In my opinion, the task of engineering geomorphological mapping is determined by the fact that not only the direct base of the technical establishments but also the relief of the environment should be evaluated. The state and evolution trend of relief depend partly on the physical environment and partly on the effects of the technical establishment. In a given landscape the components of the physical environment (relief, rocks, water-courses, climate, soil and vegetation) as well as the endogenous and exogenous forces from a system of mutual control. This is a self regulatory system and an open one. Its dynamic agents drive the system towards an equilibrium.

The equilibrium, the harmony in the landscape or only in the relief itself is locally incomplete or maintained for a limited period since the individual factors may counteract each other. This equilibrium, however, does not mean static immobility but the change itself proceeds in a dynamic equilibrium.

In applied geomorphological mapping and especially when evaluating the relief of landslides - in a supplementary description - the main task is to explore the equilibrium state of relief. Here the main question is whether one of the forms have reached the dynamic equilibrium during its evolution or is only approaching to it. The next question is how stable

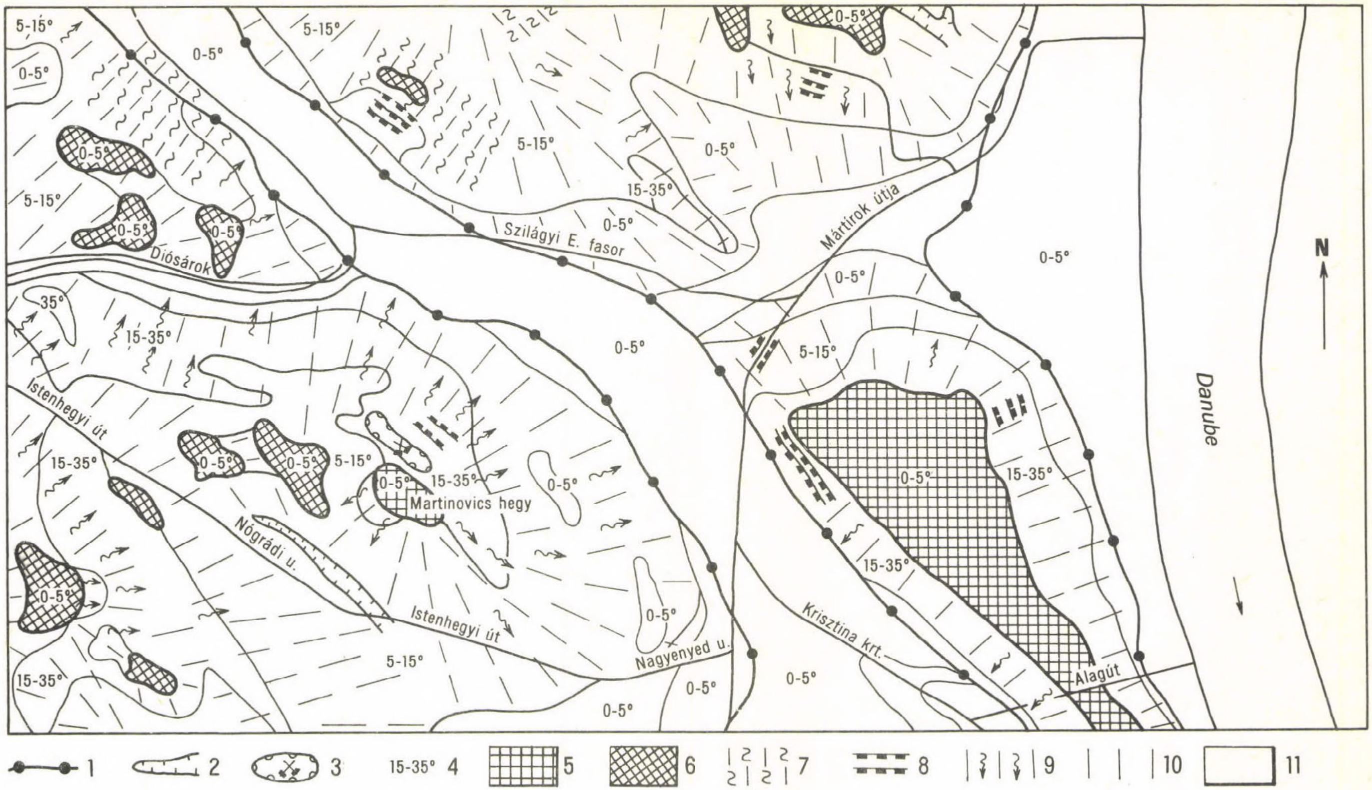

Fig. 3 Detail of the engineering geomorphological map of the Buda Mountains and districts of Budapest (by JUHÁSZ, Á.)
1 = boundary of regional aggradation and degradation; 2 = erosion valley; 3 = excavated depression, abandoned quarry; 4 = slope categories; 5 = plateau; 6 = hill crest; 7 = slope with fossil landslides; 8 = recent landslides; 9 = intensive slopewash; 10 = stable slope; 11 = valley floor and flood-plain

Fig. 4 Recent geomorphic processes (after LOVÁSZ, Gy. 1983)
1 = intensive material transport by rainwater; 2 = intensive marial transport by rainwater and landslide hazard; 3 = very moderate material transport by rainwater; 4 = moderate material transport by rainwater; 5 = no geomorphic change; 6 = deluvial accumulation; 7 = fluvial accumulation; 8 = deflation processes; 9 = geomorphic processes in the inner areas of settlements

this equilibrium is. Are the balance of agents and the changes of form periodically repeated or can only a single upset of equilibrium be expected? It is important to know to what extent the surface movement and changes of landform are due to the physical environment or to the social intervention or to their interaction.

This survey and assessment may be necessary for the safe operation of existing establishments and for the protection of the physical environment; this is done however most often for complex preliminary regional planning.

The engineering-geomorphological maps show

1. the slope categories, often in separate sheets;
2. the states of slopes;
3. the orographic forms;
4. the accumulation forms;
5. the channels and valleys;
6. the karstic forms;
7. the states of sand forms;
8. the anthropogenic forms.

The inclusion of special accumulation form into the legend depends first of all on the character of the region to be studied *(Fig. 3)*. The following forms are usually represented: flood-plain forms along rivers, terraces, alluvial fan remnants as well as valleys or small basins of different size and dynamics, sand forms and karst erosion forms. In the regions of streams, lakes or coasts different erosional or accumulational forms are also demonstrated.

In the engineering-geomorphological maps the representation of slope categories, depending on the purpose, is given either in slope angles or in slope classes:

1. Rock slopes and normal slopes belong to the stable slope category of prolonged equilibrium state.
2. Unstable slope types of sensitive equilibrium state being in tranquillity for a certain period.
3. Unstable or mobile slopes in disequilibrium affected by movements also recently as well as slopes of landslides or collapses or slopes rock debris fall.

The engineering-geomorphological mapping evaluates the relief elements first of all from the orographic point of view. This means that the morphography, location, extension of the forms are primarily assessed by quantitative parameters (see *Table 1*). To show the recent dynamic evolution of landforms another map can also be drawn *(Fig. 4)*.

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PRINCIPLES AND METHODS OF ESTIMATING EROSION HAZARD AROUND LAKE BALATON

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Relief evolution and geomorphological studies in the physico-geographically heterogeneous catchment area of Lake Balaton are of special importance for water quality in the lake. The amount and quality of pollutants reaching the lake are highly dependent on the erodibility of watershed. To determine it author elaborated the integration principle and method below on the basis of criteria of factors influencing erosion hazard in the region *(Table 1)*. It is to be emphasized that the grades of erosion hazard *(Table 2)* only indicate the general resistence capacity of the surface, its attackability and the potential dislocation of surface materials and point to differences between surfaces in this respect. The degree of actual erosion is dependent on the following, too: amount, frequency and primarily intensity of precipitation of random spatial and temporal distribution and momentary surficial conditions. The redeposition-transportation route of the displaced material, its distance, site of accumulation is, in addition to the above, a function of slope length, configuration (arrangement of gentle segments), the nature and size of surface details functioning as base level, site of deposition. To measure in a concrete case from where how much sediment and chemicals reach the lake from the watershed in a mechanical way and in solution and deteriorate water quality, an extremely complicated multivariate function would have to be solved. The final aim is to measure this load, differentiate it in space and time with the fundamental help of partial information from geomorphological mapping and with guidance of the above principles and methods.

Table 1 Grades and criteria by factors of erosion hazard in the vicinity of Lake Balaton

Grade of surface resistence	Lithology	Slope angle	Soil	Surface cover	Land use
1. no erosion hazard	limestone, dolomite, phyllite, basalt, gravel	less than 3%	lessivated brown forest soil	more than 90%	closed forest, meadow, pasture, urban area
2. slight erosion hazard	clay, marl basalt tuff, peat	3-12%	brown forest soil, chernozem brown forest soil on loess and solid rock	60-90%	vineyard with contour plantation, sparsely built-up area
3. medium erosion hazard	red sandstone, Pannonian sandstone, conglomerate, silt	12-17%	chernozem rendzina	30-60%	vineyard with lines traversing contours, arable with cereals
4. heavy erosion hazard	sand (Pannonian, fluvial, windblown), loess-like deposits, loose slope deposits	more than 17%	humous sand soils, rust brown forest soil, brown forest soil with 'kovárvány' on sand	less than 30%	vineyard with contour plantation, garden, arable with row crops

Table 2 Possible integration based on criteria by factors
(4 surface resistence grades for 5 factors = 20 scores at maximum)

1. no erosion hazard if
   - a) total score: max. 5
   - b) total score: 5-10 but within it either slope angle or land use is 1

2. slight erosion hazard if
   - a) total score: max. 10
   - b) total score: 11-13 but within it either slope angle or land use is 1
   - c) total score: below 8 but within it either slope angle or land use is 3 or 4

3. medium erosion hazard if
   - a) total score: max. 15
   - b) total score: 16-17 but within it either slope angle or land use is 1
   - c) total score: below 10 but within it either slope angle or land use is 4

4. heavy erosion hazard if
   - a) total score: above 18
   - b) total score: 15-17 but within it either slope angle or land use is 4
   - c) total score: 10-13 but within it slope angle and land use together is 7-8

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SUBJECT AND METHODOLOGY OF EXPERIMENTAL GEOMORPHOLOGY

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ABSTRACT

Numerous attempts have been made to define experimental geomorphology. Author is, however, dissatisfied with these definitions. In his opinion, experimental geomorphology is the branch of geomorphology which reveals relationships and regularities between landforms, geomorphic processes and the materials involved in the processes on the basis of laboratory or field measurements under controlled conditions and finally delimits the scope of validity for these relationships and regularities. This definition raises the following conceptual problems (elaborated in the paper): 1. the complexity of processes; 2. interpretation of (the order of magnitude of) landform; 3. description of the properties of materials by quantitative parameters; 4. the achievable degree of control; 5. what can be measured and to what exactitude; 6. the scope of validity of the regularities found and their inclusion into geomorphological knowledge. Of the methods best known are those applied in the study of weathering and soil erosion.

* * *

Following the general trend of development in the natural sciences, physical geography has become an experimental discipline only belatedly, not before our days. The arising need for a quantitative attitude, the demand for quantitative description as well as the spreading of mathematical methods resulted in a *quantitative revolution* in geography. This process started about twenty years ago and is regarded finished by now. The quantitative revolution has been criticized by many. Without going into the details of these criticisms, we can say as a summary that, as a matter of course, numerous exaggerations, 'overquantifications' occured, as a whole, however, the spreading of quantitative methods is considered a positive phenomenon of great use. It gave rise to experimentation and measurements in physical geography. In experimental geomorphology the methods essentially applied attempt to reveal the *mechanisms of the processes* in addition to their numerical description based mostly on statistics.

Many are sceptical about the investigation of processes in geomorphology. Their main argument is that it is not possible to simulate nature and only some manifestations of the complicated processes in nature can be grasped through experiments and measurements. All these facts point to the intricacy of the task and do not indicate its irresolvable nature, since most of the natural sciences undertake the investigations through experiments of complicated processes difficult to approach - successfully in most of the cases. Scepticism is the less rightful, as some encouraging results have also been attained in our science.

It is worth to note certain experimental methods in geomorphology had developed earlier in Hungary than in other countries. This development is detectable both in physical geography and in the related sciences.

Agronomists, hydrologists and pedologists as well as physical geographers, who cooperated with them, directed their attention to soil erosion research as early as the 1950s. B. KAZÓ (1966, 1967) developed a rainfall simulation instrument. The results of erosion measurements and experiments were published in the 1960s and 1970s (SALAMIN, P. et. al. 1965-75, PUSKÁS, T.-OLÁH, L. 1969, PINCZÉS, Z.-BOROS, L. 1966-67, GÓCZÁN, L. 1974, SOMOGYI, S. 1975). Besides field methods measurements in laboratory appeared early (see BORSY, Z.-KÁDÁR, L.-PINCZÉS, Z. 1971). More recently, in his investigations, A. KERÉNYI (1981, 1982) applied both field methods and laboratory experiments. In karst studies, L. JAKUCS (1960) incorporated experiments and measurements to help reconstruct the origin of karst landforms.

It is not easy to venture into a new attitude and investigation method in the lack of precedents, the experience of forerunners and the established school. Even the most recent handbooks on geomorphology seldom mention laboratory and field experiments among the methods (see LOUIS, H.-FISCHER, K. 1979). The experimental methods already established in the related sciences may be of help. Researchers in agronomy and pedology have long been applying experimental plots and the laboratory and field experiments of hydrologists also have a long history and their experience is useful in geography too. Although the problems geography and the disciplines mentioned are faced are different, their *interdisciplinary analyses and solutions* are to be approached.

SUBJECT OF EXPERIMENTAL GEOMORPHOLOGY

According to AHNERT, F. (1978) experimental geomorphology is part of functional geomorphology. It investigates the relationships between landform, material and processes *(Fig. 1)*. Its goal is to interpret and explain the evolution of landforms. Depending on the place of experimenting, there are *laboratory and field experiments*. In the international literature the latter are dealt with in more detail and numerous authors have attempted to define field experiment. SLAYMAKER, O. (1979) claims that field experiment is a series of experiments carried out under controlled field conditions in order to reveal general

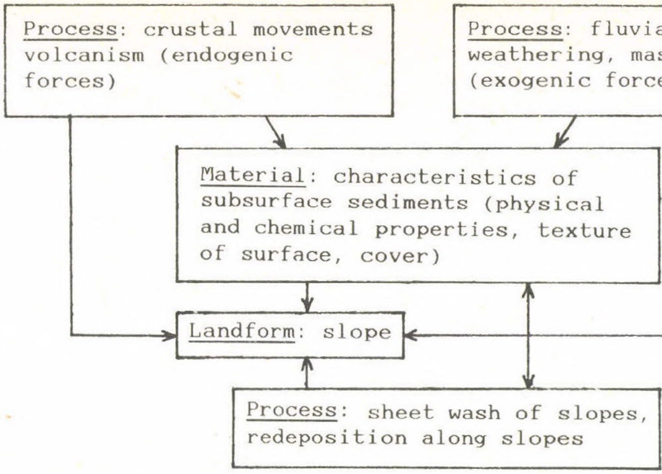

Fig. 1 Relationships between landform, material and process (example: a way of slope evolution - after AHNERT F. 1978)

laws of the development of landforms. None of the definitions is precise enough. In my opinion, *experimental geomorphology is the branch of geomorphology which determines relationships and regularities between landforms, geomorphic processes and the materials involved in the processes on the basis of laboratory or field measurements under controlled conditions and finally establishes the scope of validity for these relationships and regularities.*

This definition raises the following conceptual problems: 1. the complexity of processes; 2. interpretation of (the order of magnitude of) landform; 3. description of the properties of materials by quantitative parameters; 4. the achievable degree of control; 5. what can be measured and how exactly; 6. the scope of validity of the regularities found and their inclusion into geomorphological knowledge. Another difficulty deriving from the definition should be mentioned: experimentation had been rather alien to traditional geomorphology; the *natural historical attitude* had been prevalent which does not easily alter or match to the methods of experimentation.

1. The *complexity of processes* and the combination of various processes is a fact to be taken into account in the methods of experimentation through *selection*. Processes can only be investigated simultaneously in limited number (most often only one or a few). If, therefore, the evolution of a landform is influenced by factors $n1 \ldots nk$, the process is described by the function $f/n1 \ldots, nk/$, we have to suffice to take - at the initial stage at least - $k = 1, \ldots 3$, for instance, into consideration. In other words, it means that a *hypothesis* has to be formed about the problem under study. Consequently, first we have to assume that the problem can be solved through the investigation of a single specified process or of a few processes. The selection itself is, consequently, an assumption founded by previous knowledge accumulated through the description of ob-

served facts. Here again the related sciences should be mentioned; in hydrology, for instance, this kind of method has a past of almost a century.

Thus, experimentation is based on a hypothesis and, at the same time, means the testing of the same hypothesis. SLAYMAKER, O. (1979) lists five criteria of field experiments. They are

a. testing a hypothesis;

b. during field experiments special attention is devoted to the types within the area under study (areal stratification), to representative sampling within the types ("layers") as well as to the relationship between the time factor and representativity;

c. innovations in the planning of experiments;

d. repeated measurements and the conditions to allow repetition;

e. analysis of the original hypothesis and drawing final conclusions.

2. *Landform* - it is not a precise or standardized concept. Mount Tokaj and an erosion rill are both landforms. The example gives an idea about the problems of order of magnitude on the one hand and of the delimitation of the form on the other. As regards order of magnitude, no restriction is necessary: both the rill and the mountain are the subjects of study of equal right. Order of magnitude only influences the scope of validity of the conclusions to be drawn and, closely related to it, their exactitude.

The delimitation of forms seems to present the heavier task. *Morphometric methods* are called to give a help and the boundaries can be drawn based on quantitative data. Order of magnitude also becomes clear, since morphometric methods reveal the hierarchy of forms too. It becomes known what is part of what and belongs where (KERTÉSZ, Á. 1974, 1976).

It is to be emphasized, however, that *each landform is to be inserted into the spatial pattern of the given area.* Under the climatic conditions of Hungary, the uniform and unambiguous framework of spatial organization is provided by *catchment systems.* Every form and element of form can be included in this system. In special cases - when it is not the catchment but, for instance, the system of ridges that is under study or when special landforms (e.g. sand forms or periglacial forms) are involved - this approach may be abandoned.

3. The *materials* affected by the processes are analyzed and described by various techniques (petrological, pedological and ground mechanical methods and so forth). Here attention has only to be paid to select the quantitative parameters most appropriate to the subject and goal of the investigation out of the set available from the research of related sciences.

4. The *control of experiments* is vital in the experimenting approach and decisive concerning the nature of the experiment. SLAYMAKER, O. (1979) mentions three methods:

a. The deliberate and controlled intervention into the natural conditions as a simulation of form development. At the same time, this is the most 'elegant' method closest to laboratory conditions. As an example a paper by MACKAY, J.R. (1973) can be cited where he studied the evolution of pingos through observations and measurements on an artificially drained lake bottom. Life often provides such opportunities (river regulations, reservoir construction etc.). The success of the experiment depends on whether one manages to chose a relatively simple form or whether measurements and observations are of proper frequency.

b. A landform is chosen and the changes resulting from the effect of one or several agents are recorded in the function of time. It appears to be the simplest approach and it is no surprise that it is applied in most of the experiments (JAHN, A. 1976 etc.).

c. The 'stratification' of the studied area by a certain criterion and recording the changes in two or more 'layers' in the function of time, with regard to one or several agents. This latter procedure has been gaining in importance. It is also the 'most geographical', as it is concerned with the areal differences in the processes. Regions may be delimited by lithology, land use, the geomorphological threshold value (SCHUMM, S.A. 1973), climate (RAPP, A. 1974), catchment boundaries (divides), microregions (or "land systems"; CONACHER, A.J. and DALRYMPLE, J.A. 1977) or altitudinal zonation (BOVIS, M.J. 1978) A major advantage is the simultaneous investigation of the *temporal and spatial changes and differences in the components of mass equilibrium.*

Areal stratification often presents serious problems to researchers in English-speaking countries. The reason for this is they do not know the German (classical) geomorphological school sufficiently. They disregard the results of climatic geomorphological research which indicate the primary role of climate and the secondary importance of lithology within the given type of climate. The necessary reconnaissance survey of the physical geography of the area is usually neglected.

5. *What to measure?* The main point to make is that measurements have to serve the goal of the experiment, the testing of the initial hypothesis. Unfortunately, it often occurs that the measurement is the starting-point and the goal is adjusted to what can be most easily and quickly measured in a given area. Exactitude will be tackled later.

6. The usefulness of the experiments is decided by the scope of the formulated laws, the representativity and transferability of results. In hydrological measurements it frequently happens that the process itself remains hidden behind data demonstrating states. The same may apply to geomorphological experiments too. Process has also to be defined exactly. Processes as temporal changes are studied in a simplest and most successful way if a problem of applied geomorphology is investigated.

WAY TO EXPERIMENTATION

As all kinds of geomorphological research, the experiment is also preceded by *observations of qualitative or quantitative attitude.* The first mean the verbal description of the geomormorphological process or phenomenon in question. Numerical data here do not serve further quantitative analysis, but only as documentation. As an example slope wash is mentioned; it has been observed, described and the data base supporting the observations has been collected (slope angle classes and their areal distribution, precipitation conditions and soil properties etc.).

A *quantitative observation* in strict sense is data collection for statistical analyses (AHNERT, F. 1980). Information can be compiled on landforms or processes or material. In the example of slope wash, data can be captured on landforms, on the slopes where this process takes place. Data (e.g. slope angle, slope length etc.) are collected here for statistical analyses. The parameters for the material (ground mechanical, physical and chemical ones) are great in number. Data on process can be exemplified, among others, by the rate of denudation at various dates.

The way to experiment is through *measurement based on observation*. Several authors suggest a distinction between measurement based on observation and experiment (AHNERT, F. 1980). The first measurement is only directed to a natural process (e.g. of sediment and water accumulated at the footslope due to sheet wash); *no human intervention took place*. According to AHNERT in an experiment deliberate human intervention is inevitable (if artificial rain substitutes the natural or the experiment is carried out in the laboratory). Although it is right to distinguish experiment from measurement, both belong to experimental geomorphology. In the international literature the ratio between measurements and experiments is about 9 to 1. It cannot be explained by the fact that it is easier to measure than to experiment, but by the substantially higher financial, instrument and labour demands of experiments.

A synonym for experiment is *model* (or simulation), as it involves the artificial generation of natural processes in the laboratory or in the field.

The *stages of experimentation* can be outlined as follows *(Fig. 2)*. An experiment or a measurement is always preceded by observations. On the basis of qualitative and quantitative observations a *hypothesis* is formulated on the geomorphological process to be investigated. Starting from this hypothesis the experiment or a measurement is *planned*. The plan makes it clear *what data have to be measured* and what *instruments* are necessary for the measurements. When they are obtained and installed, the process of *the experiment* itself *takes place*. After repeated experiments with modifications *the original hypothesis is analyzed*. The conclusions are compared with previous knowledge on the studied process. If necessary, the assumption is modified or abandoned and a new hypothesis is set up. The confirmed hypothesis may alter or contradict earlier views on the subject. The scope of validity has to be exactly given *in space and time* for the results. To cite our example, it must not happen that conclusions should be drawn from an event or a series of events of slope wash measured on a small plot to the erosion conditions of a whole physical geographical region or from some measurements during the growing season secular or 'million-year' rates of denudation should be calculated.

Hypothesis → Planning of experiment

Data to be measured and instrumentation

Experimentation proper

Repetitions, modifications

Analysis of the original hypothesis

Final conclusions

Comparison of results
with previous knowledge

Extrapolation, review
of previously held opinions

Fig. 2 Stages in experimentation

METHODOLOGY OF EXPERIMENTAL GEOMORPHOLOGY

To the present date measurements and experiments in greatest number have taken place concerning weathering, the various correlative sediments and their transport and finally the action of rivers. The laboratory investigation of *physical and chemical weathering* is feasible in several ways. PISSART, A. (1974) simulated the development of polygons. On the field measurements and simulation in laboratory of processes in the climatic zones numerous papers have been written (SMIDT, B.I. 1977).

The best known methods have been elaborated for the study of *sheet wash on slopes* and *soil erosion*. First of all, instrumented plots for erosion studies as sites of measurement belong here; they give opportunities both for the measurement of natural processes and for experimentation (with the help of rainfall simulation). Closely associated with measurements of soil erosion (GÓCZÁN, L.-SCHÖNER, I.-TARNAI, P. 1973; RICHTER, G. 1975) are those of splash erosion (KERÉNYI, A. 1981) carried out first in laboratory and subsequently in the field. Perhaps the measurements of soil erosion have the richest literature. Measurements and experiments concerning eolian erosion are also known (BORSY, Z. 1973, 1974). Erosion is recorded when the development of erosion gullies and gorges are measured (PINCZÉS, Z. 1968). The method applied here is similar to the continuous monitoring of mass movements on slopes; stakes (or rods) are fixed into the soil in the immediate neighbourhood of the landform and the displacements are related to them.

Measurement and experiments of fluvial action were made in Hungary primarily by hydrologists. In the international literature the most important comprehensive work is by GREGORY, K.J. and WALLING, D.E. (1973).

Although it is an only recently developed discipline, there is a considerable amount of information accumulated on the methods of experimental geomorphology. The Commission on 'Field Experiments in Geomorphology' of the IGU has been active for more than ten years now and even its predecessor, the Commission on 'Present-day Processes' had also provided plenty of publications in this field. The material for a handbook on methodology has more or less accumulated. In spite of all this, we are far from being able to compare the results and having the appropriate quantitative methods of comparison at disposal.

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THE SELF-REGULATORY ROLE OF RELIEF IN SURFACE EVOLUTION

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ABSTRACT

The principle of dynamic equilibrium in geomorphology says that the lapse of time itself does not bring about qualitative changes in landforms; in the case of unaltered substrate and constant geomorphic processes, each relief element is equally modified. Variations in the areal extensions of the particular forms can be explained by their self-development. Our morphometric analyses allow us to draw the conclusion that if the dimensions of landforms change under the influence of a geomorphic process, the effect is multiplied and eventually it is not only the altered process that shapes the surface but the change in extension itself may also increase or decrease the rate of denudation by mobilizing some processes or reducing their activity or responding to them in any particular manner. Consequently, the changes in extension anticipate the developing relief features in a self-regulatory way. Most of the landforms are not mere products of denudation, but themselves are active, indirect geomorphic factors.

* * *

In the geomorphology of our days the assessment of relief as the setting of the economic-technical activity of society has come to the fore and the forecast of development perspectives has gained in importance. Recent research has revealed that relief evolves in response to the effect of many factors and through states of dynamic equilibria. More and more effective human intervention has made this equilibrium more susceptible and occasionally disequilibria have also occurred. This raises an important general problem of geomorphic evolution which is a cue for the forecast of the trends of further change.

The principle of dynamic equilibrium in geomorphology (as elaborated by PENCK, W., MACKIN, J. H. and others) *says that the lapse of time itself does not bring about essential qualitative turns in geomorphic evolution: with constant substrate and geomorphic processes, each relief element is modified to the same degree. In the concept of geomorphic evolution through states of dynamic equilibria* variations in the extensions of the surfaces of particular forms are explained by the *self-development of landforms*. This is one of the fundamental approaches to the problem.

The other side of the problem, however, the *effects triggered off by the geometrical surface of the substrate*, has not yet been studied. Our morphometric analyses allow us to draw the conclusion that if, owing to some geomorphic process, surficial relief (absolute surface - the real geometric surface of the landform; it is larger than or equal to the projected surface represented on maps) undergoes a change, a chain of trade-offs is set in motion. It means that it is not only the altered process that shapes the surface but the change in extension itself may also increase or decrease the rate of denudation by mobilizing some additional processes or, in the opposite way, reducing their activity or responding to them in any particular manner. Consequently, the change in extension, through self-regulation, predetermines the resulting relief situation. Most of the landforms are *not mere passive products of denudation, but themselves are active, indirect geomorphic factors*.

In the evaluation of relief self-regulation, to judge how and to what degree geomorphic processes respond to the extension or surface, two statements need verification: a. The increase of real surface is a proper indicator of complex (vertical and horizontal) dissection. b. In a constant climatic and morpholithogenic situation, *the extent of dissection is closely correlated to erosion* (which is obviously true). In this manner, an indirect logical verification is available for the assumption that the areal extension of the real surface provides a direct estimate to the rate of denudation. It is useful to apply dissection as a mediatory element, since it is well defined morphometrically, although, at the same time, it restricts the validity of our statement to the environments of predominantly 'normal' (fluvial) erosion.

MEASUREMENT OF AREA OF ABSOLUTE SURFACE

Several parameters of horizontal dissection (length of watercourses per unit area) and vertical dissection (altitude of base level, slope inclination, relative relief etc.) have been analyzed in detail by many (HORTON, E. 1945; STRAHLER, A. N. 1958; HORMANN, K. 1971) under various lithologic, climatic and orographic conditions. As TABIDZE, D.-KOROSHINADZE, M.-KHABAZASVILI, M. (1975) pointed out *complex dissection* can be expressed by the percentage growth of real surface of a given terrain compared to its projected area on map.

The ratio between *real surface* (P_0) and *projected surface* (P) has been calculated for 14 terrains of different origin both in Hungary and abroad. Our measurements have been supplemented by data from literature.

The calculations were made on 1:25,000 scale topographic map base. On the map sheet areal units of 5 x 5 km² size were selected and five parallel topographic transects were drawn with another five rectangular to them. The lengths of curves of the surface in the transects were measured and their average calculated for the two directions and real surface area was described by their product (*Table 1*).

Table 1

The indicator of real surface area for test areas

Area (1:25,000 map sheet names)	Percentage growth of real surface (P_0) compared to projected (P)
1. Hódmezővásárhely (Great Hungarian Plain)	0%
2. Győr (Little Plain)	1%
3. Előszállás (Mezőföld - loess plain)	1.5%
4. Ágasegyháza (Great Plain)	1.5%
5. Bükkösd (Mecsek Mts)	3.0%
6. Zalaegerszeg (Zala Hills)	3.5%
7. Aggtelek (Aggtelek Karst)	5.5%
8. Répáshuta (Bükk Mts)	6.0%
9. Bódvaszilas (Aggtelek Karst)	7,5%
10. Nagybátony (Heves-Borsod Hills - 1-10 = Hungary	12.5%
11. Vysoké Tatry (Slovakia)	39.0%
12. Main range of the Gagra Mts (Caucasus Mts Georgia, Soviet Union)	61.0%
13. Hohe Tauern (Austria)	60.0%
14. Himalayas (India)	65.0%

Calculating from small surfaces it is useful to apply the more exact method described by VOLKOV, N. G. (in: ARISTARKHOVA, L. B. et al. 1970). Here the formula for real surface is

$$P_0 = P\ /1+\frac{2\ H}{R}/\ \sec\alpha\ ,\ \text{where}$$

P_0 is real surface;
P is projected surface on map;
α is slope angle and
$\frac{2\ H}{R}$ is a correction factor which depends on altitude above sea level.

If it is required by the goal of the investigation, the calculation can be made more exact (for instance, by classifying the relief into slope categories).

The calculated values enabled us to identify some *genetic types* besides providing a descriptive and comparative figure for surface dissection. Some typical values are presented in *Table 2* for the purpose of orientation.

Table 2

Percentage growth of real surface (P_0) compared to projected one (P) for some genetic types of surface

Type of surface	Percentage growth
Accumulation plain	0.0-1.0%
Deflational, fluvial erosional lowland	1.5-2.5%
Erosional-accumulational hilly	3,5-5.5%
Loess with piping	1.5-2.0%
Karst erosional	5.5-10.5%
Fluvial erosional low mountain	10.0-25.0%
Fluvial erosional high mountain	25.0-40.0%
Glacial erosional	60.0- %
Nivational	55.0- %
Abrasional	2.0-3.0%
Faulted (structural)	25.0-35.0%

EXAMPLE OF RELIEF SELF-REGULATION

The response of relief evolution to the dimensions and shape of landforms is best observed at microscale (for dolines, erosion or derasion valleys and so forth). At this scale form elements are of the same origin, lithology, similar in water budget, vegetation and soils. Thus, the relationship between geomorphic agents and the resulting landform is evaluated in an exact way.

Through the morphometric survey of morphofacies, on *karst surfaces* the response of the change in the extension of solution forms on the dynamics of karst corrosion has been quantified earlier (MEZÖSI, G.-BÁRÁNY, I. 1978). (At the level of macroforms, because of numerous agents, it is much more difficult to measure this effect.)

In our method we conceived the surface of temperate continental or subtropical solution dolines as a spherical calotte (*Fig 1*). The surface available for corrosion is expressed by the formula:

$$A = \pi/2 \varrho^2 + m^2/, \quad \text{where}$$

ϱ is mean doline diameter and
m is average depth.

As it is known, not too deep soil indirectly promotes karst corrosion, while soils of great depth (mostly accumulated on doline floor), because of the impermeability of red clay, hinder the process. Under these circumstances solution becomes most effective on the doline margins. Therefore, in mid-latitude continental environments dolines rather tend to broaden than to deepen, with reducing altitude of the surface or the col separating dolines (*Fig. 1b*). (In tropical environments sheet erosion is substantially more effective and soil accumulates in large amounts on doline floors and this result in intensive deepening; corrosion becomes stronger and relative relief increases - *Fig. 1a.*)

Taking a doline of 100 m mean diameter, 15 m average depth and having a surface of about 7,400 m². (In tropical environments about 2-2.5 m deepening already leads to 500 m² increase in area and far-reaching influences are involved. The process is maintained until the surface is eroded to the base level; for the landscape tower karsts and adjacent plains are characteristic.) Under continental climate there are two possible trends, regarding, on the one hand, that on doline floor deep clay fill often hinders deepening and the rather stable relationship between depth and diameter (meaning about 10 m broadening) on the other. The size of karst area may change between 6,700 m² and 7,700 m²; on one occasion (below 7,400 m²) it results in form preservation, while above 7,400 m² it leads to slow growth.

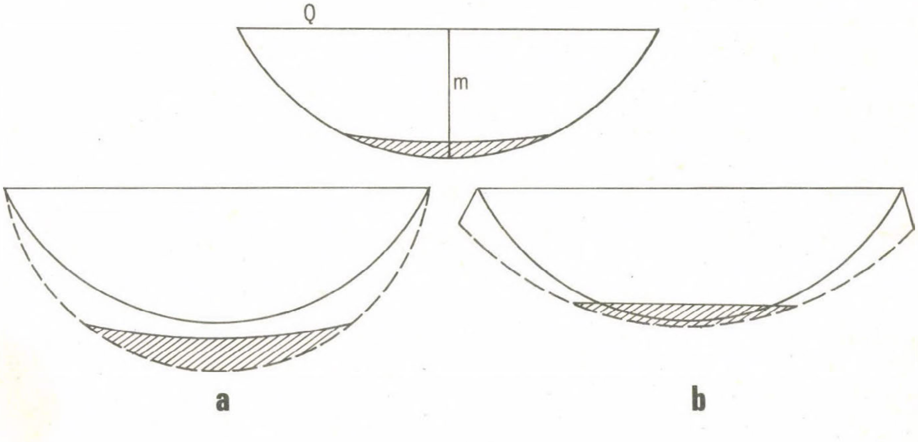

Fig. 1 Trends of doline development in temperate Mediterranean (b) and tropical environments (a)
Q = mean doline diameter; m = average depth

As a matter of course, the change in geometry cannot be considered a geomorphic agent. The main point in our argument is that the change in geometry itself is the product of geomorphic processes and, at the same time, it is a cause for further surface evolution. It means that the process-form relationship is manifest through cause-and-effect chains in which the change in geometry can be monitored and measured and, thus, the resulting landform can be forecast.

In our opinion, the self-regulatory role of relief is to be taken into account in the forecast of the evolution of individual landforms as well as in the study of the rate of erosion or in denudation chronology.

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THE EFFECT OF TOPOGRAPHY ON THE DEVELOPMENT OF SALT-AFFECTED SOILS IN HUNGARY

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ABSTRACT

The paper wants to stress the governing role of topography in the spatial distribution of salt-affected soils and in the constellation of conditions inducing solonchak formation. Especially the flood-plain salinic geomorphological pattern i.e. natural levees and enclosed depressions, filled meanders etc., governs the surficial and groundwater movement and flood-plain deposition. Thus, among the geomorphological, lithological and hydrogeological factors there has formed close interactions. As a whole, all these control the ecological potentials of sites through determining soil formation processes according to the climatic conditions characteristics of the region in question. The salt-affected soils studied in the test area show close and causal relationships with micromorphology.

* * *

In Hungary about 10 per cent of agricultural land consists of alkali soils of different type. Taking the viewpoints of agro-ecological potentials these soils represent the least favourable sites. Considerable loss in production is caused and their cultivation needs great surplus investment.

In Hungary, along the Danube valley, the overwhelming majority of salt-affected soils occur on flood-plains, low terraces and alluvial fan surfaces, similarly to other extensive salinic regions of Europe and Asia.

Pedologists, agrogeologists, physical geographers and geobotanists have been dealing with the conditions of solonchak formation for about a century, and have discovered nearly all the factors. Nevertheless, in our opinion the role of topography in the arrangement of salt-affected soil spots as well as its governing role in the groundwater movement have not been satisfactorily elucidated.

The interpretation of the origin of alkali salts has long been debated. Numerous researchers related the *possible accumulation of alkali salts* in the salinic soil profile to the redeposition of weathering products of volcanic rocks of the Carpathians and to their accumulation along lowland rivers. Other researchers believed that the saline waters in the marine sediments filling the Carpathian basin in several thousand metres thickness reach the near-surface layer by migration along the fault-lines of river valleys. Another group also took into account the solutions of surface watercourses and considered these factors together as primary salt sources. Airborne dust and the salt content of precipitation, as well as the alkali salt bearing weathering products of near-surface rocks accumulated due to meadow and marsh vegetation and soil formation, were assigned to the secondary salt sources. In addition to the weathering processes, the relating reviews of SOMOGYI, S. (1965) and SZABOLCS, I. (1961) also underline microbial activity.

When studying the development of salt-affected soils the decisive role of water-soluble sodium salts which occur in two forms in Hungarian soils is emphasized.

a) in form of water-soluble salts (with carbonate, hydrocarbonate, sulphate, subordinately chloride anions),

b) in form of ions adsorbed by soil colloids.

Mg^{2+} occurring together with Na^{+} contributes also to alkalization and favours its conditions. Where in the soil Na^{+} occurs in water soluble form, the solonchak formation proceeds. On the contrary, where Na^{+} is found mainly in adsorbed form, the solonetz type alkalization occurs. Nevertheless, in Hungarian salt-affected soils the two kinds of Na^{+} occur together in the soils (e.g. in the solonchak-solonetz soils).

Among the factors promoting alkalization* a considerable role is attributed to the mid-summer long-lasting drought characteristic of the Carpathian basin of moderate continental climate. In the growing season the soil solutions may capillarily rise up to or near the surface and the alkali salts may precipitate**. From the point of view of capillary water rise, in addition to the moisture content of the soil profile, the subsurface water table and its fluctuation play important role. It has been demonstrated that in the Great Hungarian Plain, where the capillary water rise zone does not reach the root zone, ·the groundwater table remains below 2 m, no solonchak formation occurs.

SALT-AFFECTED SOIL SPOTS AND TOPOGRAPHY

Surficial salt accumulation is generally observed in places where in some depression the groundwater rises seasonally in the soil profile. Thus, most of the alkali soil researchers and hydrogeologists attribute a major role to the *local geomorphological factors*, that, disregarding the local impermeable character of the subsoil, decisively affect the groundwater table. Several researchers studying the geographical distribution of soils (STRÖMPL, A. 1931; ENDRÉDY, E.1941;

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* Main factors of alkalization are: 1. accumulation of alkali salts; 2. climatic conditions; 3. hydrogeological conditions; 4. (micro) relief; 5. the impermeability of the parent material and of the subsoil.

** The infiltration of precipitation assures the leaching of accumulating salts only down to 130 to 150 cm in non-salinized soils.

A. NAGY, M.-KORPÁS, E. 1956; RÓNAI, A. 1961; SZABOLCS, I. 1961; SOMOGYI, S. 1964) considered the depressions of the surface of various size (their marginal zones) particularly liable to solonchak formation.

In the Great Hungarian Plain, in the extremely flat alluvial plains of the Danube and Tisza, the abandoned river beds, the filled meanders and point-bars, the dense network of natural levees resulted in a characteristic micro-morphology of shallow depressions.

Along the main streams and their by-channels as well as along the meanders natural embankments, *natural levees* were developed and among them *enclosed shallow depressions* were left over. Their origin was explained with floods entering the wide flood-plains produced a braided channel system. Floods moving from the main and by-channels had deposited the major part of their suspended load directly at the two sides of the river bed. This resulted in the gradual rise of the bed margin, so especially the by-channel beds rose above the general level of the flood-plain and by means of their elongated natural levees numerous depressions of varying size came about with poor or no run-off *(Fig. 1)*. Along the natural levees the coarsest fraction of suspended load (fine sand and sandy silt) were deposited. In the depressions of backswamps, however, finer silt and clay were deposited from stagnant waters. Further, the dissolved salts were precipitated from the water of surges which evaporated in mid-summer.

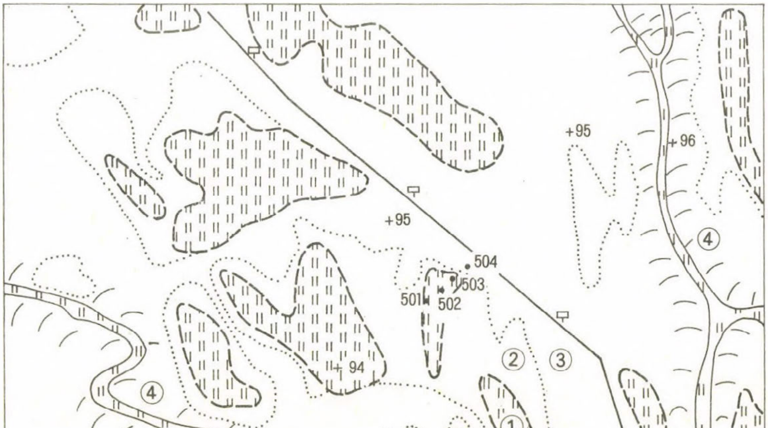

Fig. 1 Salinic spots in the Szabadszállás environs.
1 = Solonchak meadow solonetz; 2 = solonchak medium meadow solonetz; 3 = meadow chernozem on natural levees; 4 = by channels of the Danube and natural levees. Heights a.s.l. in metres. 501-504 = samples.

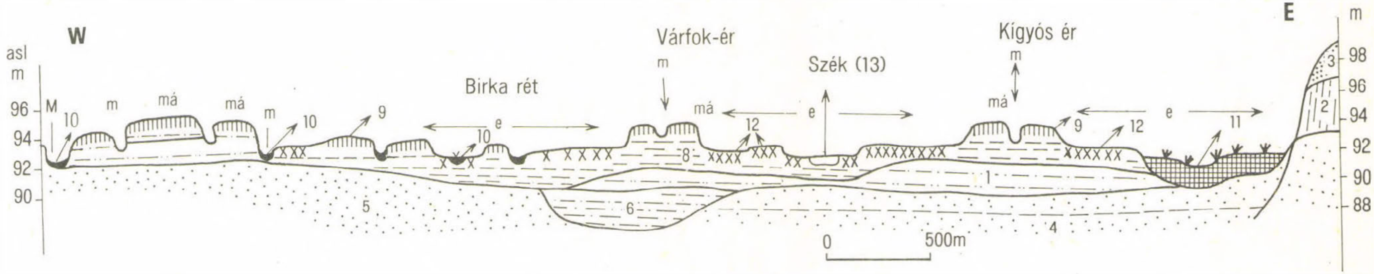

Fig. 2 The micromorphological pattern in the Kiskunság floodplain of the Danube valley. Natural levees (ma), enclosed alkali depressions (e), relationship between lithology and soils
1 = Upper Pleistocene fluviatile sand; 2 = Upper Pleistocene sandy loess; 3 = Early Holocene blown sand; 4-5 = Early Holocene fluviatile sand, silty sand; 6-7 = Holocene silty sand, sandy silt; 8 = flood-plain alluvium, loessy silt; 9 = meadow chernozem; 10 = meadow soil, boggy meadow soil; 11 = boggy meadow soil and peat; 12 = salt-affected soils; 13 = alkali lake; M = filled meander, peat; m = filled by-channel, parameander; má = natural levee (Uferdamm); e = depressions enclosed by natural levees (backswamps), low flood-plain horizons, meadow soils, salt-affected soils

In the course of this type of flood-plain erosion-accumulation mechanism a rather characteristic micromorphological pattern of natural levees, backswamps, abandoned beds, and erosion scars of meanders developed and automatically controlled flood-plain deposition. Together with the formation of this micromorphological pattern, spatially corresponding lithological facies developed *(Fig. 2)*. The resulting *morpho-lithogenic* factor has controlled possible groundwater and surficial water movements in a particular manner. Thus close cause-and-effect relationships developed between the geomorphologic, lithologic, and hydrogeologic factors which ultimately control the ecological potentials of sites and soil formation processes, under the climatic conditions characteristic of the Carpathian basin.

The micromorphological pattern of backswamps isolated from the rivers by natural levees the flood-plain provides one of the most common physiognomic precondition to alkalization, apparently not only in the Carpathian basin but also elsewhere in the flood-plains of great rivers under dry summer conditions.

Although the major part of the Hungarian alkali soils occurs in the geomorphological situation described above, there are types of depression where solonchak formation is of different origin.

On the alluvial fans and terraces of the Danube, Tisza and of their tributaries lying higher than the flood-plain, extensive surfaces of blown sand and loess occur. In the depressions enclosed by blown-sand dunes the salinic formations showing downwind elongation are common.

It is also frequent that in the smaller depressions of loess surfaces of karstic piping origin, in loess dolinas or in the valley-floors of smaller water-courses solonchak formation arises. The widening of salinic loess dolinas, the coupled accretion of depressions was mentioned more than half a century ago (STRÖMPL, G. 1931).

This phenomenon was the basis of conclusions that in the process of sodification the salinic depressions usually grow and widen, the depressions are widened by "salinic erosion" or by karstic piping. It is to be emphasized here that this explanation is not valid of the salinic backswamps along rivers with natural levees, since they are essentially forms enclosed by fluviatile accumulation. Solonchak formation produces only microform, salt berms (salinic steps) that can be interpreted as erosional elements.

Salinic soils naturally occur in other plain forms of relief too, e.g. on flat basins enclosed by the alluvial fans of rivers (e.g. the Lake Fertő environs), these being essentially an enclosed, dammed form of poor run-off and similar to the backswamps enclosed by natural levees.

INTERACTIONS OF FLOOD-PLAIN MICROMORPHOLOGY, GROUNDWATER AND LITHOLOGY IN THE DISTRIBUTION OF SALT-AFFECTED SOILS

The *shallow depressions* (backswamps) *enclosed* between natural levees are mostly saucer-shaped negative forms of 1 to 2 m depth and extremely gentle slopes *(Fig. 1)*. Their surface is usually covered by silty-clayey flood-plain deposits. The remnants of filled *meanders* or *by-channels* in the flood-plain can be certainly distinguished from their environs. They are several ten or several hundred metre wide and meander through kilometres. Between these two common forms numerous transitional facies exist, their classification however is neglected here (see PÉCSI, M. 1958, 1971 for details).

Groundwater lies at the floor of these microforms, in the deepest parts of their cross-sections and closest to the surface. Occasionally, groundwater may seasonally or permanently even reach the surface. On the gentle slopes of these depressions and in the horizons lying some decimetres higher than the floor, groundwater less and less frequently approaches the surface. The annual range of groundwater table change may be 0.5 to 4 m.

In some depressions due to the surficial and groundwater supply seasonal or permanent water—logging may occur. If the surface of the wide enclosed depressions consists of impermeable clayey formations, the seasonal small lakes are recharged by the surficial waters. Their water is not recharged from groundwater, in summer the water surfaces are gradually shrinking or completely evaporates. In these cases the salinic zone gradually increases towards the depression centre and after evaporation the salt is precipitated ('effloresced').

In the depressions where groundwater rises to the surface or remains subsurface during most of the arowing season, peat-bog, boggy meadow, meadow soils and meadow soils salinic at depth form. These soils and their associations occupy the central, lowermost part of the depression, while the gently rising marginal slopes, where groundwater lies 0.5-1 m below the surface, are covered by increasingly alkali soils *(Fig. 1)*. On the natural levees forming locally wider headlands the groundwater lies deeper than two metres during the growing season. These latter forms consist mainly of sand and silty sand. In these types of site usually meadow chernozems or meadow chernozems saline at depth occur.

In this situation the soil spots (both the salt-affected and the non-salinic types) are rather mosaic-like, but are in close relationship with the morpholitogenic factor. Therefore, in these regions it is expedient to carry out soil mapping combined with geomorphological mapping and surveying of micromorphology.

ANALYSES OF SOME SALT-AFFECTED SOIL PROFILES IN THE FLOOD-PLAIN OF THE DANUBE

Field and soil laboratory analyses were carried out to demonstrate the relationships of arrangement of flood-plain form facies, of alkali and non-alkali soils. The catena's type locality was chosen in the salinic puszta of Kiskunság, in the flood-plain of the Danube *(Fig. 1)*, in a depression enclosed by two natural levees. The soil profiles were chosen to obtain exact information on the soil types of the lowermost part of the depression (sample Nº 501), of the gently rising slopes (samples Nº 502 and 503) and of the highest point of the natural levee (sample Nº 504). The height difference between the lowest lying central part of the depression and the highest point of the natural levee proved to be 1.5 to 2.0 m.

The soil formed at the deepest point of the region (sample Nº 501) proved to be *solonchak type deep meadow solonetz*. Samples Nº 502 and 503 lying higher than the first one proved to be *solonchak type medium meadow solonetz* soil. At the highest point, *at the edge of the natural levee calcareous meadow chernozem with shallow humic layer* developed.

The intensity of solonchak formation is gradually increasing from the lowest salt-affected soil (sample Nº 501) to the higher lying samples (Nº 502 and 503), while at the highest point non-alkali meadow chernozem soil developed.

MECHANICAL COMPOSITION:

According to the analyses* *(Table 1)* the soils are mostly of light mechanical composition. In the B horizon of the solonetz meadow soil and in the upper horizons of the crusted solonetz the finer-grained fractions bear higher proportions.

The data support the strong stratification also observed in the course of surveying; it often occurs within the individual soil horizons too.

ANALYSIS OF THE AQUEOUS EXTRACT

In the aqueous extract of 1 to 5 ratio of the samples from the soil horizons the hydrocarbonate, carbonate and sulphate anions predominate. Out of the cations sodium occurs in greatest quantities *(Table 2)*. The least sodium content was found in the meadow chernozem, while its largest amounts were obtained from the solonetz soils, especially in the aqueous extract of the samples from the B horizon of the soils. In this horizon the hydrocarbonate content is always increasing.

EXCHANGEABLE CATIONS

Exchangeable cations were determined from ammonium acetate extracts, the absorption capacity was measured from sodium acetate extracts *(Table 3)*.

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* The analysis of the mechanical composition was carried out by means of pipette after the preparation according to the international "A" prescription.

Table 1 Data of mechanical analyses

Depth cm	Particle diameter mm/g %						%	
	2-0,2	0,2-0,05	0,05-0,01	0,01-0,005	0,005-0,001	0,001	sand	clay
Szabadszállás 501.								
2-7	1,09	25,47	39,63	11,03	4,02	2,70	66,18	17,75
13-18	1,10	35,92	37,04	3,38	3,27	2,68	74,46	9,33
25-35	0,84	32,86	34,22	9,36	4,11	3,32	67,91	16,80
46-57	4,52	12,48	41,20	15,57	8,55	3,90	58,19	28,02
67-77	0,52	62,04	6,66	2,43	7,37	4,63	69,23	14,44
Szabadszállás 502.								
1-5	0,30	46,00	28,28	3,04	2,52	3,82	74,59	9,37
5-9	0,67	8,30	23,88	9,24	14,92	28.19	32,85	52,35
15-27	0,20	12,45	19,06	7,64	13,26	32,70	31,72	53,60
40-50	1,27	26,00	52,97	0,42	0,46	3,63	80,24	4,50
65-80	0,58	5,36	71,18	3,66	1,09	3,59	77,12	8,34
120-130	0,92	55,25	9,57	3,75	9,51	2,92	65,74	16,18
Szabadszállás 503.								
1-5	0,93	24,78	21,01	5,41	9,20	2,01	46,72	36,61
9-15	2,55	24,47	24,62	6,71	11,15	51,64	51,64	29,69
26-32	0,54	40,91	29,82	3,98	3,17	6,60	71,27	12,75
38-45	0,63	36,09	29,02	6,86	7,24	2,77	66,03	16,87
51-56	0,42	37,35	27,61	6,72	7,92	3,92	65,38	18,56
70-85	0,20	63,16	13,03	2,33	0,35	2,86	76,39	5,54
Szabadszállás 504.								
0-10	1,22	46,50	22,21	4,87	4,37	3,33	69,94	13,57
15-25	1,11	50,59	19,18	4,78	3,85	4,50	70,87	13,14
27-32	1,44	52,64	16,89	4,02	4,45	3,89	70,96	12,36
45-54	0,58	53,79	15,02	4,13	5,20	3,24	69,39	12,57
80-90	3,43	64,38	7,13	1,08	1,99	4,25	74,95	8,32
140-150	0,51	62,31	13,14	1,84	0,81	1,51	75,95	5,16

Table 2 Analyses of aqueous extracts of 1 to 5 ratio of the Szabadszállás soils

Profile number	Depth cm	pH	CO_3^{--}	HCO_3^-	Cl^-	SO_4^{--}	Total anion	Ca^{++}	Mg^{++}	Na^{++}	K^+	Total cation
			mg eq/100 g soil									
501	2-7	8,2	0,45	1,40	0,35	0,70	2,90	0,60	0,10	2,47	0,06	3,25
	13-18	8,5	0,60	1,85	0,40	0,65	3,50	0,20	0,15	3,25	0,07	3,67
	25-33	8,4	0,85	1,85	0,25	0,55	3,50	0,11	3,77	3,77	0,07	4,14
	45-57	8,45	0,60	1,80	0,30	0,80	3,50	0,12	0,18	3,90	0,05	4,25
	67-77	8,3	0,30	1,40	0,30	0,85	2,85	0,30	0,30	2,82	0,04	3,46
502	1-5	8,15	0,50	1,25	0,40	0,32	2,47	0,92	0,00	2,30	0,02	3,14
	5-9	8,10	0,60	1,75	0,50	1,20	4,05	0,80	0,20	3,55	0,04	4,59
	15-27	8,30	1,00	3,05	0,45	1,48	5,98	0,70	0,28	7,16	0,05	8,19
	40-50	9,10	1,50	2,40	0,75	1,40	6,05	0,20	0,20	6,51	0,04	6,95
	65-80	8,70	0,50	1,37	0,60	1,07	3,54	0,20	0,12	2,98	0,04	3,34
	120-130	7,25	0,00	0,75	1,60	0,75	1,60	0,30	0,20	0,60	0,04	1,14
503	1-5	7,5	0,40	0,80	0,75	0,55	2,50	0,60	0,30	1,13	0,06	2,09
	9-15	8,2	0,70	2,45	0,65	0,15	3,95	0,25	0,15	3,86	0,05	4,31
	26-32	9,1	1,50	4,00	1,10	0,60	7,20	0,40	0,20	7,16	0,02	7,78
	38-45	9,1	1,30	3,05	1,00	1,25	6,60	0,10	0,40	6,41	0,02	6,93
	51-56	8,5	0,55	1,65	0,25	0,85	3,30	0,15	0,20	2,82	0,03	3,20
	70-85	8,0	0,35	0,92	0,35	0,80	2,40	0,20	0,20	1,43	0,03	1,86
504	0-10	7,9	0,20	0,20	0,20	0,60	1,20	0,70	0,50	0,11	0,04	1,35
	15-25	8,1	0,20	0,50	0,25	0,35	1,20	0,92	0,28	0,13	0,13	1,46
	27-32	7,9	0,20	0,55	0,20	0,35	1,30	1,00	0,20	0,13	0,04	1,37
	45-54	7,9	-	0,70	0,20	0,91	1,81	0,40	0,22	0,61	0,02	1,25
	80-90	7,75	0,15	0,65	0,20	0,96	1,96	0,23	0,23	1,30	0,02	1,78

Table 3 Exchangeable cations of the Szabadszállás soils

Profile number	Depth cm	Ammonium acaetate extract mg equiv.per 100 g soil				Total	Sodium acetate extract mg equiv.per 100 g soil	
		Ca	Mg	Na	K		T	Na T %
501	2-7	15,62	3,95	2,61	0,56	22,74	7,60	17,0
	13-18	16,56	4,94	5,21	0,64	27,35	10,42	32,0
	25-33	8,75	4,42	7,38	0,67	21,22	8,69	63,5
	45-57	14,06	3,90	4,88	0,35	26,34	7,38	46,8
	65-77	15,31	3,90	3,69	0,27	25,60	6,52	38,8
502	1-5	12,31	2,71	4,34	0,41	27,10	14,33	19,8
	5-9	16,25	5,00	5,86	0,41	27,52	11,94	34,7
	15-23	15,62	4,53	11,51	0,67	32,33	22,80	38,1
	40-50	10,46	3,12	12,49	0,78	26,85	17,38	52,6
	65-80	7,81	4,42	0,65	0,90	13,78	11,51	-
	120-130	15,62	3,69	0,54	0,27	20,12	12,49	1,8
503	1-5	8,75	3,90	2,17	1,45	16,27	33,01	4,24
	9-15	15,05	5,20	8,47	0,76	15,93	22,80	28,6
	26-32	11,87	5,92	12,81	0,76	26,03	21,06	40,7
	38-45	14,37	5,77	10,20	0,43	30,77	17,38	36,0
	51-56	3,00	6,82	4,34	0,43	24,91	7,82	41,0
	70-85	12,81	4,52	1,73	0,11	19,17	4,34	21,0
504	0-10	15,62	2,76	0,22	0,39	18,99	17,59	1,1
	15-25	14,37	2,46	0,22	0,63	17,68	18,02	0,70
	27-32	12,18	2,11	0,54	0,48	15,31	18,68	2,4
	45-54	15,00	2,41	0,65	0,17	18,23	7,38	1,3
	80-90	6,81	3,11	1,41	0,12	11,45	3,04	20,0
	140-150	6,87	2,20	2,06	0,12	11,25	4,34	-

Table 4 Mineral composition (%) of the fine fractions of the Szabadszállás soils

		Illite	Montmor-illonite	Illite-montmor-illonite	Illite-chlorite	Chlorite	Quartz	Feldspar	Hydroxides
501	A_1	65	-	-	5	10	15	5	-
	A_2	50	5	5	10	15	10	5	-
	B_1	40	15	5	10	15	10	5	-
	C_1	50	5	5	10	10	10	5	5
502	A_1	65	5	-	5	15	5	5	-
	B_1	55	10	-	5	15	10	5	-
	B_2	55	10	-	5	15	10	5	-
	C_1	55	10	5	5	10	5	5	5
503	A_1	50	10	5	5	10	10	5	5
	B_1	50	10	5	5	10	10	5	5
	B_2	50	10	5	5	10	10	5	5
	C	50	10	5	5	15	5	5	5
504	A	50	5	5	5	15	10	5	5
	A_1^{sz}	45	10	5	5	15	10	5	5
	B	40	15	5	5	15	10	5	5
	C	35	15	5	10	15	10	5	5

Table 5 $CaCO_3$ content of the Szabadszállás soils

Profile number	Soil horizon	Depth cm	$CaCO_3$ content %
501.	A_1	2-7	30,28
	A_2	13-18	35,40
	B	25-33	53,37
	C_1	45-57	61,65
	C_2	65-77	31,24
502.	A_1	1-5	31,56
	A_2	5-9	36,86
	B_1	15-23	31,99
	B_2	40-50	43,86
	C_1	65-80	51,61
	C_2	120-130	32,42
503.	A	1-5	17,50
	B_1	9-15	18,72
	B_2	26-32	34,46
	B_2	38-45	56,15
	C^2	51-56	48,77
	C_2	70-85	37,44
504.	A	0-10	32,33
	B	15-25	28,53
	C	27-32	31,91
	D	45-54	48,77
	E	80-90	73,02
	F	140-150	39,71

Out of the exchangeable cations calcium occurs in greatest quantity, about 50% of all of the exchangeable cations. Magnesium is also found in considerable amounts, in the B horizon of solonetz soils its slight increase can be observed. The sodium content is changing, in the B horizon of solonetz soils its large-scale accumulation is detected.

The study of the fine disperse fractions of the soils in question indicated that no considerable difference exists in the mineral composition of the profiles. In the fine fraction of the soil illite predominates. Further considerable amounts of montmorillonite, quartz, chlorite, feldspar and illite-chlorite mixed-layer mineral were determined. Illite-montmorillonite mixed-layer mineral and the minerals of sesqui-hydroxides were not found in all the samples. Montmorillonite was only absent from one sample (*Table 4*). $CaCO_3$ contents in each profile are demonstrated in *Table* 5.

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EXPERIMENTS TO MEASURE SOIL AND FERTILIZER LOSSES AND TO MINIMIZE THEM

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As part of research into agrogeomorphic processes, the amount of soil loss, surface runoff and the fertilizer content of the eroded soil and of the suspension caught in the recipient are measured under controlled conditions (registered rainfall intensity, given type of cultivation and crop and set amounts of fertilizer).

The purposes of these investigations are the more successful planning of the reduction of surface runoff and prevention of soil and fertilizer losses as well as the minimization of environmental pollution due to wash-off (with special regard to the eutrophication of living waters such as Lake Balaton).

The three-year research activity has already supplied results which can be applied for soil conservation in vineyards.

Today in the vicinity of Lake Balaton vine cultivation goes on with the observation of strict soil conservation rules in order to preserve water quality in the lake. To reduce soil erosion by showers of high intensity and the concomitant water pollution soil surfaces in the vineyards which were weeded previously are now sodded.

The densely grown sod helps reduce soil erosion by violent summer showers and surface water loss in the desirable extent.

Our experiments revealed a new problem. The densely grown sod does not inhibit runoff due to low intensity autumn rainfall, on the contrary, it increases runoff.

It has two *disadvantageous consequences*. Under the climatic conditions of Hungary soil moisture replenished by autumn and winter rainfalls is indispensable for plants. In vineyards on the southern slopes moisture from autumn and winter precipitation stored in the soil is available with traditional soil cultivation. With the present technique of soil cultivation with sodding, in springs with lesser precipitation drought occurs in vineyards. Another harmful phenomenon is the wash-off of fertilizers as a result of autumn-winter surface runoff. Reaching Lake Balaton it accelerates the process of eutrophication.

To prevent this damage experiments were made. We had to be careful to stop soil erosion when it occurs again in summer. We decided on the device that in the inflexion zone of slope a strip of grass of only 1 m width was left rectangular to the isohypses of slopes and in a similar way on the margin of the concave segment of slope another 1 m wide strip of sod was grown. Other soil surfaces were weeded. Thus a compromise of unambiguously positive environmental protection effect was attained with a possible increase in production.

The two narrow strips of grass were sufficient to reduce soil erosion and to filter the suspension running off on the surface during summer showers. At the same time, the low intensity rains of autúmn and winter could infiltrate into the soil, consequently autumn surface runoff becomes minimal and the pollution of living waters with fertilizers is of insignificant degree.

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MAPPING DIRECT SOLAR RADIATION HEAT FOR AGRICULTURAL PURPOSES

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ABSTRACT

This paper is a brief information on computing heat from direct solar radiation during the growing season. The distribution of incidenting heat depends on the inclination and exposure of slopes in a hill region of a given latitude. A map showing this distribution can contribute to the re-designing of cropland pattern of hill agricultural areas in Hungary.

* * *

Agrogeographical research is one of the recently developed branches of landscape study in Hungary. It surveys and assesses the effects of physical geographical factors on crop cultivation. Its aim is to produce some kind of a cropland pattern map showing the order of preference of different plants on the basis of physical environmental endowments. These cropland pattern maps could be then directly applied by state farms and agricultural co-operatives.

Unlike the quantity of solar radiation in the growing season, unfavourable soil, precipitation and even topographic endowments can be - at least theoretically - improved over large areas (consider amelioration, irrigation, reclamation and strip cultivation, etc). Consequently, we decided to construct a method for mapping solar radiation heat to enable agricultural farms on hilly terrains to adjust their field boundaries to the amount of heat received complying with the requirements of plants.

The basic idea we used is extremely simple. We superposed the slope exposure (*Fig. 1*) and slope angle (*Fig. 2*) maps of the same area. The resulting mosaic map shows an areal distribution of heat (*Fig. 3*). The slope exposure has 8 categories (N, W, S, E, NW, SW, SE, NE). The slope category map - as usual in Hungarian agricultural application - has the following classes: 5-12°, 12-17°, 17-25°, 25°< and the flat surface 5°>. Thus, besides constructing slope exposure and angle maps we need a table showing radiation heat for each of the 8x4+1 topographic conditions. Using the so called 'cloud filter' factor we can compare the heat requirement of a plant during the growing season and the mosaic map showing the areal distribution of heat.

The mountain we chose as an example is found in West Transdanubia. Mount Somló is 432 metres high, built up of basaltic rocks and famous for its vineyards and grape vine plantations. The *algorithm* for computing the heat distribution table is described below.

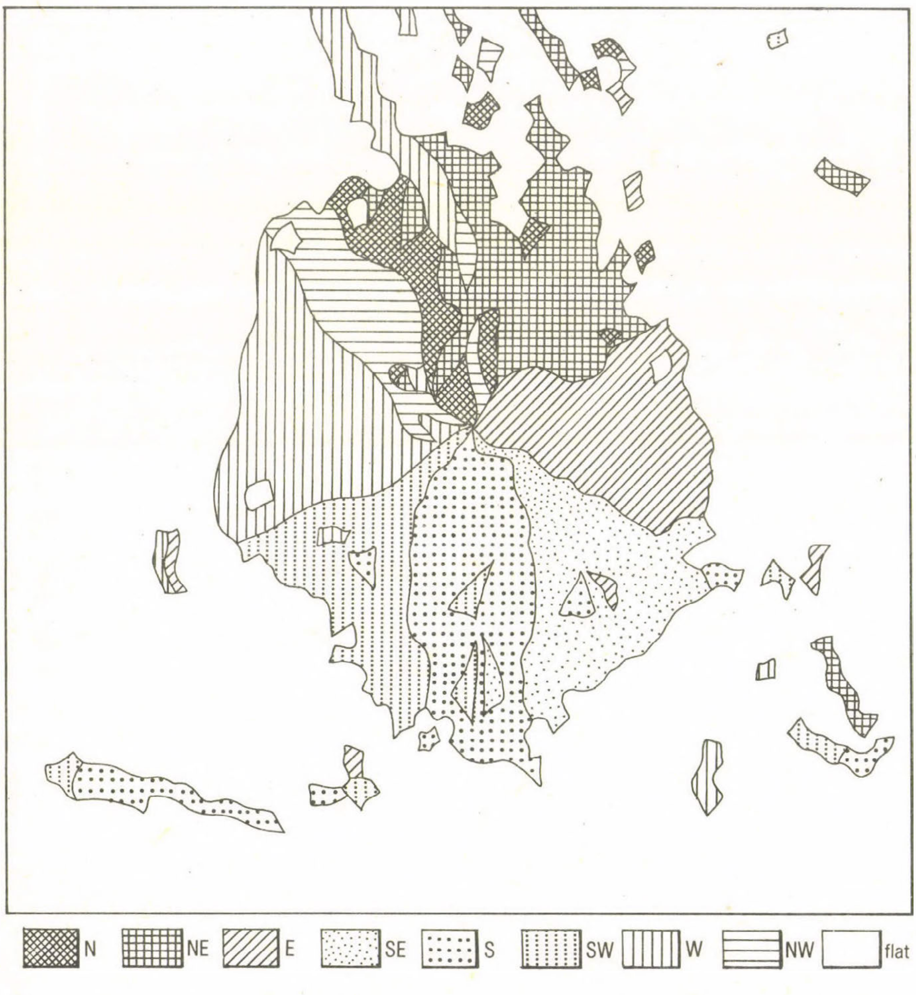


Fig. 1 Slope exposure map of Mt. Somló

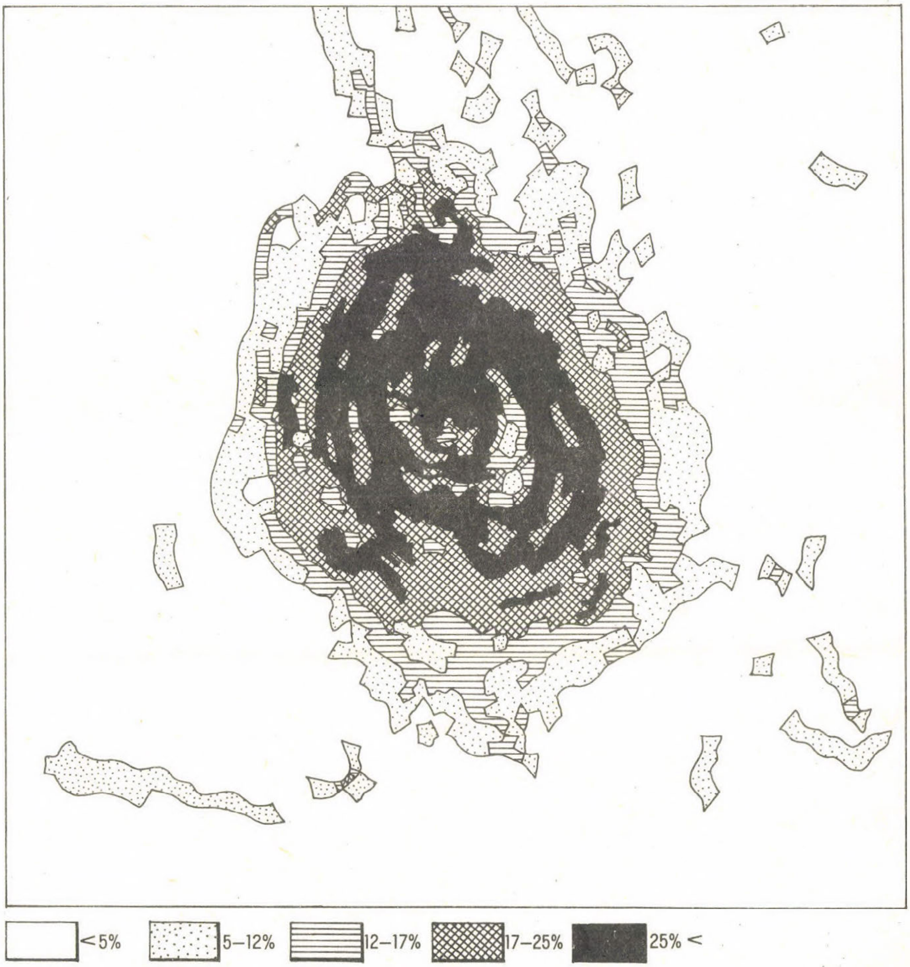
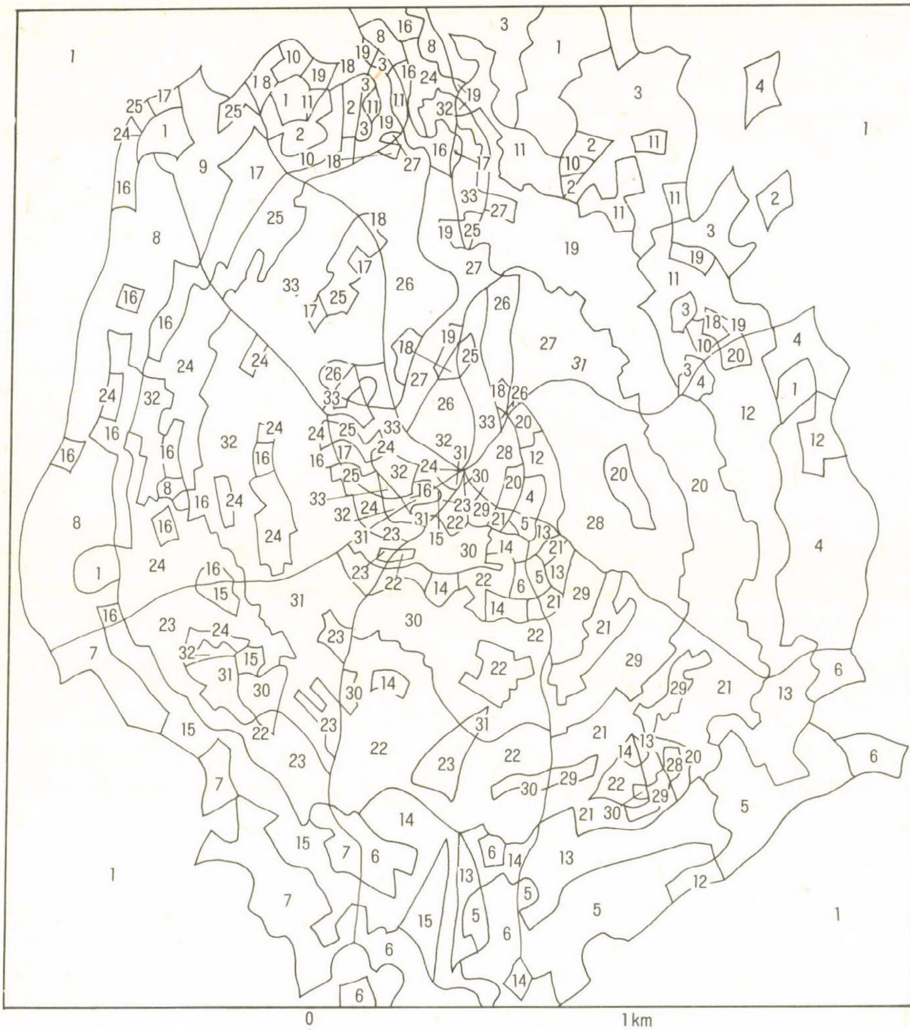


Fig. 2 Slope categories map of Mt. Somló



Slope angle	flat	EXPOSURE							
		N	NE	E	SE	S	SW	W	NW
< 5%	1	–	–	–	–	–	–	–	–
5–12%	–	2	3	4	5	6	7	8	9
12–17%	–	10	11	12	13	14	15	16	17
17–25%	–	18	19	20	21	22	23	24	25
25% <	–	26	27	28	29	30	31	32	33

Fig. 3 Heat distribution map of Mt. Somló

Solar constant: $I_o = 1354 \frac{J}{I_o m^2}\ \frac{W}{m^2}$ at a mean Sun-Earth distance

$\ell = \frac{\text{actual Sun-Earth distance}}{\text{mean Sun-Earth distance}}$ given for each day

q = complex transmissivity coefficient of the atmosphere (q = 0,93)
A = opacity factor of the atmosphere (eg. A = 35)
m = sun elevation angle

φ = longitude

δ = sun declination

ω = sun hour-angle

ω_o = sun hour-angle at sunset ($-\omega_o$ = sun hour-angle at sunrise)

Knowing and the sun elevation angle in hour-angle function is:

(1) $$\sin m : \sin\varphi \cdot \sin\delta + \cos\varphi \cdot \cos\delta \cdot \cos\omega$$

Hence the hour-angle of sunset (sin m = 0):

(2) $$\cos\omega_o = -tg\,\varphi \cdot tg\,\delta$$

a = sun azimuth

The relationship between azimuth and hour-angle:

(3)
$$ctg\ a = \frac{\sin\varphi \cdot \cos\omega - tg\,\delta \cdot \cos\varphi}{\sin\omega}$$

$$a = arc\ ctg \cdot \frac{\sin\varphi \cdot \cos\omega - tg\,\delta \cdot \cos\varphi}{\sin\omega}$$

O = slope azimuth (exposure)
i = slope angle (inclination)
z = path of solar radiation in the atmosphere

(4) $$z = \begin{cases} 39.7 \exp(-0.315\ m) & \text{if } 0° < m \leq 3° \\ \frac{I}{\sin m} - 66.6\ m^{-2.58} & \text{if } 3° < m \leq 8° \\ \frac{I}{\sin m} - 161.8\ m^{-3.02} & \text{if } 8° < m \leq 35° \\ \frac{I}{\sin m} & \text{if } 35° < m \end{cases}$$

Direct radiation onto a flat surface in a particular case:

(5) $$I_v = I_o \cdot \frac{I}{\ell^2} q^{Az} \cdot \sin m$$

Let us transfer the value of the solar constant from mp into radian:

(6)

$$\frac{86400}{2\pi} \cdot 1354 = 18\ 681\ 836 \cdot \frac{I}{s\ m^2} = 18.62 \cdot \frac{M\ I}{s\ m^2} = C$$

this angle is measured in radian.

Direct radiation received by a slope at a given moment:

(7) $$I_\ell = I_o \cdot \frac{I}{\ell_2} \cdot q^{Az} \cdot [\sin m \cdot \cos i + \cos m \cdot \sin i \cdot \cos (a - a_\ell)]$$

S = sum of daily radiation

Sum of daily radiation can be obtained by the integration of the function describing radiation in a particular case from sunrise to sunset:

(8) $$S = C \cdot I_o \cdot \frac{I}{\ell_2} \int_{-\omega_o}^{\omega_o} q^{Az} \left[\sin m \cdot \cos i + \cos m \cdot \sin i \cdot \cos (a - a_\ell)\right] \cdot d\omega$$

- the variables are expressed by (z, m, a); it can be solved by (1), (3), (4).
- integration limits can be calculated from (2).
- value of C constant is given in (6).
- value of δ is given for each day and may be regarded as a constant for each day.

These formulas of the above algorithm allow the automated computation of direct solar radiation heat received by 33 types of terrain (with varying exposure and angle) for each day of the growing season (183 days on the average in Hungary).

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AN OUTLINE OF THE PALEOHYDROLOGY OF THE GREAT HUNGARIAN PLAIN DURING THE HOLOCENE

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ABSTRACT

Starting form the dimensions of river meanders, author has calculated - with the help of empirical functions showing the relationships between dimensions and discharges for the Great Hungarian Plain - the mean and high water discharges of several lowland rivers for various stages of the Holocene period. With these numerical results it becomes possible, for the first time, to reconstruct stage by stage the real hydrological conditions for the past 10,000 years, through mathematical-statistical methods. The hydrological conditions studied include the extents and directions of changes in discharge, absolute and relative range of river regime (hydrograph), total annual runoff (ΣQ) and specific runoff (q). 'Paleohydrology' is understood by author as the approach and reconstruction of events, geomorphic evolution in the Holocene through this method and the term is contrasted with 'paleohydrogeography' meaning the summary of all results produced by the research to date. The tables and diagrams attached to the paper represent the first step in this research direction, the remote goal of which is the numerical description of Holocene climate (first of all, precipitation conditions) in an exact manner in order to give a more profound picture on relief evolution in this period.

* * *

Fluvial geomorphic action have been playing a decisive role in the evolution leading to the present landscape of the Great Hungarian Plain. One of the primary goals of geomorphic research of the basin terrain and margins has been the study of such processes. Ample knowledge has accumulated, through various kinds of sedimentological analyses and the investigation of present fluvial landforms as evidence to the most recent events, on river deposition, its spatial and temporal periodicity and regional changes in stream network. The results summarize the paleohydrogeography of the Great Plain, i.e. the system of facts and assumptions (supported by more or less convincing evidence) which enable us to outline changes in drainage and the spatial differences in erosion and deposition for most of Hungary (and adjacent areas) in various geologic periods. In addition, some geomorphological considerations also allow the reconstruction of river mechanisms and the disclosure of the origin of present surfaces and their age.

In contrast, the term *'paleohydrology'* means *the study of the physical and statistical laws quantitatively and qualitatively governing ancient river dynamics.* For this research numerical data are needed to allow the quantitative statistical investigation of momentary hydrodynamic conditions for various periods in the past. Recently, on geomorphological basis, numerical estimates have been made for the discharges of Great Plain rivers in the various stages of the Holocene and, thus, I am able to reveal some fundamental features of real paleohydrological conditions.

The starting-point for investigations had been the old observation that there is a *relationship between the meander sizes and discharges of meandering rivers.* Along given sections of the present rivers discharge can be measured or calculated by hydrological methods (they are available from hydrological publications in archives) and the typical sizes of meanders in the vicinity can be determined from topographic maps. The

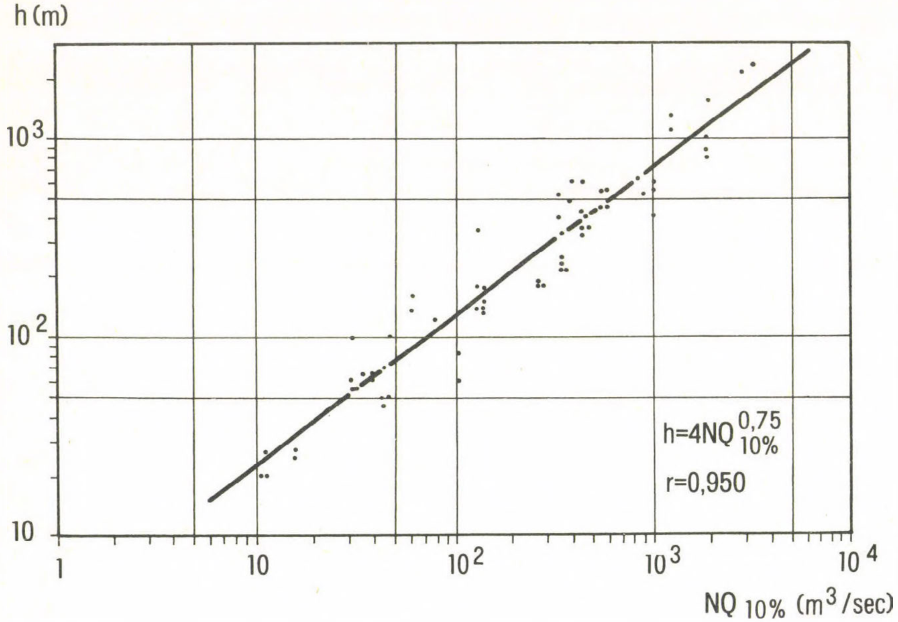

Fig. 1 Relationship between floods of 10 per cent probability ($NQ_{10\%}$) and the length of chord of meanders (h) for the Tisza and tributaries

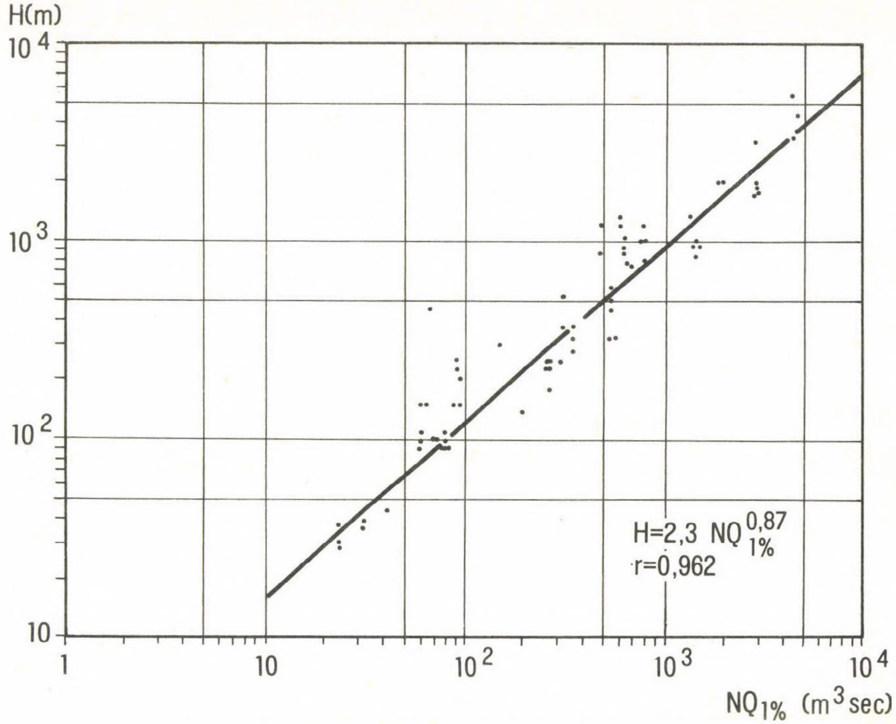

Fig. 2 Relationship between floods occuring in a hundred years ($NQ_{1\%}$) and the length of chord between the inflection points of meanders (H) for the Tisza tributaries

corresponding meander size—discharge data pairs, plotted in a log-log coordinate system, are arranged along a straight line, so the probable relationship between meander size (L) and discharge (Q) is of the

$$L = aQ^b$$

type *(Figs. 1 and 2)*, the constants of which (*a* and *b*) can be calculated by linear regression analysis. The formulas published in world literature, however, cannot be directly applied for the Hungarian rivers, since neither among the meander sizes nor among discharges can we find similar values to the Hungarian ones. Moreover, it is also clear by now that the coefficients of the previous formula are altered, even in the case of data pairs of the same type, with the changes of the geographical environment (of climate, vegetation and the like). Consequently, the functions had to be recalculated with Hungarian data. The three meander parameters used in Hungary (length of chord, arc between inflection points and meander amplitude) as well as the discharge data (mean water, peak discharges occuring in 10 years, 33 years and 100 years) allowed the establishment of altogether 12 equations with 12 *a* and *b* constants. Meander sizes are obtained from topographic maps of 1:25,000 scale (GÁBRIS, Gy. 1970) and for smaller water-courses from those of 1:10,000 scale. Since calculations indicated high correlation coefficients of the data pairs (0.937-0.965), other influencing factors in the formation of meanders in addition to discharge (channel slope, bank material etc.) are avoided in this first approach. Here the remark should be made that data collection for other factors is under way to promote the formulation of a planned more exact and multivariate function.

From the ample paleogeographical literature concerning the Great Hungarian Plain supplemented with the results of the present investigation I managed to compile a summarizing table for ancient rivers of various age (GÁBRIS, Gy. 1985). From the sizes of abandoned meanders, by the 12 equations, likely mean discharges and the different peak discharges for the period of channel formation could be estimated. Thus, numerical data is available for the likely discharges of the Great Plain streams in the various stages of the Holocene.

The diagrams drawn from the discharge data calculated *(Figs. 3-6)* clearly demonstrate, in accordance with previous assumptions, the trends in the various stages of Holocene. It is fundamental, however, that the quantitative information obtained allows the estimation of the extent of changes in addition to their trends. If e.g. mean annual discharges are compared to the present figures, it appears that stream discharge was 9.5 times greater in the Preboreal stage, 8.5 times in the Subboreal and 4 times in the Subatlantic stage than today. In the Boreal stage, however, they had, on the average, one-third of the present discharges. It is also obvious from the data that in the Atlantic stage discharge was maximum, although there are some incredibly great differences and too great standard deviations. The numerical values for peak discharges support the same trend but with lesser range.

In spite of the vast differences (ten times greater figures) the meandering streams in the Great Plain seem to have preserved their sinuosity during the Holocene; this can only be explained by slight modifications in bed load and the alternation of meandering and cutting or depositing types of river reaches (SOMOGYI, S. 1983). Other changes in the types of river reaches cannot be assumed in the Holocene.

Table 1 shows the various discharge parameters of the ancient streams investigated compared to their present counterparts (the ratios are e.g. Atlantic $NQ_{10\%}$ per present $NQ_{10\%}$). A note to discharge figures: one of the difficulties of discharge calculation from cut-off channel dimensions may be that the values for loops at varying stages of development result unreal figures. Therefore, in the same way as in the calculation of the constants in the 12 equations of meander size—discharge relationships, discharges for the Holocene were determined from the parameters of well-developed and mature loops (with arc length /H/ and chord length /h/ ratios between 1.4 and 2.0 and arc height /m/ and chord length /h/ ratios between 0.4 and 1.0). I was compelled to neglect the stage of development as a factor of exclusion in the cases when only a single characteristic ancient meander section could be determined at the present level of research (these instances are indicated

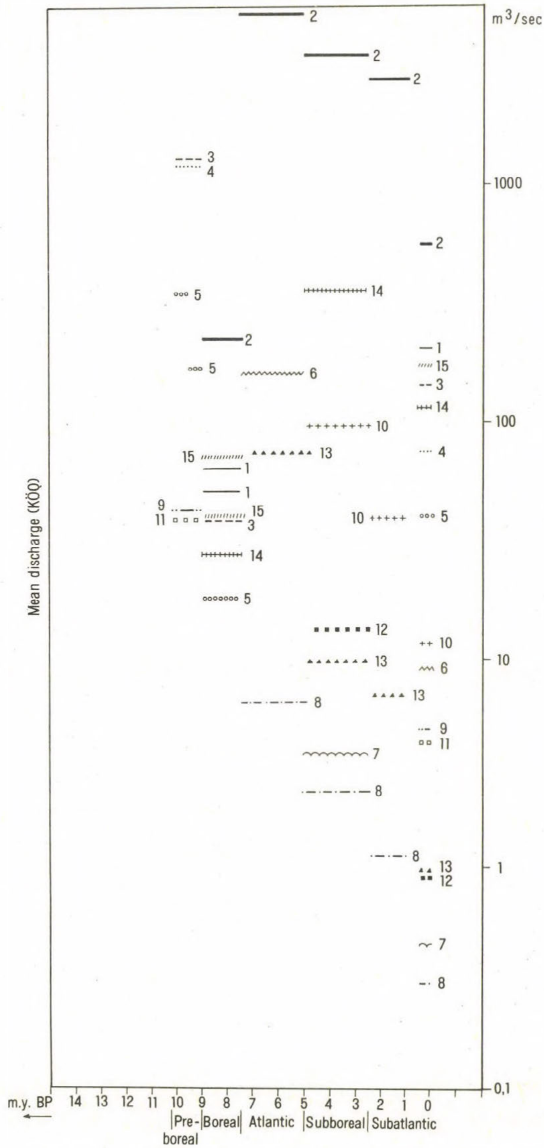

Fig. 3 Present and Holocene mean discharges for the various reaches of the Tisza tributaries
1 = Upper Tisza; 2 = Middle Tisza; 3 = Szamos; 4 = Sajó-Hernád; 5 = Sajó; 6 = Bódva; 7 = Szuha-patak; 8 = Kácsi-patak; 9 = Tarna; 10 = Lower Zagyva; 11 = Upper Zagyva; 12 = Galga; 13 = Tápió; 14 = Triple Körös; 15 = Maros

Table 1 Holocene discharges for 15 Great Plain rivers and their ratios to present discharges

1	2	3	4	5	6	7	8	9	10
Stream		Holocene discharges and ratios to present discharges							
	KÖQ (m^3/sec)	Hol KÖQ / Pres KÖQ	NQ10% (m^3/sec)	Hol $NQ_{10\%}$ / Pres $NQ_{10\%}$	NQ3% (m^3/sec)	Hol $NQ_{3\%}$ / Pres $NQ_{3\%}$	NQ1% (m^3/sec)	Hol $NQ_{1\%}$ / Pres $NQ_{1\%}$	Age of channels
Upper-Tisza									
Karcsa at Örös	55	0,29	620	0,33	824	0,33	950	0,33	Boreal
Tarpa-Hete-Tákos	44	0,23	530	0,28	707	0,28	820	0,28	Boreal
Márokpapi-Csaroda-Gelénes	117	0,62	960	0,51	1250	0,50	1430	0,49	Atlantic?
Middle-Tisza									
Üllö-lapos*	5520	10,4	10900	3,9	12900	3,5	13950	3,2	Atlantic
Oktalan-lapos	2855	5,4	7530	2,7	9010	2,5	9590	2,2	Subboreal
Tiszaigar channel*	3670	6,9	8660	3,1	10300	2,8	11300	2,6	Subboreal
Kösély	250	0,47	1590	0,57	2020	0,55	2300	0,52	Boreal?
Hortobágy	790	1,5	3450	1,2	4220	1,2	4690	1,1	?
Kadarcs	840	1,6	3540	1,3	4340	1,2	4800	1,1	?
György-ér (Tiszasüly)	208	0,39	1440	0,5	1840	0,5	2080	0,47	Boreal
Szamos									
Nagy-Éger	1250	9,7	4520	4,5	5470	4,4	6010	4,2	Preboreal
Jánk-Császló	34	0,26	434	0,43	548	0,44	680	0,47	Boreal
Bodrog									
Karcsa (Karos)*	43	0,40	517	0.57	688	0,69	790	0,59	Subboreal
Sajó-Hernád									
Énekes-ér*	1740	26,5	5730	10,4	6890	10,4	7420	9,6	Preboreal
Énekes-ér (only from 'h'value)	1120	17	4400	8	5200	7,9	6100	7,9	Preboreal
Sajó									
Matotaér	330	10,3	1970	5,1	2480	4,9	2780	4,7	Preboreal
Tözeges-Szil-Dercs-ér	155	4,8	1185	3,1	1530	3,0	1750	2,9	Preboreal
Borsod flood-plain	52	1,6	596	1,6	790	1,6	910	1,5	?
along the Hejö	15	0,47	258	0,67	352	0,70	410	0,69	Boreal
Bódva									
at Szalonna*	200	27	1400	23,3	1800	24	2000	22,2	Atlantic
at Szalonna (only from 'k' value)	146	19,7	1200	20	1500	20	1800	20	Atlantic
Szuha									
Szuhakálló (abandoned channel)	3	6,9	96	3,2	138	3,1	170	2,9	Subboreal
Kácsi-p.									
Mezönagymihály (abandoned ch.)	5	17,3	133	6,6	189	6,3	230	5,8	Atlantic
-"- -"-	2	7,0	73	3,7	107	3,6	134	3,4	Subboreal
-"- -"-	1	3,7	51	2,6	75	2,5	95	2,4	Subatlantic
Zagyva									
Mély-ér (Zagyvarékas)	34	3,5	450	3,5	606	2,8	713	2,3	Subatlantic
-"- (to the E)	84	8,7	800	6,2	1050	4,8	1210	3,9	Subboreal
Zagyva									
Horgas-ér (Jászfelsöszentgyörgy)	33	9,4	436	9,9	585	9,8	685	9,5	Preboreal
Tarna									
Árpás-ér	37	9,3	480	6,2	643	5,6	750	4,9	Preboreal
Galga									
Hévízgyörk	11	12,2	216	5,5	297	5,2	350	4,2	Subboreal
Tápió									
Tápiószele	65	68,4	696	22,5	1000	21,7	1050	17,2	Atlantic
Tápiógyörgye	8	8,3	175	5,6	245	5,3	297	4,9	Subboreal
-"-	5,5	5,9	142	4.6	200	4,3	245	4,0	Subatlantic
Körös									
Kurca (Mindszent)	24	0,23	350	0,4	475	0,6	557	0,46	Boreal
-"- (Szegvár)	109	1,04	933	1,07	1210	1,18	1400	1,16	?
-"- (Szentes)	55	0,52	604	0,69	800	0,78	930	0,78	?
-"- (Csongrád)	140	1,33	1080	1,24	1400	1,35	1600	1,26	?
Korogy-ér	340	3,2	1930	2,2	2420	2,3	2740	2,3	Subatlantic
Mágocs-ér	107	1.02	920	1,06	1200	1,16	1380	1,15	?
Kurca (Mindszent)	24	0,23	337	0,39	458	0,44	540	0.45	?
Maros									
Száraz-ér (Battonya)	64	0,40	658	0,54	870	0,55	1010	0,53	Boreal
-"- (Mezökovácsháza)*	307	1,9	1780	1,5	2260	1,4	2540	1,3	?
-"- (Tótkomlós)	34	0,23	427	0,35	580	0,37	695	0,37	Boreal

* approximate discharge estimates from underdeveloped or overdeveloped loop data

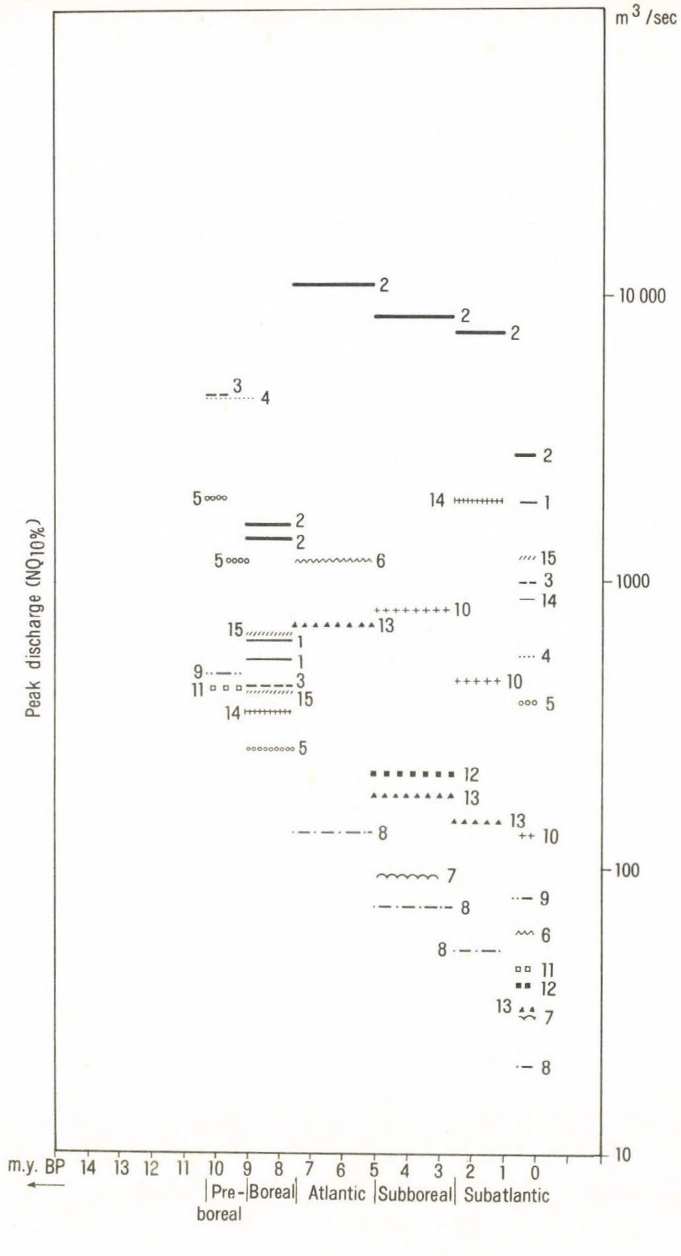

Fig. 4 Present and Holocene peak discharges of 10 per cent probability for the various reaches of the Tisza and tributaries. For legend see Fig. 3

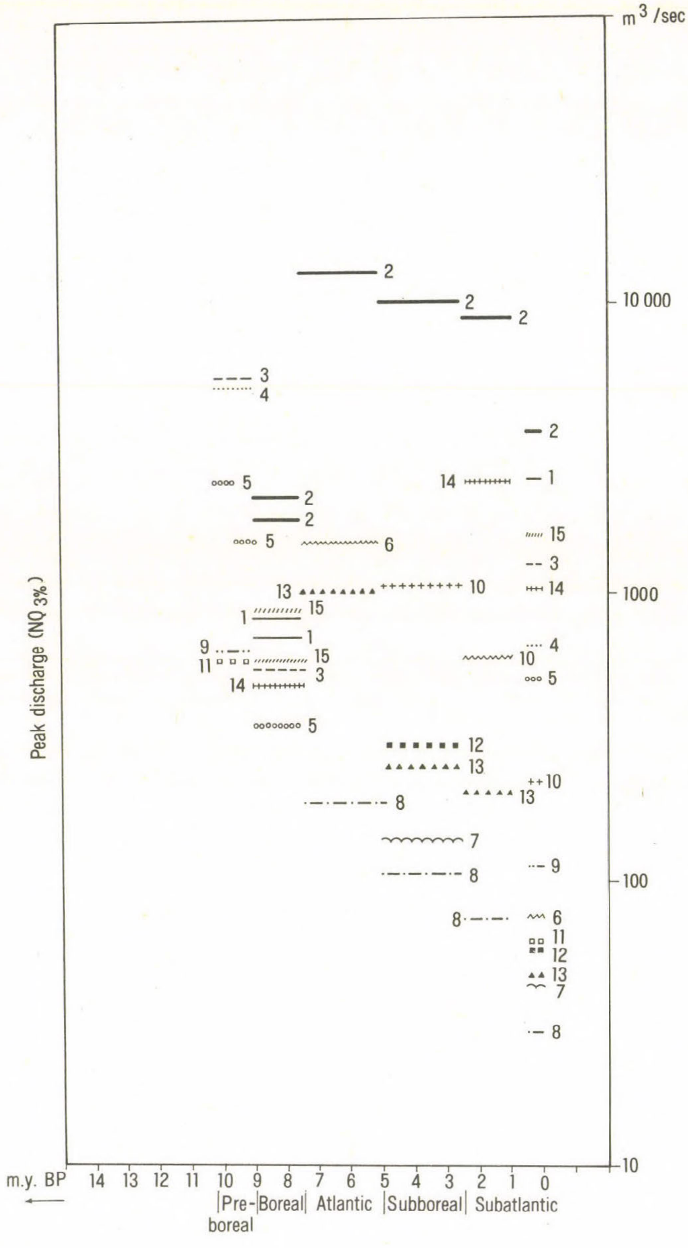

Fig. 5 Present and Holocene peak discharges of 3 per cent probability for the various reaches of the Tisza and tributaries. For legend see Fig. 3

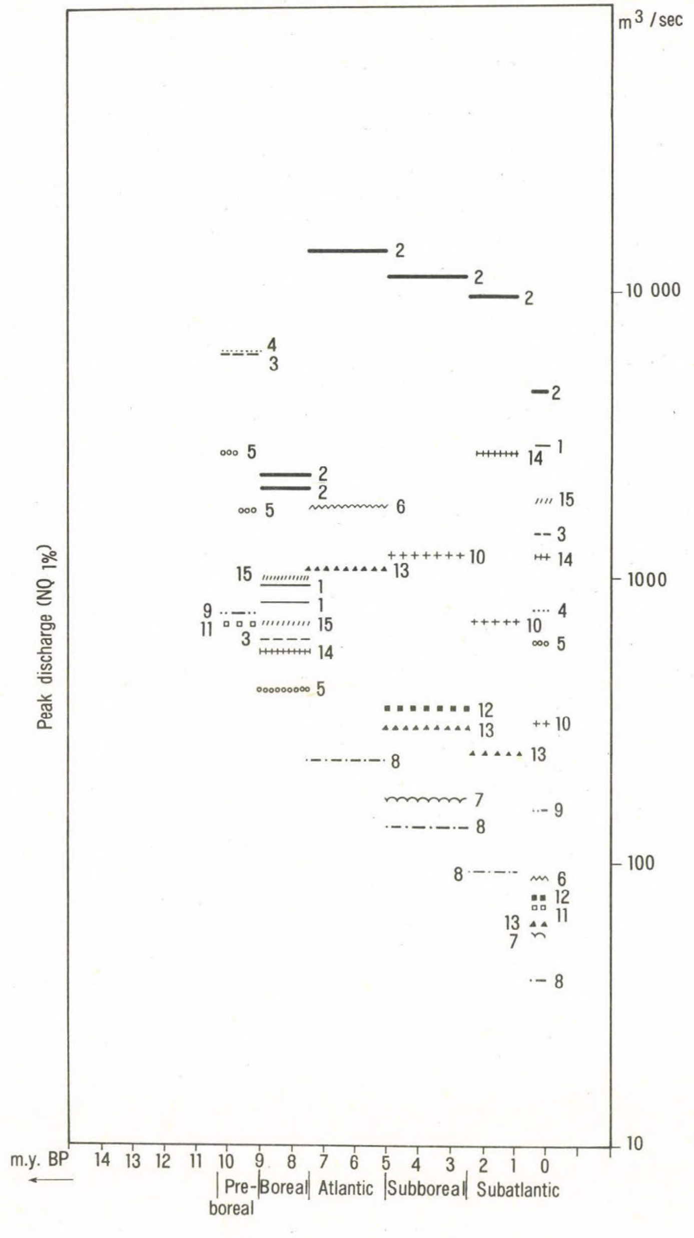

Fig. 6 Present and Holocene peak discharges of 1 per cent probability for the various reaches of the Tisza and tributaries. For legend see Fig. 3

with *x* mark in the table to give a warning about the reliability of such data).

The changes in the ratios of discharges of the same stream but of various frequency may be interpreted in the following way:

1. if increase is towards high waters, it means greater extremities in discharges in the given period;
2. if there is decrease, figures point to a more even hydrograph.

It is only in the Boreal stage that ratios tend to grow. Consequently, extremities were very great, much exceeding the present ones. In other stages the ratios show a rather decreasing trend toward less and less frequent peak discharges; this proves a more even hydrograph. For the range of the river regime, however, no information is provided by these figures. To this end, the 100-year discharges ($NQ_{1\%}$) and the annual mean discharges of ancient streams were related to each other in order to attain a more exact picture of the differences in discharge. The data, however, showed a vast range and did not promote the solution of the problem. Nevertheless, it was conspicuous that the ratios for larger rivers are lower, while those for shorter streams of lesser discharge are higher. An inverse relationship could be assumed between the $NQ_{1\%}$ per KÖQ ratio and the KÖQ on the one hand and between $NQ_{1\%}$ per KÖQ and the catchment area (F) on the other. Plotting the data of *Table 2* against each other on a millimetre grid, it appeared that the points are arranged along a curve indicating exponential relationship between these factors *(Figs. 7 and 8)*. This gave hope for the interpretation of the *'half-ratios' of range of discharge* for the stages of the Holocene in comparison with those for the present time *(Table 3)*. The name 'half-ratio' indicates that it only refers to *the difference between mean water and high water*, since there is no information available for low waters in the Holocene). The quotients of the two ratios are surprisingly similar for the various stages of the Holocene for all streams, but they are characteristically distinct from each other by periods. The relationships of present and Holocene range of discharge by periods could be demonstrated both graphically and by calculating correlation between them *(Fig. 9)*. Unfortunately, with the exception of the Boreal stage, few data were available for the calculations and, consequently, the results are only for orientation, even if some conclusions can be drawn. Correlation coefficients are high (above 0.9), but the steepness of the regression line varies with periods. The relationship is observed in each period, although manifest in a different way; the range of discharge varied with the various stages.

The information for the Boreal stage satisfies the minimum requirements of statistical processing; some of the data, however, are irreconcilable with the general picture. Regarding all the ratios, the correlation coefficient is only 0.57, while calculating from six data, it is 0.91. This irregularity may have two explanations. One is that the ranges of discharge are greatest in this period, also manifest in the higher standard deviations of the ratios. The other consideration raises

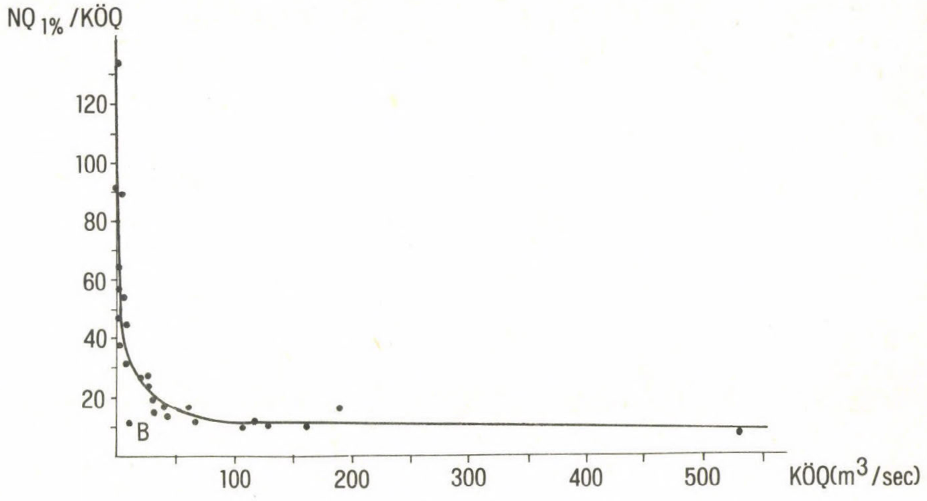

Fig. 7 Relationships between mean discharges (KÖQ) and the high water-mean water ratio ($NQ_{1\%}$/KÖQ for the Tisza and tributaries

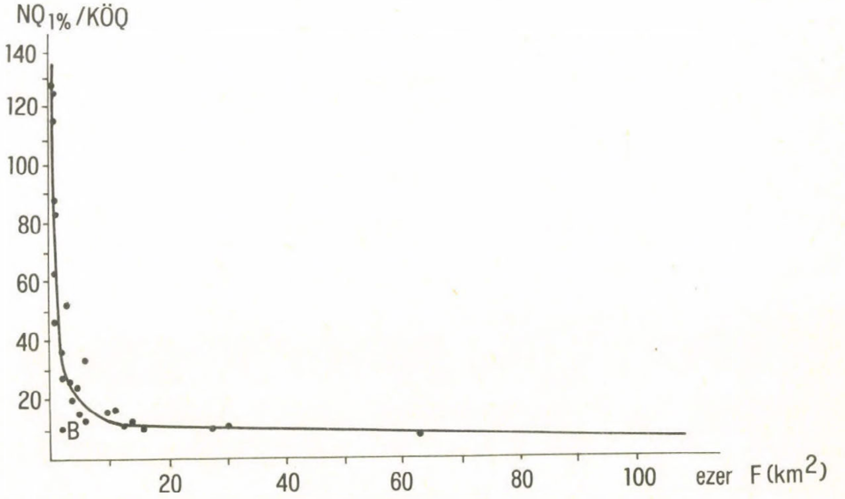

Fig. 8 Relationship between catchment area (F) and the high water-mean water ratio ($NQ_{1\%}$/KÖQ) for the Tisza and tributaries

Table 2 Mean discharges (KÖQ), catchment areas (F) and $NQ_{1\%}$/KÖQ ratios of the Tisza and tributaries

	KÖQ (m^3/sec)	F (km^2)	$NQ_{1\%}$/KÖQ
Upper-Tisza	190	9693	15,37
Middle-Tisza	530	62716	8,36
Lower-Tisza	815	138399	5,77
Szamos	130	15882	11,08
Kraszna	5	3142	54,00
Bodrog	115	13579	11,74
Ronyva	2,25	522	88,88
Bózsva	0,95	-	90,52
Sajó (at the border)	20,40	3239	26,47
Sajó (at confluence)	65,6	12708	11,74
Hangony	0,7	-	95,71
Bán-p.	0,9	-	75,55
Szuha-p.	0,45	212	128,88
Ménes-p.	0,09	-	266,66
Rakaca-p.	0,55	-	110,90
Szinva-p.	1,4	-	64,28
Hernád (at the border)	29,9	4008	20,07
Hernád (at confluence)	32	5435	15,00
Takta-p.	1,4	-	57,14
Eger-p.	2,6	892	47,30
Kánya-p.	0,42	-	138,09
Kácsi-p.	0,3		133,33
Laskó-p.	0,5	365	128,00
Upper-Zagyva	3,5	1955	20,57
Zagyva	9,6	5676	32,29
Tarján-p.	0,3		140,00
Herédi-Bér-p.	0,7		107,14
Galga	0,9	568	83,33
Tarna	4,0	2116	38,00
Gyöngyös	0,8	544	116,25
Ágói-p.	0,32	-	165,62
Tápió	0,95	898	64,21
White-Körös	26	4275	24,62
Double-Körös	60,4	10470	15,89
Black-Körös	42	4729	15,24
Swift-Körös	25,2	2489	26,98
Swift-Körös	39,4	-	16,50
Triple-Körös	105	27537	11,43
Berettyó	7,8		44,87
Berettyó	10		32,00
Maros	160	30149	11,12

Table 3 The half-ratios' of present and Holocene range of discharge of the Great Plain streams and their quotient

Stage	River	Pres $NQ_{1\%}/KÖQ$	Hol $NQ_{15}/KÖQ$	$\frac{Hol\ NQ_{1\%}/KÖQ}{Pres\ NQ_{1\%}/KÖQ}$
Preboreal	Sajó-Hernád	11,74	4,26	0,36
-"-	Sajó	18,66	8,39	0,45
-"-	Szamos	11,08	4,77	0,43
-"-	Tarna	38,00	20,30	0,53
-"-	Upper-Zagyva	20,57	20,76	1,01
Boreal	Upper-Tisza	15,37	17,34	1,14
-"-	Upper-Tisza	15,37	18,70	1,22
-"-	Szamos	11,08	20,00	1,88
-"-	Sajó	18,66	27,47	1,47
-"-	Middle-Tisza	8,36	9,99	1,21
-"-	Middle-Tisza	8,36	9,20	1,10
-"-	the Körös rivers	11,43	22,46	1,97
-"-	the Körös rivers	11,43	16,95	1,48
-"-	Maros	11,85	15,83	1,32
-"-	Maros	11,85	20,44	1,61
Atlantic	Middle-Tisza	15,37	2,53	0,31
-"-	Bódva	12,16	12,33	1,01
-"-	Tápió	64,21	16,15	0,25
-"-	Kácsi-p.	133,33	44,40	0,33
Subboreal	Zagyva	32,29	14,40	0,45
-"-	Galga	83,33	31,91	0,34
-"-	Tápió	64,21	37,59	0,59
-"-	Szuha-p.	128,88	54,84	0,42
-"-	Kácsi-p.	133,33	63,81	0,49
Subatlantic	Zagyva	32,29	20,97	0,66
-"-	Tápió	64,21	43,75	0,68
-"-	Kácsi-p.	133,33	86,36	0,78
-"-	the Körös rivers	11,43	8,09	0,72

a more general problem: starting from the dating of cut-off channels with insufficient exactitude, the assumed sequence of the particular channel generations is only a rough approximation (with few reliable C^{14} dating). More minute dating within the stages is as yet impossible, although it is a major precondition to further progress. The dating of much more channels with various methods (pollen analysis, dendrochronology, absolute and archeological dating) is necessary in order to obtain more reliable and detailed knowledge on the hydrology and climate of the Holocene. Dating is probably most difficult in the Boreal stage with streams of extreme water regimes and the greater differences in the ratios and in discharges can be explained by channel formation overlapping in time with the much more humid stages either immediately before or after the Boreal stage. It is assumed, for instance, that of the two

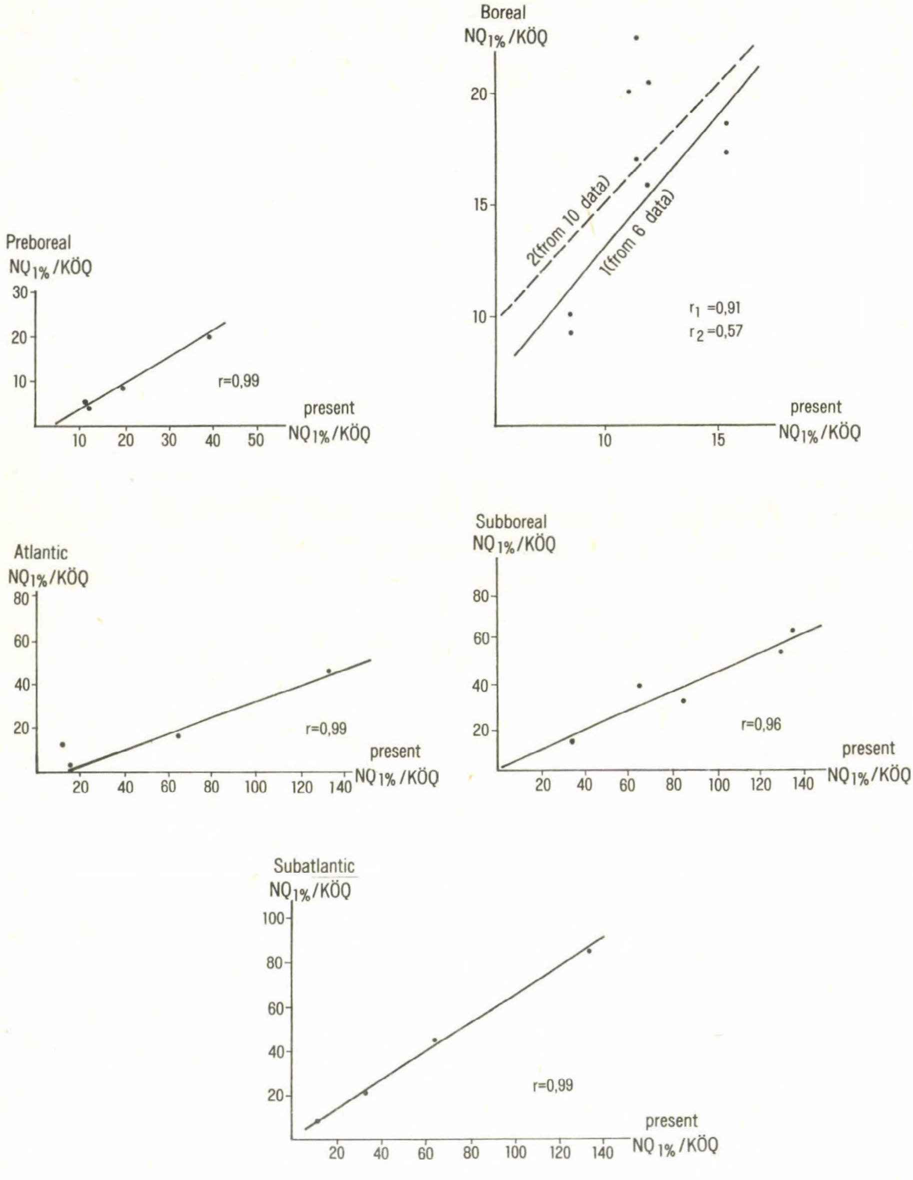

Fig. 9 Relationship between present and Holocene high water-mean water ratios for the Great Plain rivers

Table 4 Annual total discharges (ΣQ) of the Great Plain streams in the various stages of the Holocene

Stream	ΣQ (10^6 m^3)					
	Present	Preboreal	Boreal	Atlantic	Subboreal	Subatl-antic
Upper-Tisza	6002	-	1560	-	-	-
Middle-Tisza	16742	-	7230	174000	116000	90200
Szamos	4106	39600	1040	-	-	-
Sajó	1087	10500	474	-	-	-
Bódva	234	-	-	4610	-	-
Szuha	14	-	-	-	98	-
Kácsi-p.	9,5	-	-	164	66	35
Zagyva	303	-	-	-	2650	1070
Zagyva (without the Tarna)	109	1040	-	-	-	-
Tarna	126	1160	-	-	-	-
Galga	28	-	-	-	347	-
Tápió	30	-	-	2050	250	177
Triple-Körös	3317	-	758	-	-	10700
Maros	5054	-	1070	-	-	-

Table 5 Specific runoff (q) of the Great Plain streams in the various stages of the Holocene

	Specific runoff; q ($l/sec/km^2$)					
	Present	Preboreal	Boreal	Atlantic	Subboreal	Subatl-antic
Upper-Tisza	19,6		5,7			
			4,5			
Middle-Tisza	8,45		4,0			
			3,3	88,0	58,5	45,5
Szamos	8,2	79,1	2,1			
Sajó (at confluence)	5,16	27,6	1,2			
Szuha-p.	2,12				14,6	
Upper-Zagyva	1,79	16,9				
Zagyva	1,69				14,8	6,0
Galga	1,58				19,4	
Tarna	1,89	17,5				
Tápió	1,06			72,4	8,8	6,2
Triple-Körös	3,8		0,9			12,3
Maros	5,27		2,1			
			1,1			

different Boreal channel generations of the Maros and the Körös rivers, one dates back to the driest, extremely arid section of the stage, while the other - in accordance with the channels of the same age of other streams under investigation - points to altered conditions within the Boreal. The irregular data for the Bódva river in the Atlantic stage are also worth mentioning. The irregularity cannot be explained as yet, but it is worth to notice that in *Figs. 7 and 8* it is the river with quite deviant figures (indicated with *B*) and, thus irregular data for the Holocene are not surprising.

The *quotient of ratios of range of discharge* by periods (*Table 3*, last column) shows the range compared to the present one. The river regime is the more even, the higher the quotient and it follows the following sequence in the stages of the Holocene:

1. Boreal, 2. Present, 3. Subatlantic, 4. Subboreal, 5. Preboreal and 6. Atlantic.

A remote goal of this paleohydrological research is to describe the climate (primarily precipitation conditions) of the Holocene in a new approach and, if possible, in numerical form. With the reconstruction of climate in mind, *Tables 4 and 5* are worth to study. They show the total discharge ($\sum Q$) for some Great Plain streams in various periods and give comparative information on Holocene and present values of specific runoff (q). To the letter table the note should be made that calculations were based on the present catchment areas and major changes were not assumed for the last 10,000 years.

The above paleohydrological results only represent the first step towards the reconstruction of precipitation conditions. The factors influencing runoff should be studied in more detail by catchments, since there is an intricate relationship between precipitation and runoff. The value of q depends on climatic factors (temperature, evaporation) and catchment parameters (area, altitude, shape, slopes of main and subsidiary valleys, relief, permeability of soils, vegetation cover etc.). The way from the knowledge of runoff conditions to the detailed *reconstruction of* precipitation and, in general *climate of the Holocene* leads through the profound analysis and numerical evaluation of these factors.

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SURFACE EVOLUTION AND SOIL EROSION AS REFLECTED BY MEASURED DATA

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ABSTRACT

In a test area the soil loss due to rill erosion was calculated from the dimensions of rills formed by marked events of precipitation and, similarly, the amount of accumulated material was determined by volumetric calculations. The data show that 56.7% of all soil losses are accumulated in the piedmont area after 1-2 km of transportation. It was found that sheet erosion translocated six times as much material as the amount of soil removed from the erosion rills. Data are presented here to show that in other regions of Hungary with different geology and landforms, the rate of sheet and rill erosion may considerable differ from the data obtained in the Tokaj-Hegyalja. Finally, calculated data are presented to prove that in the Pleistocene period the rate of denudation in the Hungarian mountains did not reach the present-day intensity of accelerated soil erosion.

ROLE OF RILL EROSION IN SLOPE EVOLUTION

First, the characteristics of rill erosion must be emphasized. In *agriculturally cultivated areas* tillage destroys the rills created by natural processes and *soil loss is manifest areally over a long interval of time.* Another essential point in connection with rill erosion is that rill depths never exceed the depth of soil. They occur not only on soils in the strict sense of the word, but also on loose deposits as e.g. barren loess surfaces, Pannonian sediments, etc. (BOROS, L. 1977).

Rill erosion plays an important part in *slope evolution.* Its true significance can be judged if the loss caused by a given amount of rainfall is determined immediately after the event. This is accomplished in the following way: Measurements are performed for the width and depth of rills, their cross-sections are recorded with geometrical figures (e.g. triangle, rectangle, trapeze, etc.) characterizing the cross section most exactly. The measurements must be taken at several sites along the longitudinal section of each rill (possibly at equal intervals) since the depth of the rill may change significantly along the longitudinal profile.

With the above method repeated surveys were made in the Bodrogkeresztúr region in the years 1975-80. During this interval the largest amount of erosion was observed after a rainfall of 83.4 mm, lasting for three days (June, 1976), on which occasion there occurred in a vineyard area sloping at an angle of 8° a soil loss up to 280 m^3 per hectare. This corresponds to the removal of a 28 mm thick surface layer.

For the demonstration of the areal differences of erosion, the individual measurements mostly limited to small surfaces were less suitable than the large-scale survey concluded in February 1979 involving broader areas. In this period rill erosion was induced only by some precipitation of 44 mm, fallen on more than one occasion (rainwater to a greater, meltwater to a lesser extent). The maximum single event of precipitation only amounted to 12.1 mm.

From the above facts it follows that, although the absolute amount of soil eroded from the area of 3 km^3 is not too large, the data obtained *(Table 1)* permit some geomorphological conclusions. (A separate study gives account on the methods of mapping and of processing the data by covariance analysis KERÉNYI, A. 1984).

Table 1 Loss of soil calculated from the dimensions of erosion rill in the Bodrogkeresztúr semi-basin (18-23 February, 1979).

1) Total amount of soil eroded from the mapped area		513.32 m^3
from plots	448.14 m^3	
from dirt roads	65.18 m^3	
2) Total amount of soil accumulated in the mapped area		228.32 m^3
on plots	213.17 m^3	
on roads and in roadside ditches	15.15 m^3	
3) Amount of soil removed from the mapped area (1-2)		285.00 m^3
4) Amount of soil accumulated south of the area[1]		50.00 m^3
5) Total accumulation (2+4)		278.32 m^3
6) Soil transported to Bodrog river (1-5)		235.00 m^3
7) Short-distance material displacement within plots		29.96 m^3
8) Total amount of displaced solid material		543.28 m^3

[1] Value estimated from earlier measurements

56.7 per cent of the total soil loss calculated from the dimensions of rills was accumulated on the piedmont slope of 2-4°. This means that *nearly 300 m³ of soil accumulated after some transportation of only 1-2 km.* Thus, *the opposite processes of erosion and accumulation both promote surface planation at a geologically rapid rate.*

It is worth to remark here that about half of the accumulating soil sedimented at the 4-5 m high slide slope of the main road (as an artificial obstacle in consequence of wrongly planned culverts) traversing the area. The process of accumulation is regularly iterated here, as a result of which the depth of soil accumulation since the building of the main road has reached 1 m in the cetral area of the semi-basin. *All this points to the immediate influence of engineering structures on the geomorphologic process.*

5.5 per cent of the total amount of the removed solid material (to which an unknown quantity of soil moved by splash erosion, sheet wash and microsolifluction should be added) settled only after a short distance of transport (100-200 m). The geomorphological role of this soil mass is evaluated on the basis of some field observations that it fills up smaller depressions on the slope and the concave segments of the steeper (5-8°) composite slopes.

The data quoted show that *in recent surface evolution of a piedmont region short-distance material transport which does not increase the load of the recipient rivers plays a significant part.*

The cultivated plants greatly influence rill formation. Heterogeneous land use makes the areal distribution of rill erosion mosaical, as has been previously proved by several erosional maps taken in the semi-basin (KERÉNYI, A. 1984, PINCZÉS, Z.-KERÉNYI, A.-MARTON-ERDÖS, K. 1978). *Thus, crop rotation can modify recent morphodynamics as well.*

As has already been mentioned, all the erosional rills are eliminated in the course of tillage. On the other hand, sheet erosion may be so intensive on long and steep or poorly overgrown slopes even after a single heavy shower that a permanent surface form, the *erosion gully* can be formed.

THE ROLE OF EROSIONAL GULLIES IN SURFACE EVOLUTION

The Hungarian literature is rich in studies concerned with the development, evolution, and geomorphology of erosion gullies (ÁDÁM, L. 1967, BOROS, L. 1977, MARTON-ERDÖS, K. 1981, PÉCSI, M. 1955, 1975, PINCZÉS, Z. 1968, PINCZÉS, Z.-KERÉNYI, A.-MARTON-ERDÖS, K. 1978, ZÁMBÓ, L. 1970, ZÁMBÓ, L.-GÁBRIS, Gy. 1977).

A special emphasis must be laid on the work of ÁDÁM, L. who deals in detail with the interrelation of forms and soil erosion. (To this author's calculations for erosional gullies some further references will be made later.) The rate of gully development was analysed in detail by MARTON-ERDÖS, K. 1981 and ZÁMBÓ, L.-GÁBRIS, Gy. 1977, based on maps prepared at different time intervals. Since this form of soil erosion resulting in the most obvious geomorphological consequences, has been thorouhgly studied by numerous researchers, we want only to present here some data characteristic of our area under study, with a relatively dense network of gullies (2,3 km/km^2).

A question may be raised whether it was the qullies, appearing as striking features, from which more material was lost, or the loss was more significant through sheet erosion 'only' truncating soil horizons.

Utilizing the soil erosion maps of the area (scale 1:10,000) (in: KERÉNYI, A. 1983) the volume of the soil removed from an area of 9 km^2 was calculated. The basis of mapping were the depth of the original (non-eroded) lessivé brown forest soil and the brown forest soil profiles found in the area. The actually measured depth and the surface extension of soil falling within the given erosional category supplied further basis for the calculations. It was found that during *some thousand years since the advent of grapevine cultivation, from the area of the Bodrogkeresztúr semibasin 1,829,500 m^3 of soil was lost through sheet erosion.*

The volume of soil removed from the gullies was calculated from the data published by MARTON-ERDÖS, K. (1981), with the consent of the author. The procedure of the calculation was similar to the method applied for rill erosion, i.e. the shape of cross-section, further on width and depth values were measured.

The result obtained was a loss of 381,100 m^3. Here it had to be taken into account that the time of origin of gullies and ravines is different. The deepest ones are of Pleistocene age, but the appearance of the majority is associated with the advent of viticulture. *Thus, the volume of soil eroded from the gullies during the last one thousand years can be estimated as 300,000 m^3.* The data prove that, in the area under study, *soil erosion is responsible for the transport of six times as much material as the amount of material carried away from the permanent drainage features.* It is without doubt that rill erosion is a major contributor originally producing drainage lines which, however, were destroyed by the agricultural activity of man.

At present measured data are insufficient to estimate quantitatively the long-term effect of rill sheet runoff on slope evolution.

On the other hand, our measurements related to individual events of erosion indicate that rill erosion must be considered one of the most important forms of denudation (PINCZÉS, Z.-KERÉNYI, A.-MARTON-ERDÖS, K. 1978, KERÉNYI, A. 1983).

On the proportion of the soil removed from the gullies and by overland flow, measured data are reported from the Szekszárd hills by ÁDÁM, L. (1967).

The mapping of the deep-cut tracks in loess, and loess gorges gave an opportunity to receive quantitative data as well. In the author's opinion, in the last twenty years, *14 million m^3* of soil and loess have been carried away by rill or gully erosion from the catchment area of the 2.5 km^2 Parászta valley.

On the basis of the height of the pseudo-terraces, as man-induced landforms, the degree of sheet erosion, too, can be expressed in quantitative form. According to these "since the deforestation, *6 million* m^3 of soil and parent rock have been removed through sheet erosion from vineyards". (We do not know exactly when deforestation took place here.)

Comparing the data obtained by ÁDÁM, L. with our calculations performed for the Bodrogkeresztúr semibasin, the following statements are made considering also the uncertainties of our calculations manifested primarily in the time factor. (This is the reason for making alternative statements.)

The erosion of soils and loesses in the Szekszárd hills is by an order or some orders more rapid than that of the Tokaj-Hegyalja soils, which are more compact and formed on clayey parent rock. This can be primarily explained by the basic differences in parent rocks: the mechanical resistance of soliflunctional piedmont sediment ("gley") much exceeding that of loess and soils on loess. Some processes typical of the erosion of loess do not occur in the case of gleys. Piping and erosion by solution should be emphasized. Carbonic acid water, by dissolving the $CaCO_3$ content, contributes to the collapse of loess structure and, thus, accelerates the mechanical erosional processes as well.

THE RATE OF DENUDATION AS DETERMINED BY SOIL EROSION MEASUREMENTS

During the past one thousand years in the Bodrogkeresztúr semibasin the total erosion has amounted to 2,130,000 m^3. An area of 4.45 km^2 was affected, thus, the average rate of denudation was roughly 0.5 mm/year, which is exactly *ten times less* than denudation in the Szekszárd hills (5 mm/year, ÁDÁM, L. 1967).

Attention should be called to the fact that soil erosion was about four times faster in both territories during the last 20 to 30 years, than the mean denudation values for a thousand years. This can be accounted for, among other things, by the growth of the cultivated area (simultaneously to deforestation), with the gradual deterioration of soil structure, with the removal of more resistant soil horizons and with the decreasing use of organic fertilizers.

The rate of Pleistocene denudation was (according to SZÉKELY, A. primarily in the periglacials) 70 m on average. If it is supposed that this 70 m layer was eroded completely during the last periglacial period lasting for 60,000 years, the following conclusion can be drawn:

The average intensity of denudation makes 1.1 mm/year. This, at the same time, means that the *rate of denudation* in the Pleistocene, which is regarded to have been enormous, did not reach *the present day intensity of destruction accelerated by human activity.*

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ENVIRONMENTAL GEOMORPHOLOGICAL INVESTIGATION OF LOESS BLUFFS FOR PROTECTION AGAINST LANDSLIDES

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ABSTRACT

South of Budapest, the Danube formed a loess bluff of 30 to 50 m height and about 180 km length, where landslides and other mass movements repeatedly occur.
The observations show that sections most susceptible to landslides are the ones where considerable infiltration takes place above the impermeable layer or spring activity becomes weaker. The mobility of the loess strata is in close relationship with the geological, geomorphological and all other ecological factors. The ground mechanical investigation alone does not give sufficient information on the slide processes of slopes and steep loess bluffs, or on the periodicity and frequency of these movements. A more detailed knowledge of the dynamic changes of loess-like deposits is supported by environmental geomorphological and ground mechanical observations as well as the three-dimensional geomorphological-geological analysis of loess layers. Due to diverse protection measures, slides stopped about ten years ago and no displacement could be detected even by surveying ever since.

* * *

More than half of the territory of Hungary is covered in various thickness by loess formations of different types. From the environmental geomorphological point of view the slope loesses, which occur on pediments and hillslopes and have thicknesses between 5 and 25 m are worth mentioning and need special investigations. The low plateau loesses are also widespread. They are deposited on higher alluvial fan surfaces and their thicknesses vary between 40 and 60 m. This loess type is mostly located along the western banks of the Danube in its Great Hungarian Plain section (for more details see PÉCSI, M. 1979 and PÉCSI, M.-SCHEUER, Gy.-SCHWEITZER, F. 1979). The loess of the bluffs along the Hungarian Danube section can be fairly well separated into two members: young and old loesses.

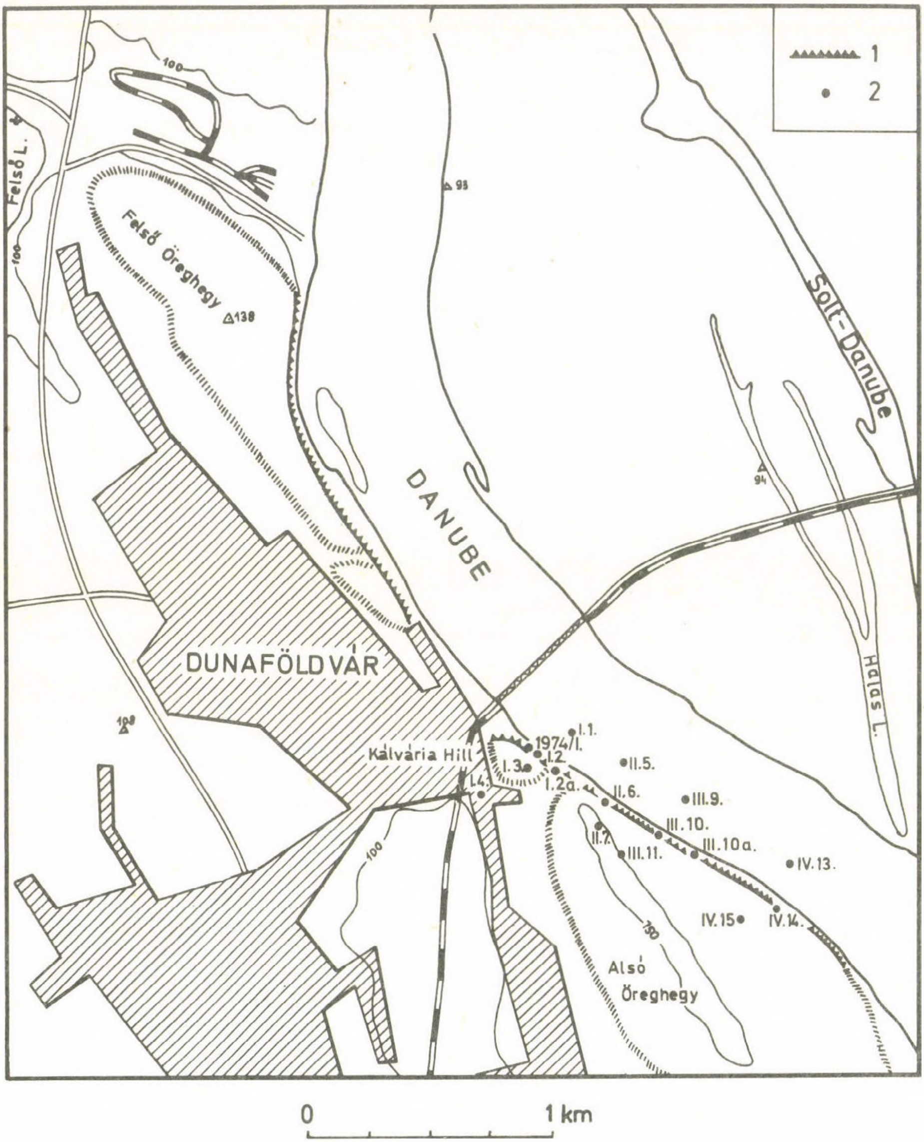


Fig. 1 Location of boreholes in the Dunaföldvár loess bluff
1 = high and steep loess bluff; 2 = borehole site and number

South of Budapest, the Danube formed a loess bluff of 30 to 50 m height and 180 km length, where landslides and other mass movements repeatedly occur. The westward shifting lateral erosion of the Danube is even now considerable. A number of settlements, including important new industrial regions, are found along the margin of the Danubian loess plateau. Furthermore, according to plans of industrial development in Hungary, in the zone of the Great Plain section of the Danube an industrial region is to be developed allocated on the source of water needed in large amounts in the technological processes.

The importance of environmental geomorphological and geological research of the loess bluffs was underlined, among others, by the intensive landslides and other mass movements of the last decades, which affected some industrial settlements and railway bridges. In order to elaborate engineering methods

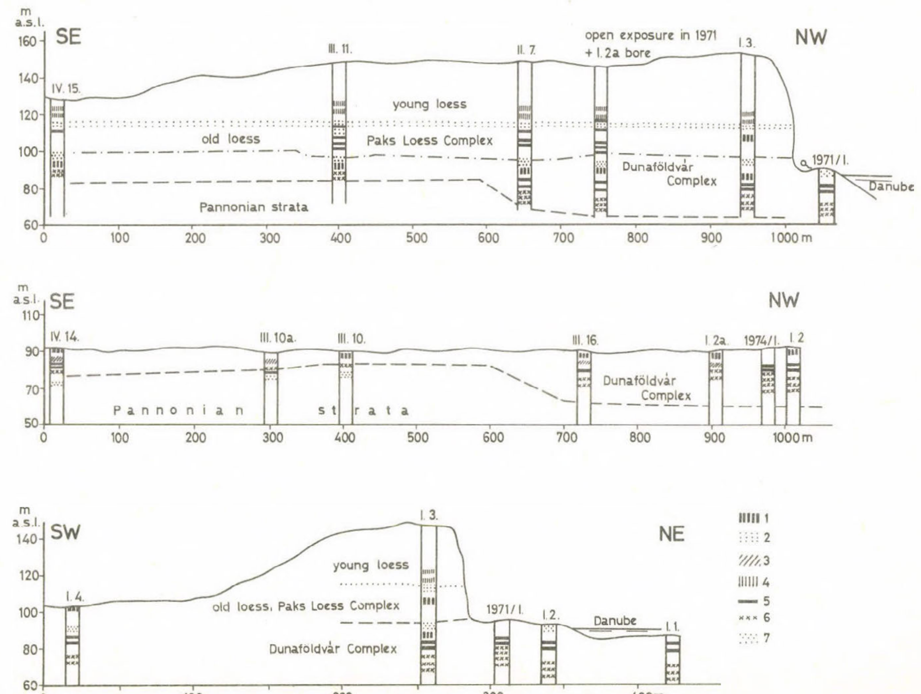


Fig. 2 Simplified geological profiles of the Kálvária Hill, Dunaföldvár 1 = meadow soils; 2 = fluvial sand; 3 = soil sediment; 4 = chernozems; 5 = red forest soils; 6 = red clay, 7 = pink coloured sandy loess

which provide protection against landslides, some case studies were carried out by Hungarian loess researchers and pedologists. The lithological properties and the spatial distribution of the loess sequences were determined by processing the data of numerous boreholes for ground mechanical investigations.

One of the most remarkable landslides occurred at Dunaföldvár, near the railroad and highway bridge. The investigations were planned to reveal the geological structure of the loess plateau, of the river bank and of the river bed *(Fig. 1)*. The practical goal of this research was to find the reasons for the landslides and to determine the sliding plane and the lithological and stability parameters of the loess sequence.

In the Dunaföldvár bluff layers are subhorizontal *(Fig.2)*. The loess sequence of about 50 m height consists of typical, sandy and alluvial loess with a number of paleosol intercalations. The old loess sequence overlies the upper Pannonian inland sea formation. Its upper strata of several metres' depth consist of sandy, silty and clayey formations. Along certain short sections, the location of the clayey substrate essentially corresponds to the mean level of the Danube, while in other places it lies 25 to 30 m lower than the river level *(Figs 2 and 3)*.

From the borehole sequence it could also be determined that the earlier landslides occurred in reaches where the Pannonian clayey basement is in higher positions, where it lies close to the mean level of the Danube. In addition, in the sandy layer between the clay and loess sequences, infiltrating waters reach the steep bluff where, unless springs issue, the lower loess layers become rather moist. At the foot of the high bluff, groundwater is unable to reach the surface because of the obstruction of several previous landslides. Thus, in certain places, water also rises as high as the upper loess layers.

Extreme accumulation of infiltrating waters is mainly promoted by humid seasons and years as well as by the slump material deposited from earlier landslides at the bluff base. Groundwater in the high bluff is not only recharged from the percipitation of the immediate neighbourhood but also from remote catchments. In the Dunaföldvár loess bluff, a sand layer in high position is also found but it retained only a small amount of groundwater. Thus, the amount of water necessary to initiate a landslide cannot be stored in this high-lying sandy layer *(Fig. 4)*.

The process of the landslide with a slab failure can be reconstructed as follows: At Dunaföldvár the summer preceding the date of the landslide was rather rainy with rainfall above 600 mm versus the average 500 mm. Several months before the landslide vertical fissures could be observed on the margin of the loess plateau. The fissure network has gradually widened and deepened. Our observations show that cracking in the Dunaföldvár loess bluff occurred when the silty-sand layer below the otherwise dry loess sequence moistened and cohesion bonds between its grains weakened. At the beginning the failure was insignificant but sufficient to produce further deep cracks parallel to the bank, along a fissure network of 75 to 80 degrees. The failure, however, was incomplete,

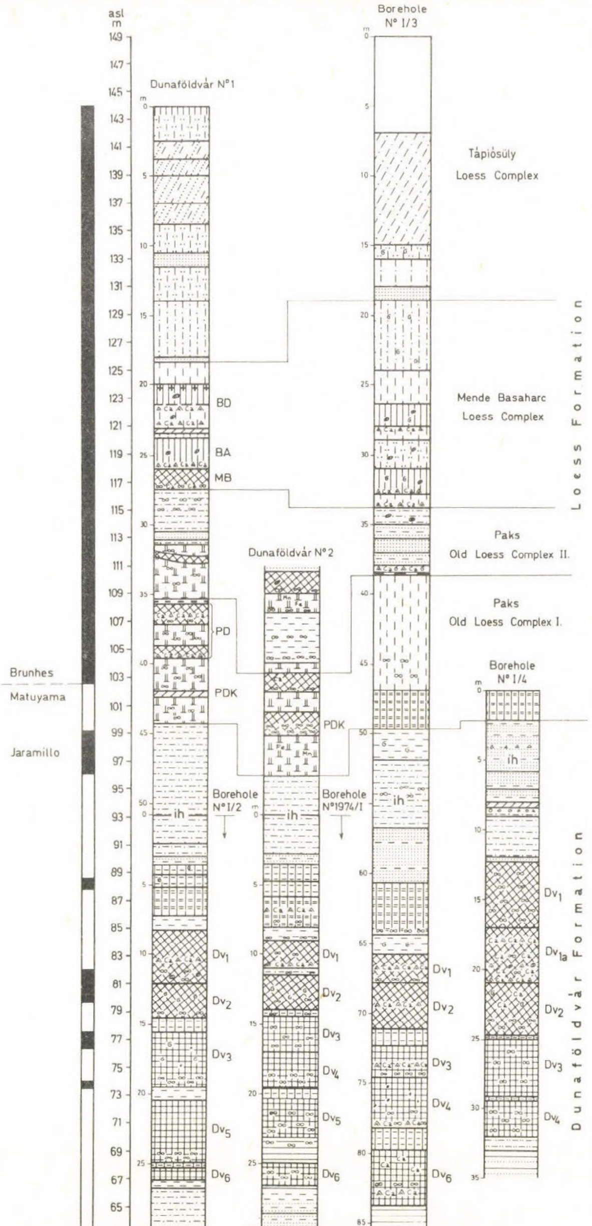
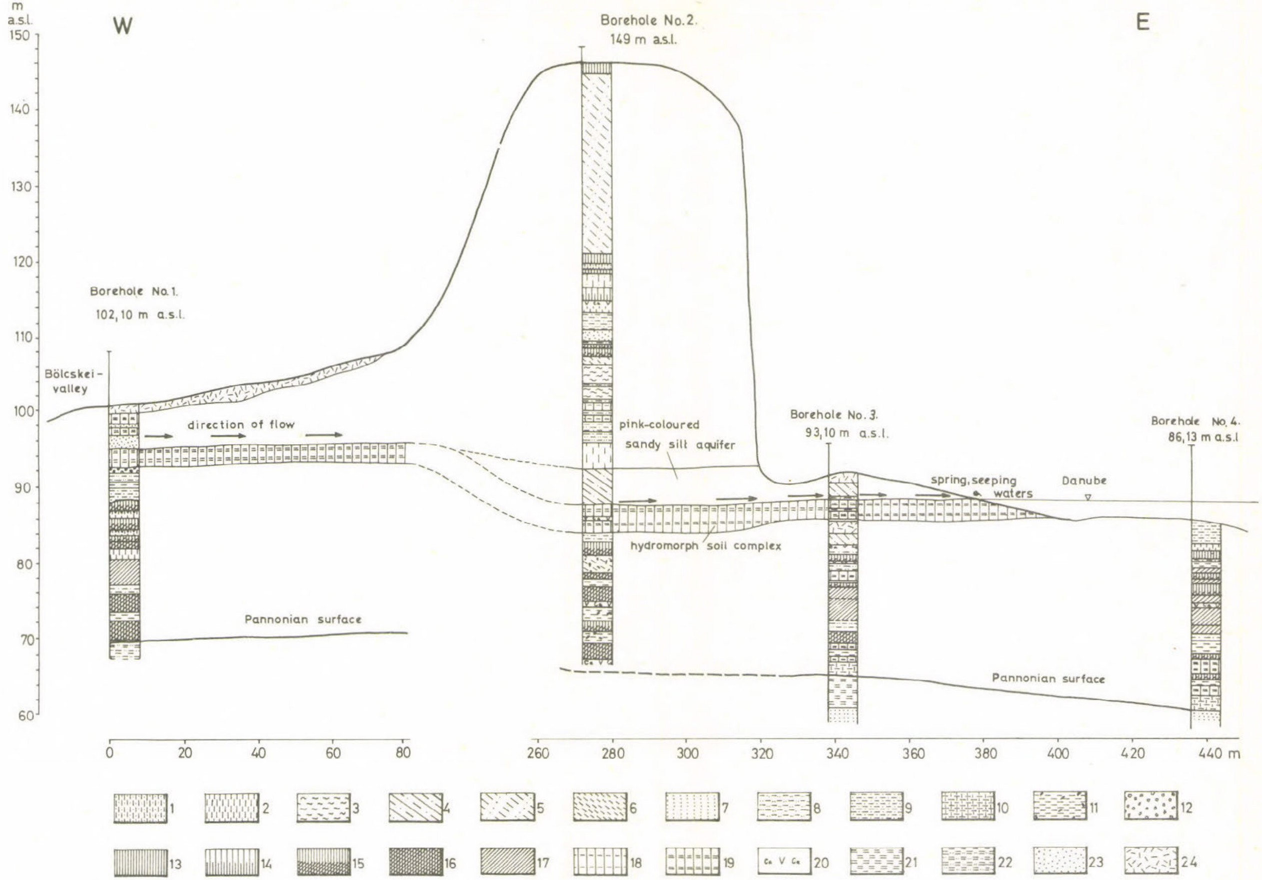


Fig. 3 Correlation of the exposure and borehole profiles at Dunafölavár (PÉCSI, M.-SZEBÉNYI, E.-PEVZNER, M. A.)



<u>Fig. 4</u> Stratigraphic profile of the Alsó-Öreghegy at Dunaföldvár based on borehole data

since the separated slabs were still supported by the bluff, which remained stable and solid. This state was prolonged for weeks or months, until the lower layers of old loess became gradually moister and moister and, consequently, cohesion was suddenly reduced as a consequence of the pressure exerted by the land slabs. This phenomenon occurred at a critical value of moisture and pressure. When in the lower layer this abrupt shear failure was generated, the whole of the overlying slab collapsed and fell onto the moistened, lubricated clayey base layer (according to local dwellers, it was accompained by a loud bang).

In the case of the Dunaföldvár landslide with a slab failure, the potential sliding plane was preformed in the contact zone of red clay of subhorizontal stratification and the loess sequence. When shear failure takes place, the huge land slabs produce enormous pressure and stress. Consequently, they will slide along a concave curve deepening into preformed sliding plane. In the foreground of the landslide, at its base, clay was squeezed out in the form of a scaled and overthrust structure. Here it resulted in two arcs of islands rising from the bed of the Danube. The island-like headland further away from the bank consists of Pannonian clay and a red clay cover *(Fig. 5)*. The island closer to the bank is built up of the two layers of the bluff and of the strata which moved upon the Danube bed during the previous landslides.

The slab landslide of Dunaföldvár is a type of mass movements differentiated from slumps.

The characteristic features of a slab landslides are as follows:

a. the potential sliding plane is preformed by the geomorphological and geological structure;
b. the slab failure and its sliding plane develops on an horizontal impermeable clay layer at the base level along the bluff; it takes the form of a gently sloping undercut;
c. the moistening effect of the aquifer above the impermeable layer;

Fig. 4

A. Eolian sediments: 1 = sandy loess; 2 = loess; B. Colluvial, deluvial sediments: 3 = sandy loess, stratified fill of a buried derasion valley; 4 = pink coloured fine sandy silt; 5 = stratified loessy sand; 6 = stratified loess; C. Fluvial-proluvial sediments: 7 = sand; 8 = silty fine sand; 9 = silty sand; 10 = coloured Fe and Mg spots in clay; 11 = brownish-yellow $CaCO_3$ concretions in silty clay; 12 = sandy gravel; D. Recent and fossil soils: 13 = 'humus carbonate' soil; 14 = steppe-type soil; 15 = chernozem brown forest soil; 16 = brown forest soil; 17 = semipedolite; 18 = hydromorphic soil; 19 = alluvial boggy soil; 20 = $CaCO_3$ accumulation; E. Pannonian: 21 = grey-yellow clay; 22 = grey-yellow silty sand; 23 = sand; F. Anthropogenic forms: 24 = mand-made fills

d. the lower moistened loess packet loses its stability owing to the load of the cover layers, at a critical value of moisture, shear follows;
e. the collapsing thick land slabs move rotationally on the preformed sliding plane, while horizontal mass displacement is negligible.

In the case of slumping, on the other hand, the sliding plane develops in the shorn clay mass itself and a semicylindrical surface functions as the sliding plane. The potential sliding plane is not expected from the geology. Remarkable differences are also observed between the above two types of mass movements in the hydrogeologic and hydrometeorologic conditions.

In slump development surficial moistening plays a predominant role, while in a slab landslide, in addition to other conditions, confined groundwater and tectonic movements are of decisive importance; this type of movement occurs typically in well-stratified loess sequences.

The most important aspect of the protection against movements resulting from slab failure is the draining of free and confined groundwaters. The observations show that sections most susceptible to landslides are the ones where considerable infiltration takes place above the impermeable layer or where spring activity becomes weaker.

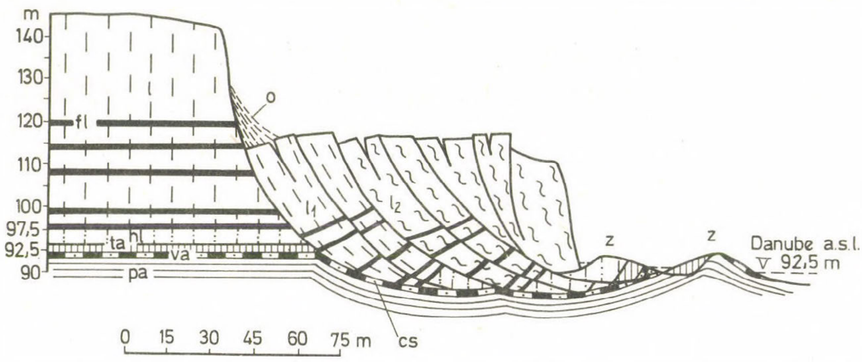


Fig. 5 The Dunaföldvár river-bank landslide to the S of the Danube's 1560 kilometre mark (PÉCSI, M. et. al. 1979)
l = loess sequence in primary position (autochtonous); l1 = loess recently displaced by sliding; l2 = waste of earlier slides; hl = pale pink sandy loess; o = talus; z = earth heap and Pannonian clay arising from the Danube's bed; fl = fossil soils; ta = dark grey clayey loam soil; pa = Pannonian clay; va = red clay; cs = sliding plane

Periodical slides come about in response to the joint effect of several factors such as humid years, major fluctuations of the Danube level, coincidence of minor seismic movements, influences of artificial damming of water and the clogging of the aquifer at the bluff base as a result of previous slides.

A similar phenomenon is observed in the Dunaújváros profile as well as in the steep undercut reaches of the Dunaszekcső loess banks etc.

The landslide at Dunaújváros took place under geological-geomorphological and hydrogeological-hydrological conditions similar to those at Dunaföldvár. This 3 km long landslide highly endangered the technical establishments of water supply in a new neighbourhood of the town. Consequently, large-scale precautions had to be done along the Dunaújváros reach of the Danube; the environmental geological and ground mechanical investigations of this project required a number of boreholes and shafts *(Fig. 6)*.

It is essential in the protection of the loess bluffs to drain the waters stored in the sandy aquifers of the Dunaújváros bluff by wells and underground canals. In addition, the bluff was sloped and surficial waters were regulated. The embanked slopes were reinforced and planted.

It is to be emphasized that loess is susceptible to collapse and the mobility of its layers is closely associated with the geologic, geomorphologic and ecological factors. The ground mechanical investigation alone does not give sufficient information on the slide processes of slopes and steep loess bluffs or on the periodicity and frequency of these movements. A more detailed knowledge of the dynamic changes of loess-like deposits is supported by environmental geomorphological and ground mechanical observations as well as the three-dimensional geomorphologic-geologic analysis of loess layers.

MAIN PRACTICAL ASPECTS OF LOESS RESEARCH

The loess regions of the Earth have played a remarkable role in sustaining the population and, even today, they still coincide with the densest populated areas.

The loess regions provide very favourable natural conditions for agriculture and in plenty of places loess was used as building material.

Loess easily erodes as a result of technical and agricultural activities. It is generally compacted under buildings and thus it loses much of its durability. Therefore, the investigation of loess and its soil mantle has a practical purpose of the maintenance and increase of agricultural production on the one hand, and the establishment and ensurance of the operation of economic and technical establishments, on the other hand.

The practical loess study with an engineering viewpoint has inevitably gained importance for the following reasons:

1. From the practical point of view, the critical property of loess is manifest in the fact that the constituent fine-grained mineral are cemented (by lime) and, consequently, its structure is porous and incompact. The pores are filled

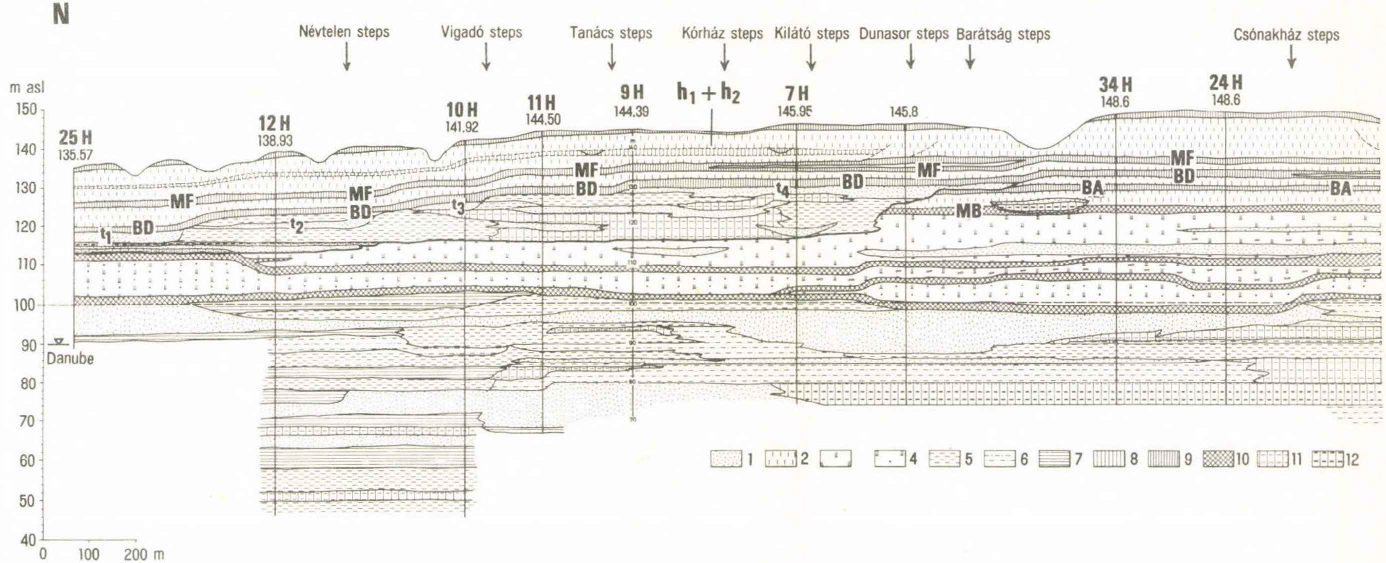


Fig. 6 Lithological profile of the loess bluff at Dunaújváros (compiled by PÉCSI, M.-SZEBÉNYI E.)
1 = sand; 2 = loess; 3 = old loess; 4 = loess silt; 5 = silt; 6 = sandy silt; 7 = clay; 8 = embrionic humic soil; 9 = steppe soil; 10 = brown forest soil; 11 = hydromorphic soil; 12 = meadow soil. t1-t4 = alluvial fan terraces of a Danube tributary covered by loess sequence. H = hydrogeological 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

with water of different bonds as well as air, which decisively affects the stability of loess as sediment.

Consequently, a loess category has to be defined which behaves critically from the environmental geological viewpoint and it has to include loesses in a genetic sense as well as loess-like formations. This classical variety of loess should be distinguished by means of physical and chemical parameters from the loess-like deposits being not of critical behaviour from other engineering aspects. This is all the more needed since the experts of loess origin include ever more loess-like formations into the category of 'loessic deposits'.

2. The investigation of the lithology of various loesses is necessary for agriculture, as they are related to fertility or the erodibility of soils on loess.

3. Some loess types are more abundant in nutrients and, therefore, the analyses and mapping of the physical, chemical and pedological features of loess and loess-like deposits are closely associated with the agrogeological investigations.

4. Mostly empirical observations and, in a limited number, measured values have been used to explain the relationships between soil erosion and the cultivation method. Thus, the way of cultivation must fit in the natural ecological equilibrium of the surface.

5. The dynamic changes (stability, collapse, slide, compaction, dissolution and piping, gully erosion on loess and so forth) in loess forms and areas as a result of natural processes and human economic-technical activity, present complex research tasks for environmental geomorphology and geology. Accurate engineering geological and ground mechanical investigations of the physical-mechanical, dynamic and even the seismic features of loess areas and layers are indispensable for planning and constructing engineers.

The number of papers concerned with practically oriented loess research has been increasing in the last decade. Recently, the complex investigation and practical evaluation of the natural properties and economic value of loess have become a major concern in regional planning and construction.

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THE ROLE OF CLAY DEPOSITS IN THE GEOMORPHIC EVOLUTION OF DOLINES

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ABSTRACT

Author has been carrying out regular field observations and the related material analyses for three years. On the basis of the accumulated information it is proposed that the characteristic water budget and CO_2 production of clayey doline deposits exert a heavy influence on the geomorphic evolution of karst dolines. A geochemical model has been developed on the changes of some main properties of the two- and three-phase systems formed in doline deposits. This model is suitable to explain the details of corrosion in the dolines and throws light on the relationship between the clayey cover deposits of the karst and karst corrosion.

* * *

The world-wide karst chemical investigations of the last decades (SWEETING, M.M. 1972) have proved the decisive role of dissolution by hydrogen-carbonates in the corrosion of karstic rocks. Therefore, it is *the amount of water in contact with limestone and its* CO_2 *content* that *predominantly control the development of corrosion forms.* A large-scale and regular series of investigations were carried out in some of the dolines of the Aggtelek Karst, N-Hungary, during the last decades (ZÁMBÓ, L. 1976, 1978, 1981). The continuous observations of three years allow us to calculate meaningful averages out of measured data and to draw some typical curves of changing factors.

SOME CONTROLS OF THE PERMEABILITY OF DOLINE FILLS AND OF LIME AGGRESSIVITY OF WATER

Doline fills are accumulations of loose structure with spatially and temporally alternating biphase and triphase (solid matter-soil solution or solid matter-soil solution-soil air) systems influenced by weather changes within the limits of climate. The controls of weather and percolation operate primarily through *the clay content of doline fills.* If this clay content is heterogeneous and varies on a wide range, the temporal appearance and motion of the biphase and triphase zones becomes irregular and dependent on the clay content (YAALON; D.H. 1955). After appropriate time it is manifested in the irregular shape of dolines too.

The amount, hydraulics and aggressivity of water percolating in sediments of low heterogeneity is described sufficiently by three parameters: soil temperature, water content of sediment and CO_2 of air in pores.

The *temperature* of clay sediments in dolines shows a regular picture with increasing depths: the changes in free atmosphere are followed to an ever decreasing extent. It is usually down to 2.5 m depth that temperature changes influence permeability as described below.

Frozen topsoil is impermeable; under the circumstances of groundfrost water from the surface cannot reach the doline. It is partly from this phenomenon that some researchers draw the conclusion that under cold weather conditions karst corrosion ceases.

Soils of relatively higher temperature dry out and crack with contraction phenomena due to the shrinkage of clayey components; permeability in the topsoil becomes extremely great. Under these conditions the doline fill takes up most of the atmospheric precipitation and ponors hardly function.

When the topsoil is drying out upward, then capillary water motion takes place and reduces the amount of water capable of corrosion and, at the same time, 'washes through' the well-ventilated upper sediment zone rich in CO_2.

Temperature changes are a heavy control on the bioactivity of the soil edaphon; the CO_2 production of the upper sediment zone is proportional to the intensity of life processes. Under the doline fill one of 2.5 m average depth temperature changes occur on a narrow range (limited by climate). Disregarding the extreme environments, the temperature of the sediment allows *continuous* infiltration, capillary water motion and the biological activity of soil bacteria (CO_2 production).

In the zone between 2.5 and 7.5 m depth, the range of temperature is insignificant and temperature corresponds to mean annual temperature in the area. In environments with above-zero mean annual temperature at these depths water motion (if recharge is sufficient) and CO_2 production is continuous all over the year.

The seasonal curve of temperature in doline fills *(Fig. 1)* shows that depending on the depth of doline fill the doline types of continuous corrosion and of temporary corrosion can be identified.

Of the forms of water included in doline fills, the capillary water of relatively free motion contributes to karst corrosion. Its motion is influenced by the porosity of sediments, which shows no great variation in the rather homogenous profile. In the clay sediments values of capillary water capacity range from 25 to 40 volume per cent for the whole of

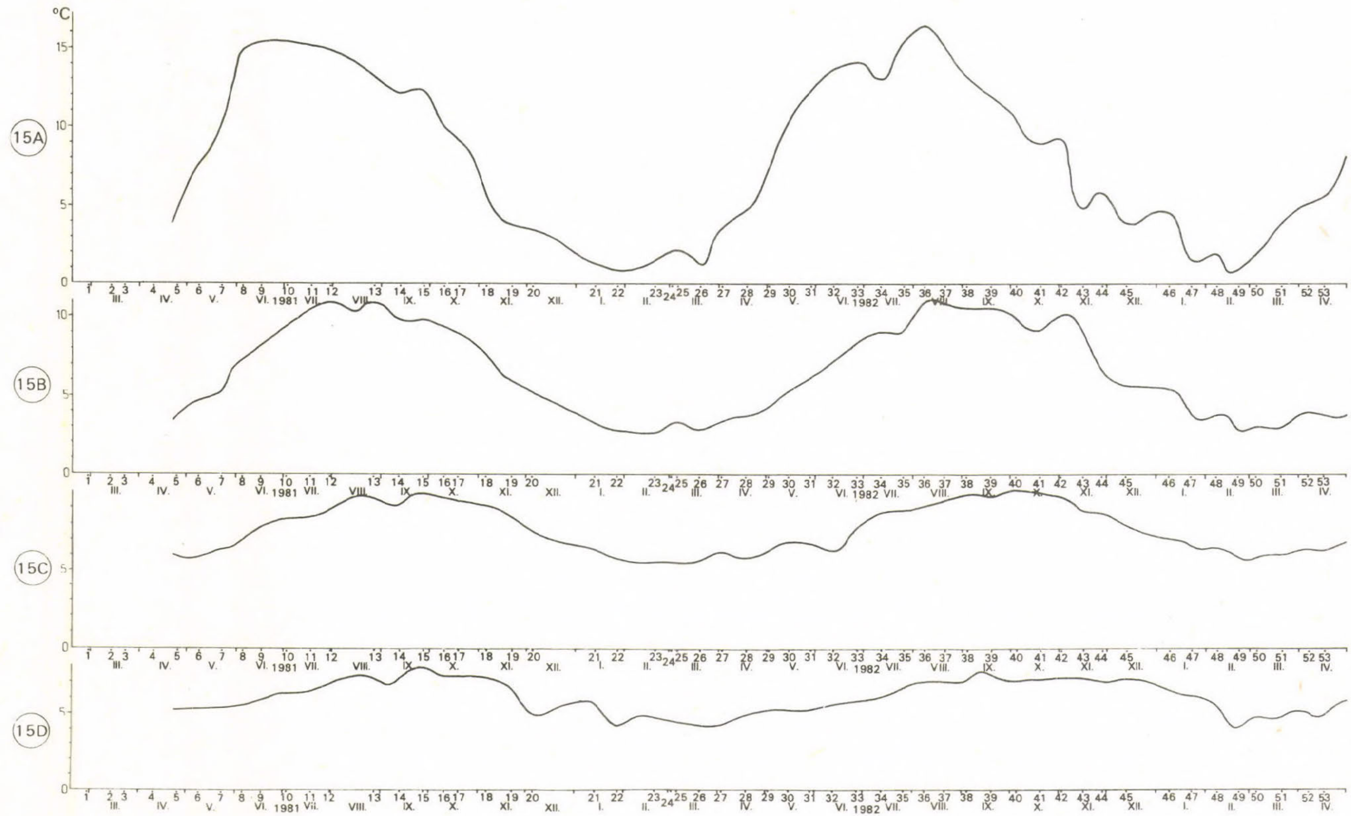

Fig. 1 Changes of soil temperature in doline fills

the doline fill. The extent of infiltration and of vertical and lateral water flow is controlled by the zone of minimum permeability; water also moves along the contact line of the doline slope, doline floor and unconsolidated sediments.

The *moisture* in pores is reduced during long-lasting warm and dry periods. The water bound stronger in pore corners, absorbs much of the CO_2, liberated even under such conditions, thus increasing aggressivity. Therefore, CO_2 production in the arid periods is 'preserved' and exerts an influence on dissolution with a time lag. In doline development under arid climatic conditions, not only the actual CO_2 content of short-term infiltrated rainwater takes part, but the CO_2 effect is felt in a cumulative way.

The amount of infiltrated rainwater in percentage of rainfall decreases towards depth with seasonal differences (Table 1).

Table 1 The percentage of infiltration by seasons

depth of sediment (m)	Dec. 16 th to March 15th	March 16th to June 15th	June 16th to Sept. 15th	Sept. 16th to Dec. 15th
0.3	100	100	100	100
2.5	80.6	59.8	55.2	25.6
5.0	35.5	54.6	12.7	31.1
7.5	116.1	76.3	23.0	22.2

Under Central European conditions the degree of decrease is highest between August 16th and December 15th and the ratio of infiltration is highest in spring (March 16th-June 15th).

In normal circumstances seasonal throughflow occurs in the relatively more permeable layers of the doline fill profile. The depth of this throughflow varies with the moisture content of the fill: there is a vertical seasonal shift. The layer where throughflow takes place is deeper in summer and winter during the dry periods, however, it is higher lying during spring, while no throughflow is observed in autumn.

Along the boundary of the limestone basement and the doline fill some percolation takes place parallel to the slope. In average 33 per cent of the amount of water reaching the limestone body is involved in this process, yet it shows great variation by seasons (in spring 28 per cent, in summer 45 per cent, in winter 69 per cent, no percolation in autumn).

Soil moisture in the upper 2.5 m horizon is subject to major seasonal variations *(Fig. 2)*: it is 23 to 82 per cent in greater depths, with an annual range less than 15 per cent, but at 7.5 m depth it increases again (to about 20 per cent) due to throughflow.

The fluctuation of soil moisture in the upper zone hinders biogenous CO_2 production in some periods (in Central Europe from the middle of summer to the end of autumn), while in deeper zones it is uniform throughout the year, although at a lower level of intensity because in the biphase system there is no air phase and only anaerobic bacteria produce CO_2.

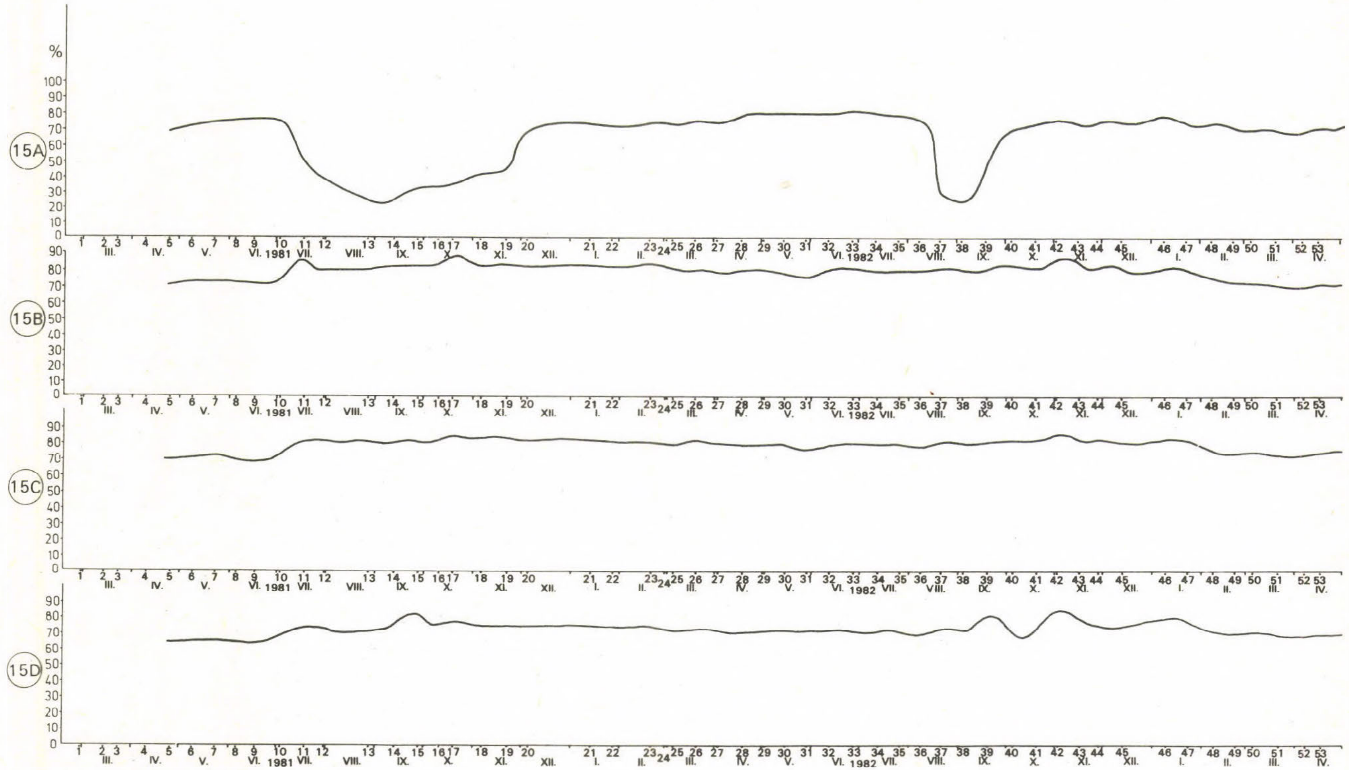

Fig. 2 Changes of soil moisture

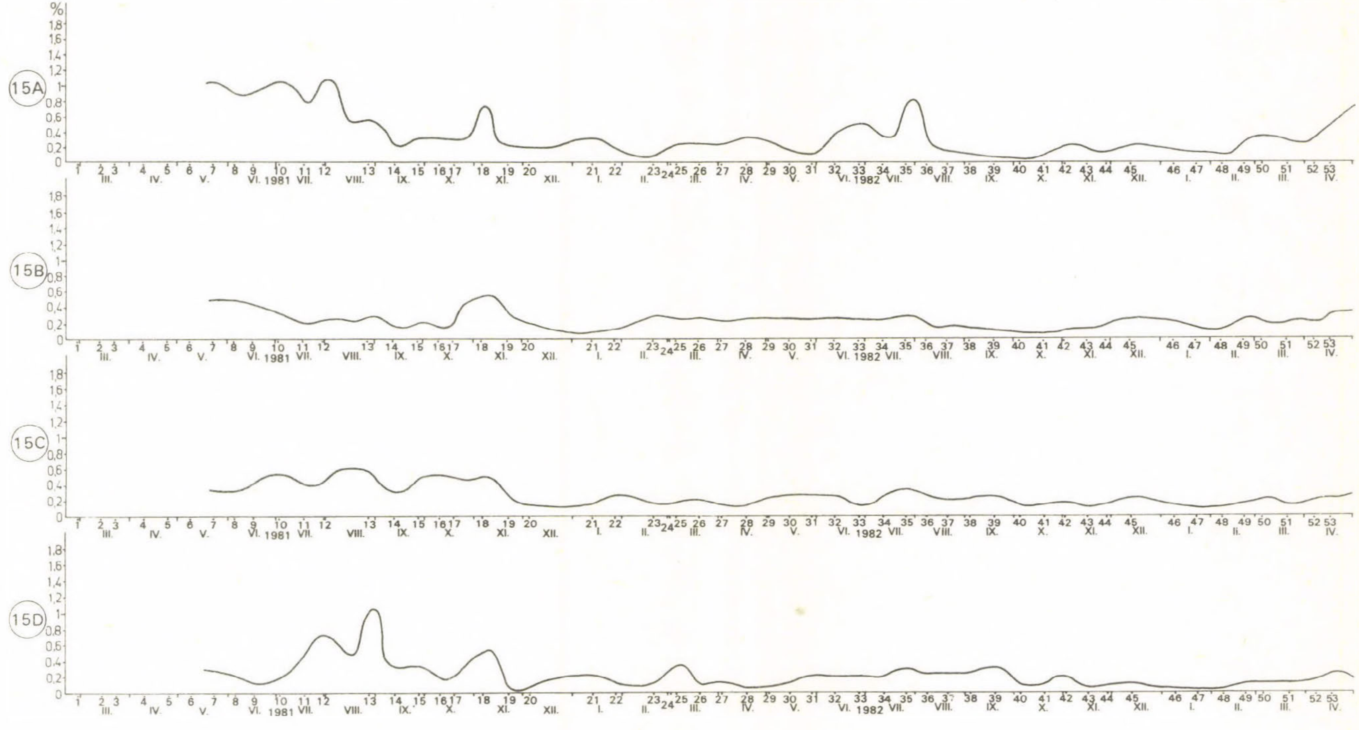

Fig. 3 Changes of CO_2 content in soil air

Most of the CO_2 contained in percolating waters of doline fill is absorbed, as experience shows, by soil atmosphere. In a triphase system, with the great amounts of CO_2 produced by soil organisms and by decomposition, air in pores contains by one order higher quantity of CO_2 than the free atmosphere. Percolating water is in contact with air in pores over an extended surface and much CO_2 is absorbed. The partial pressure for CO_2 in soil air and the pressure for free CO_2 in the water are counterbalanced. The migration of CO_2 between the gaseous and the liquid phase is going on towards an equilibrium and, consequently, CO_2 is 'dispersed' in the doline fill. The percolating water with a velocity above that of the diffusion of soil air also carries CO_2 into the biphase zone of the doline fill. Our present knowledge indicates that most of the CO_2 is produced in the uppermost zone of the doline fill. However, CO_2 production has also been observed in the deeper layers of the deposit (due to bacterial activity and decomposition).

The seasonal curve of the CO_2 content of the air in pores points to a difference by one order between favourable and unfavourable periods *(Fig. 3)*. CO_2 content is most uniform at 5 m depth, but its range is great even here (0.15 to 0.6 per cent). The wide range (0.02 to 1.3 per cent) at 7.5 m is explained by the seasonally favourable CO_2 production of anaerobic bacteria at depth and by the CO_2 liberated from throughflowing water.

The CO_2 content of the air in pores is generally the lowest in the middle zone of the doline fill.

RELATIONSHIPS BETWEEN DOLINE FILL DEPTH AND LIME AGGRESSIVITY OF PERCOLATING WATER

A part of the CO_2 absorbed by percolating water is in the form of carbonates and another part is aggressive CO_2 capable of further solutions. The amount of this latter is an indicator (in good approximation) of the solution capacity of percolating water. Our measurements show that the aggressivity of water with CO_2 content increases with depth and culminates in the zone of throughflow and towards the base of the profile. In the permanent biphase zone it is of constantly low value *(Fig. 4)*.

The seasonal relationship between lime aggressivity and sediment depth is more intricate. Maximum lime aggressivity is observed at greater depths in winter and summer, than in spring, while it is zero at some lower levels. The seasonal differences of lime aggressivity are reduced in the permanently biphase zone above the doline floor. Neglecting a small scale autumn decrease, lime aggressivity is observed at a constant level. It means that in the permanently biphase zone of the doline floor the potential solution capacity of water depends on the amount of infiltrated water and an almost linear relationship is found. As a consequence, in periods of heavier infiltration the sculpture of forms by corrosion on the doline floor is most intensive. In environments of steady infiltration

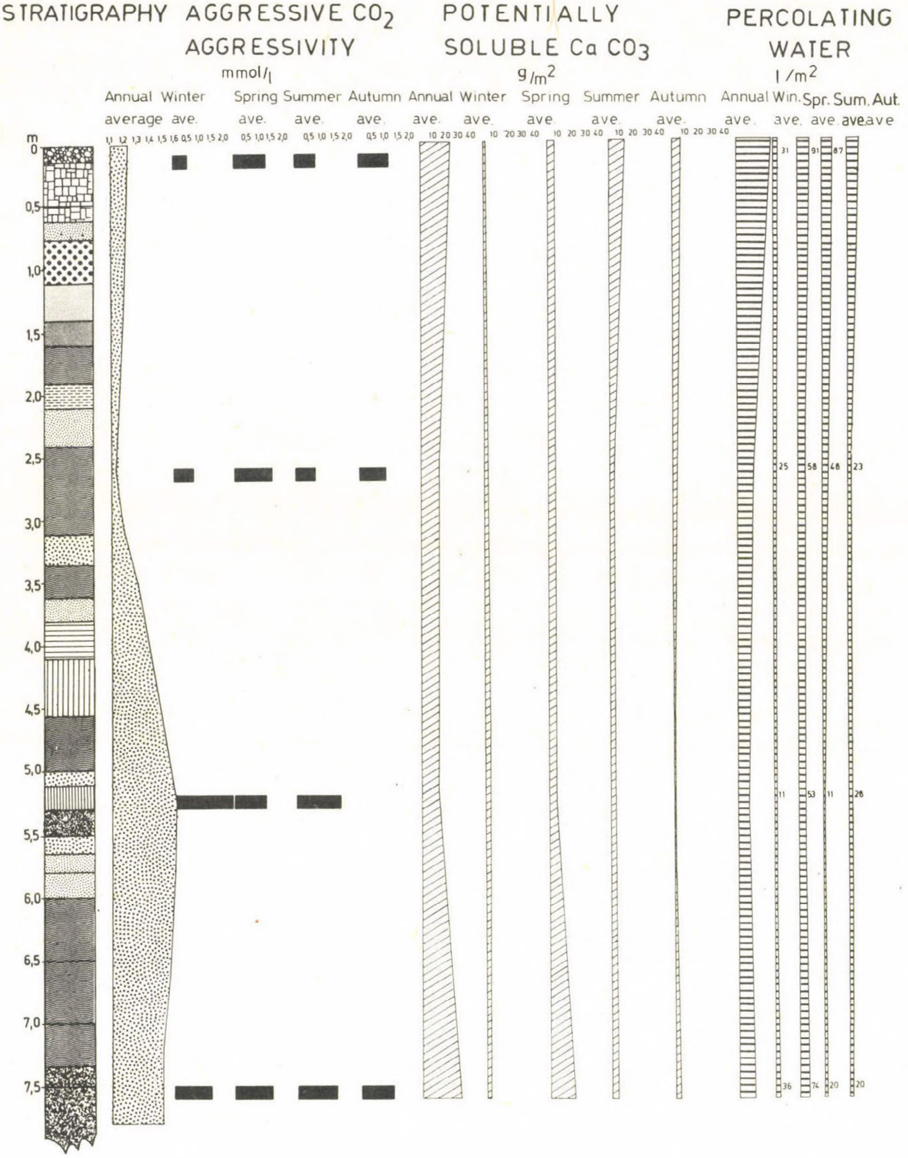

Fig. 4 Solution conditions in the vertical section of a deep red clay accumulation

the solution of limestone is a process of uniform intensity all over the year. *The intensity of form development in dolines with deep clay fill* is not a function of the climatic factors individually, but *depends on the amount of water in contact with the limestone* to the joint effect of the mentioned factors.

A HYDROGEOCHEMICAL MODEL FOR CLAY DOLINE FILLS

Based upon measured data the following model could be set up *(Fig. 5)*. In relation to infiltrating water the sediment body is divided into two main parts: the lower zone saturated with water and the upper unsaturated one. The latter is called the *aeration zone*, where isolated and communicating pores are filled with soil air and waterfilms flow on the surfaces of particles. At the contact between the aeration zone and the *saturation zone* the *capillary zone* is found where pores are either laminar or tubular and both lateral and upward water motion takes place. With the dissolution of the embedded limestone debris the calcium hydrogen carbonate content of percolating water gradually increases vertically downwards and simultaneously, at equal pace, the free CO_2 content decreases.

The water saturated portion of the deposit is subdivided into two zones: in the upper water percolates between clay particles and the layer of swelling clay below inhibits seepage. Besides vertical seepage, throughflow, which brings water rich in free CO_2 from the margins, is also significant. Dissolution is intensive, in this zone as indicated by further growth of calcium content in the percolating water. Free CO_2 content is also the highest here.

There are no pores between the particles in the swelling clay zone, so water cannot percolate through, but it is localized on the surfaces of clay grains by adsorption and hydrogen bonds. The transport of molecules (water, carbonic acid and CO_2) primarily takes place in the form of diffusion in this gelated medium, but, owing to great viscosity, it is slow.

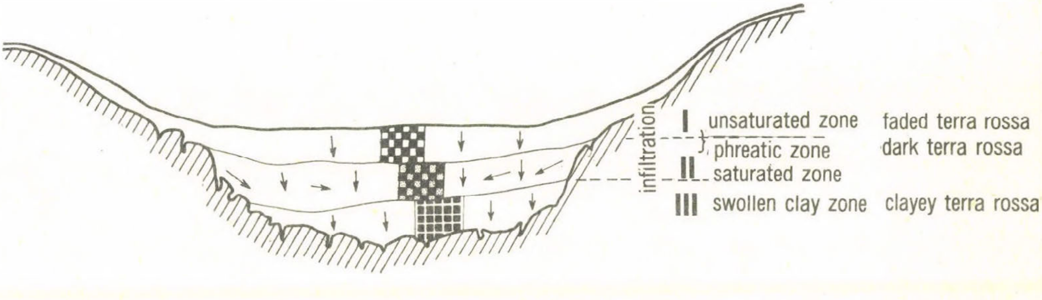

Fig. 5 A hydrogeochemical model for red clay doline fills

The ion motion, however, is accelerated by the ion exchange capacity of clay minerals. The clay mineral particles mostly have negative charges with an electric double layer of high cation concentration around them. Around the cation (calcium) sphere a layer of heavily hydrated anions is observed. Calcium hydrogen carbonate concentration is highest in the swelling clay zone; the concentration of free CO_2 is lower than in the porous saturated zone. During periods of low infiltration calcium may diffuse back from the swelling clay zone to the porous zone where some enrichment may take place.

When seepage is weak, in the swelling clay layer calcium hydrogen carbonate can be concentrated to the degree that it results in the flocculation of the gel and the swelling clay layer is converted again into a water saturated porous layer. Thus, depending on the extent of water saturation, the zones in the fill can dynamically alternate within themselves. The ion exchange capacity of the swelling clay zone accelerates ion transport. This zone is in contact with the calcareous bedrock over the largest surface, dissolution is permanent here; its rate is dependent on the phase, the rate of percolation, CO_2 recharge and diffusion. Calcium concentration in the swelling clay zone is lower than that of the porous zones. If the rate of infiltration is lower than that of ion diffusion, calcium accumulates in the zone of pores filled with water.

It is emphasized that the geochemical model will be further refined applying additional data and the picture outlined as here is a first approximation based on the data available so far.

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PERIGLACIAL SLOPE DEPOSITS AND LANDFORMS IN A HUNGARIAN MOUNTAINS OF VOLCANIC ORIGIN

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ABSTRACT

The NW part of the Tokaj (Zemplén) Mountains of 700-800 m height have preserved a rich variety of periglacial forms. There evolution was promoted by frost shattering under the cold climate of the Pleistocene, as a result of frost-thaw alternations and also by the lithology and structure of pyroxene andesite, a predominant rock type in the region. In the present study the young Pleistocene development of an almost 2 km long slope is reconstructed. By inclination the slope is subdivided into four segments: 1. The top unit is covered by rock debris from the last periglacial period. 2. The upper steep (28°) segment is dissected by cryoplanation steps, talus cones, rock and block streams and rock slides of the last and the penultimate periglacial period. 3. The middle (18-20°) segment shows periglacial landforms and in situ and redeposited sediments with increasing sorting downslope. Material transport was performed both by gelisolifluction and by water. 4. The lowest slope of 2-3° inclination is covered by thin alluvial debris.

* * *

DESCRIPTION OF THE REGION

To demonstrate periglacial slope evolution, the ridge between Hemzsö-bérc (718 m) and Nagy-Hemzsö-kö (709 m) had been chosen. It is an asymmetric ridge of 500 m length and with a NNE-SSW srike. The area is built up of acidic laminated pyroxene andesite, which is the youngest Lower Sarmatian (as estimated by GYARMATI, P. 1977) product of andesite volcanism. On Hemzsö-bérc the andesite laminae dip at 18-20° to W-SW. As a result, there are subvertical bassets overlooking to the E, which promotes the evolution of steep slopes. In the opposite direction the dip of the structural surface evolved on the bedding planes is gentle. The laminar andesite beds ending in steep cliffs are even at present the primary target of frost shattering as were, to a greater extent, in the Pleistocene. In consequence,

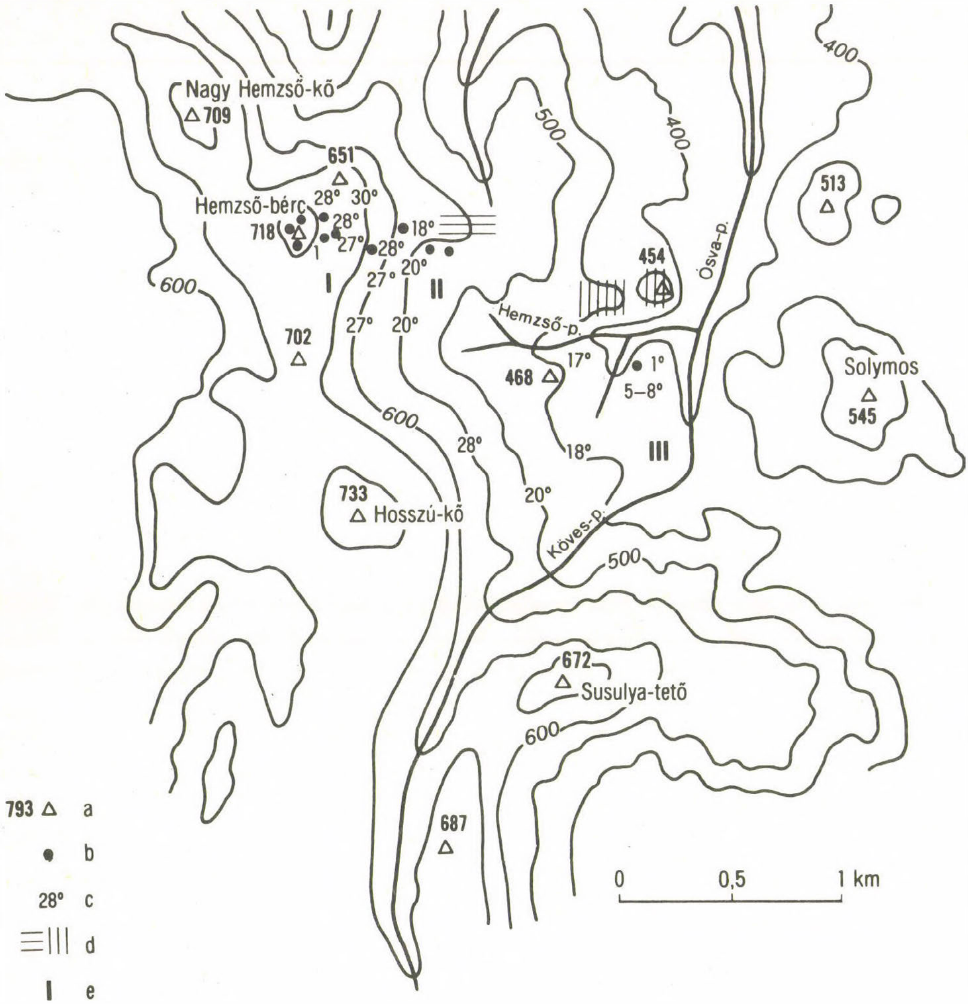

Fig. 1 Map of the surroundings of Hemzsö-bérc and Nagy Hemzsö-kö
a = spot height; b = sampling site; c = angle of slope; d = Pliocene pediment; e = slope segments I, II, III

a large amount of debris accumulated at the foot of the cliff. At the same time the destructive activity of frost was minimum on the soil-mantled gentler slope evolved on the bedding plane in opposite direction. Thus, due to the structure of the rock, the course of surface evolution was different on the two slopes. A rich variety of periglacial forms evolved on the steep cliff, whereas the the periglacial forms are missing from the gentle slope evolved on the bedding plane *(Fig. 1)*.

PERIGLACIAL FORMS ON THE RIDGE SUMMIT

The 500 m long ridge of Hemzsö-bérc - Nagy Hemzsö-kö has a 20 m to 30 m wide flat top. Nowadays the 20-50 cm fractured blocks of this autochtonous debris are seen everywhere on the summit surface *(Fig. 2)*. In the exposure of pits in the rock

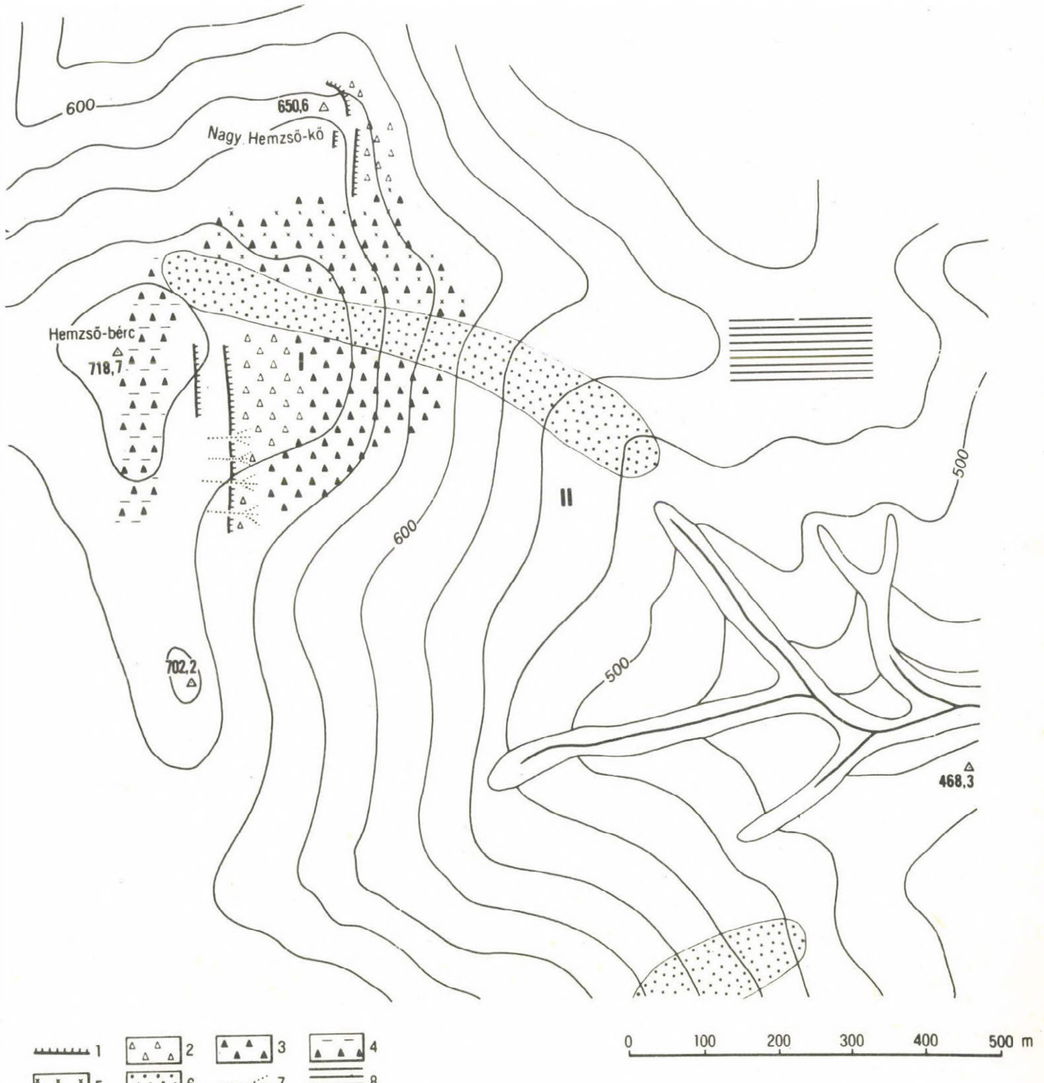

Fig. 2 Geomorphological map of the environs of Hemzsö-bérc and Nagy Hemzsö-kö
1 = frost-riven cliff; 2 = talus cone of the last periglacial period on the slope; 3 = talus cone of the last but one periglacial period on the slope; 4 = talus cone on the top; 5 = talus field; 6 = block stream; 7 = rock stream; 8 = Pliocene pediment

debris three horizons can be distinguished. In the upper 25 cm layer angular andesite blocks can be found. The underlying 25-30 cm thick layer consists of similar-size blocks and very small sharp rock fragments. The spaces among the blocks are filled up here by fine brownish, in other places ochre-yellow, material, most of which is falling dust. The lowest 30-35 cm layer is weathered, gravelly andesite with enclosed intensely wheatered and rounded blocks. The material grades downwards into weathered bedrock.

In this exposure the periglacial material is no thicker than 50 cm.

In the individual exposures there are significant differences in the grain size composition of the surface (0-25 cm) samples. The grains in the top layers of exposures I and III are finer than those of the similar material of exposure II. In the first two cases they are poorly sorted (So = 6.32, 6.30) *(Figs. 3 and 5,* curves Nº 1). The material in the top layer of exposure II is only slightly more sorted (So = 5.4). There is great similarity between the grain composition curves of the samples taken from the middle segments (depth 25-50 cm) of the exposures *(Figs. 3, 4, 5,* curves Nº 2). The nearly similar sorting (So = 9.3, 10.5, 9.3) indicates identical origin.

In all three exposures the grain-size composition of the material overlying the bedrock differs, to a greater extent, from the previous strata *(Figs. 3, 4, 5,* curves Nº 3). This layer contains the material of the weathered bedrock and, thus, it is not periglacial material.

The field observations and the laboratory results indicate that, by its form and material, the rock debris is not a block field but a talus cone. This assumption is supported by the fact that the rock debris is underlain by weathered bedrock in several places. The intact angular blocks of the rock debris

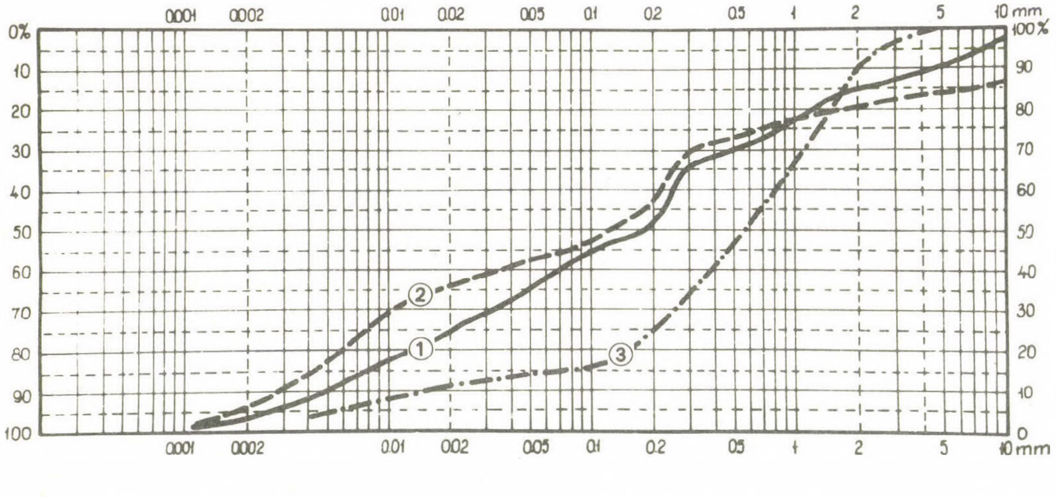

Fig. 3 Grain-size distribution curves of the samples from exposure 1 on Hemzsö-bérc

1 = 0-25 cm; 2 = 25-50 cm; 3 = 50-80 cm

cannot have originated from this weathered bedrock, but from the cryoplanation terrace outcropping from the one-time surface, or from some tors. It is these tors that were ruined and planated in the last cold period and their material covered up the weathered rock base of the cryoplanation terrace under the tors.

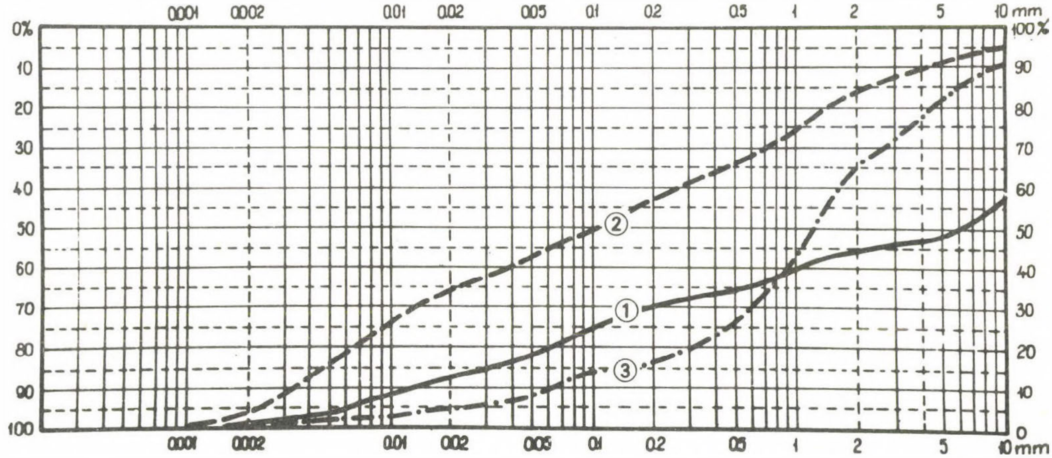

Fig. 4 Grain-size distribution curves of the samples from exposure 2 on Hemzsö-bérc
1 = 0-25 cm; 2 = 25-55 cm; 3 = 55-90 cm

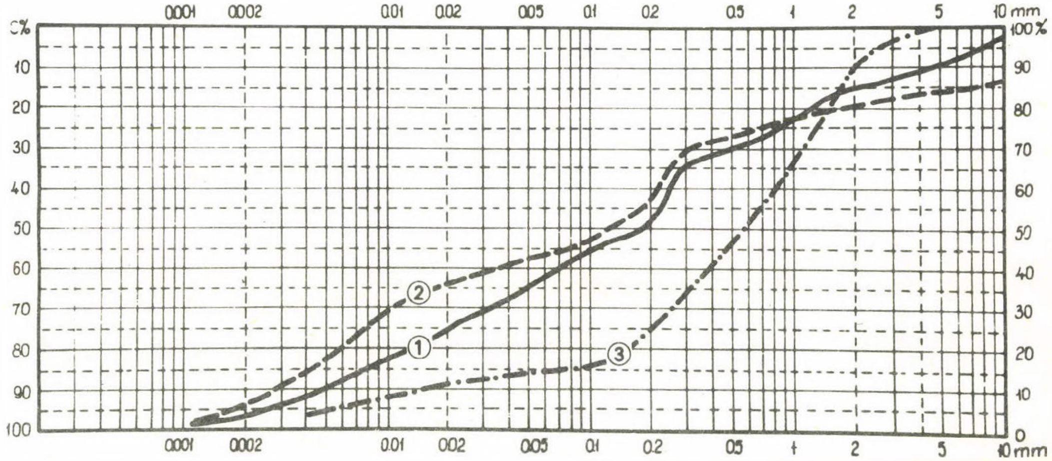

Fig. 5 Grain-size distribution curves of the samples from exposure 3 on Hemzsö-bérc
1 = 0-25 cm; 2 = 25-50 cm; 3 = 50-80 cm

LANDFORMS ON THE SLOPE

On the 1800 m long slope of Hemzsö-bérc running as far as the Ósva stream three segments can be distinguished. The uppermost 70-150 m long slope with a gradient of 27º displays a great richness of periglacial forms. The middle segment is rather moderate (18-20°). The lowest segment is a 1 km long gentle slope of 5-8°, essentially the floor of the small basin of the Ósva valley (*Fig. 1,* I, II, III). The evolution history of the three slope segments cannot be separated from one another. They belong together genetically, their development is determined by the processes taking place as a result of frost or frost-thaw changes.

THE UPPER SEGMENT

Cryoplanation step

The narrow upper segment of the slope is richest in periglacial forms *(Fig. 2)*. The most marked forms are the *frost-riven cliff* and the *cryoplanation step*. Their evolution was greatly promoted by two factors, the laminated character of andesite and the counterslope tilt of the lava beds (18-26° counterslope). The steps evolved on the outcropping bassets were rapidly destroyed by frost shattering, then receded and, at their feet, large amounts of debris accumulated. Arranged in two interrupted rows on the narrow slope, several smaller and two larger frost-riven cliffs or steps can be found. The frost-riven cliff is 5 to 7 m high. Thus, in front of the frost-riven cliff (denudational part), from rock fragments removed by frost shattering a talus cone accumulated. On the slope several smaller and two larger talus cones are found *(Fig. 2)*. The largest is 15 m wide and 120-150 m long. From the exposures on the talus cone we have learnt that the thickness of the rock debris exceeds 3-4 m. The material mainly consists of 30-60 m blocks. The talus cones stand out of the forest environment like isles. These barren talus cones date back to the last periglacial period. From their extention it can be calculated that the frost-riven cliff receded 15-50 m since.

Rock streams were favoured by the lithological and structural heterogeneity of the frost-riven cliff. Rock streams are very characteristic, about a dozen of them were counted.

Below the large talus cone on the S part of the slope, there is another, a 30 m wide one *(Fig. 2)*. This is distinct from the former, being forested. The spaces between and the cavities in the blocks were filled up by fine sediment. The position and size of the blocks are completely identical with those on its younger counterpart. The old talus cone consists of two genetically different materials. Besides the rock debris of some tens of cm size dating back to the penultimate periglacial period, the sandy and silty fraction of falling dust represents the younger generation, the last periglacial. The laboratory examination of the fine material filling up the

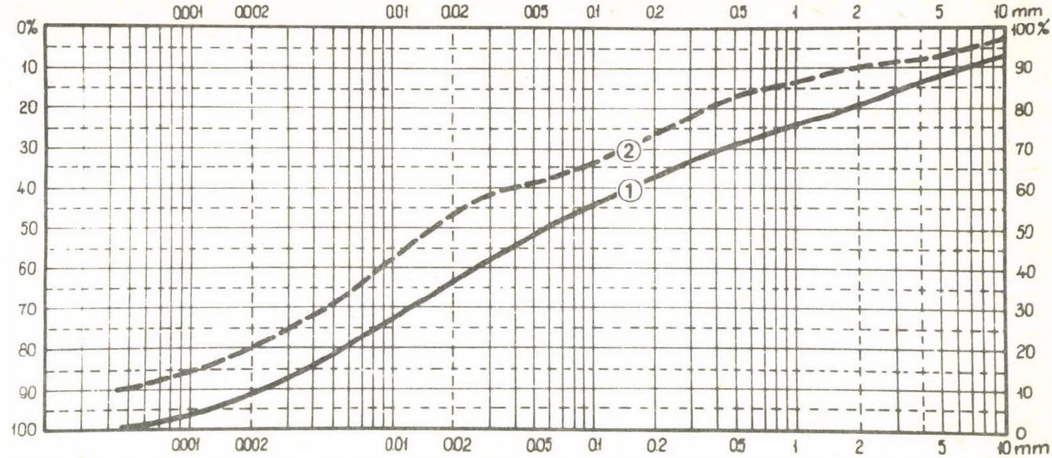

Fig. 6 Grain-size distribution curves of the matrix (fine fraction) of the forested talus cone
1 = 0-20 cm; 2 = 20-40 cm

spaces between the blocks showed that the 2-0.002 mm grains amount to 60-80 per cent of the material. It is striking that the fraction finer than 5 mm only rarely exceeds 10 per cent, and grains larger than 20 mm occur very rarely. Similarly low is the clay content *(Fig. 6)*.

The diagonal grain-size composition curve of the sample from between the blocks and the unsorted character of the material are indicative of periglacial origin.

Block stream

It is different from the rock stream not only in its size, but also in the circumstance that it is not enclosed within cliff walls. The better developed of the two block streams borders the frost-riven cliff from the N and runs up to the top. At the top it is narrower, 15-20 m wide, it is gradually widening downwards in the form of a funnel attaining a width of 75 m. The blocks lie close to one another on the surface at a stretch of about 120 m *(Fig. 2)*.
The stream character is also justified by its shallow and dell-shaped bed. In the places where a block stream formed cryoplanation steps and the accompanying talus cones are absent.

Talus field

The part of the 17° slope N of the mentioned block stream is covered by a large talus field overgrown by forest *(Fig. 2)*. The rock fragments cover the whole slope, lying closely on and beside one another. Nearly 60 per cent of the material filling up the spaces between the blocks consists of grains above 20 mm. The periglacial origin is indicated by the very low (below 1 per cent) clay content. The grain-size composition curve of the finer material shows more than one maximum: there is, however, already a major maximum in the 0.05-0.02 mm fraction (13.1 per cent), which indicates that a considerable amount of falling dust was mixed into the matrix in the last periglacial period *(Fig. 7)*.

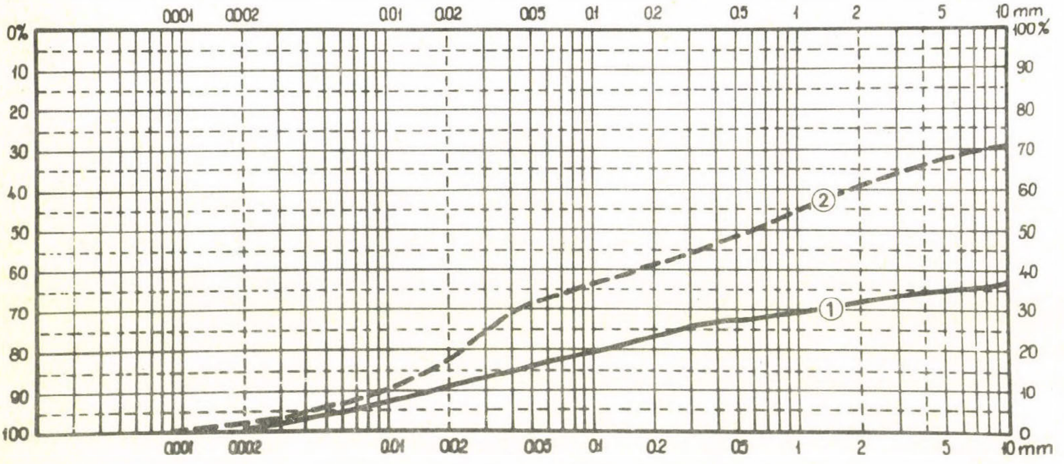

Fig. 7 Grain-size distribution curves of the matrix (fine fraction) of the talus field
1 = 0-20 cm; 2 = 20-40 cm

N and S of the talus fields the frost-riven cliffs have been preserved on the slope in two rows. Thus, different surface evolution processes are observed on two adjacent parts of the slope. This can be attributed to the differences in relative relief. Where a talus field formed, relative relief is reduced.

Block slides

The solitary rocks of block slides are common all over the slope. They partly came from the top, partly from the frost-riven cliff, and very rarely from the bedrock through cryofracture. They were moved further downslope by gravity and/or by the creep of mixed grain-size periglacial material.

FORMS ON THE MIDDLE SLOPE SEGMENT

The narrow, steep upper slope grades into a 18-20° wider one. The variety of forms here is poorer as compared to the upper part. While on the upper segment the formations were exclusively those evolved in the periglacial period, here, in addition to frost effect, the surface transforming effect of running water also played a part.

The most obvious periglacial form is block stream. It is essentially alien to this segment and the termination of the block streams evolved on the upper sections and reaching down here *(Fig. 2)*. The block stream consists, in general, of large blocks, which were in motion even in the last periglacial period, partly by gravity, partly by gelifluction.
Seven exposures were made adjacent to each other into the block stream. There are 20-30 cm blocks as well as grey gravelly sandy rock-flour-like material in the upper section. The grain-size distribution curve of the latter shows coarse periglacial material, in which the proportion of the larger than 10 mm fraction exceeds, at a depth of 15-25 cm, 50 per cent, and 33 per cent even in the sample taken at 70 cm *(Fig. 8)*. On the other hand, the proportion of clay does not reach even 3 per cent in the same samples.

In this exposure one can distinguish three horizons by the naked eye. The layers still reflect the mechanism of transport,

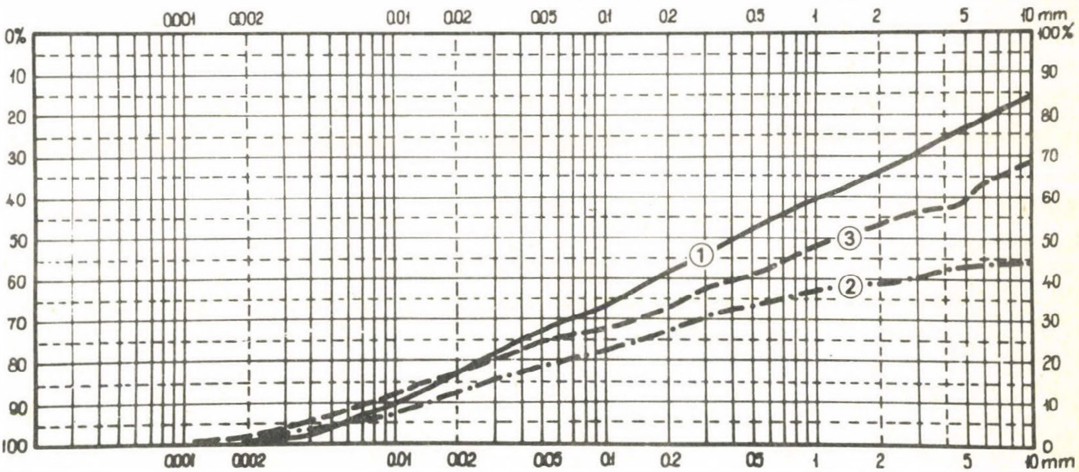

Fig. 8 The middle segment of the slope (II). Grain-size distribution curves of the sediment from the exposure in the block stream
1 = 0-15 cm; 2 = 15-25 cm; 3 = 25-70 cm

and the circumstances of primary accumulation. The sediment underwent hardly any furher autochtonous changes. It is not sorted.

The sediment of the newer exploration under the former one, at the end of the block stream, displays the features of further autochtonous disintegration. The grain-size composition curves of the samples taken from 0-20 cm and 28-80 cm are

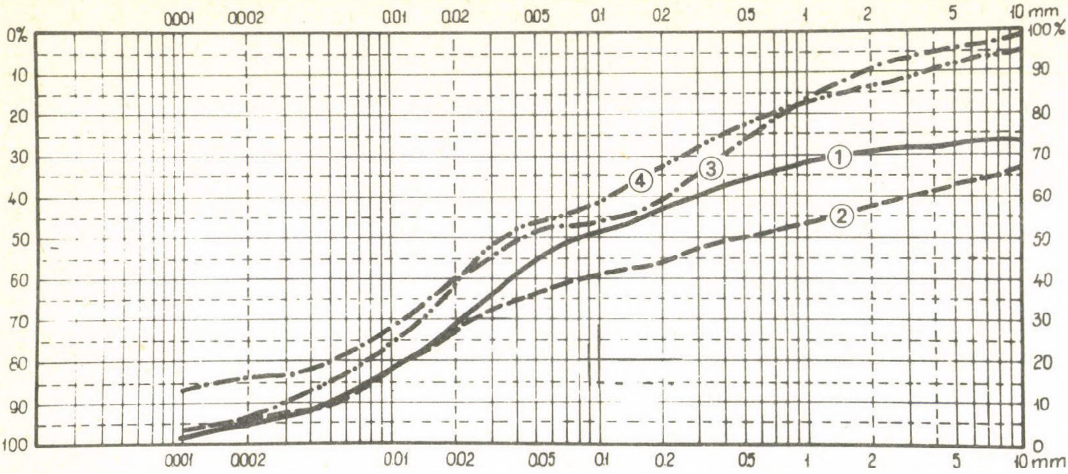

Fig. 9 The middle segment of the slope (II). Grain-size distribution curves of the sediment from the exposure at the end of the block stream
1 = 0-20 cm; 2 = 20-80 cm
Grain-size distribution curves of the material from the exposure at the lower part of the slope
3 = 0-45 cm; 4 = 45-95 cm

strikingly similar *(Fig. 9)*. This permits the conclusion that the lower part of the slope is covered by older gelisolifluctionally transported sediment, which arrived to its present place at latest in the last cold period, and was shattered further by frost on the spot *(Fig. 9. 1,2)*. This is the reason for the similiarities in the fine fractions.

The third sampling site was at the end of the middle segment of the slope. The material of the exposure refers to a sediment even finer and older than the material of the previous sample. With the growth of the distance of transportation, the larger fragments gradually disappear.

The data well reflect the characteristics of downslope material transport, the gradual refinement of sediment, sorting through transport, and, due to frost action, the enrichment of the 0.05-0.01 mm grains. It can also be established that whereas the mobilization, shaping and transformation of the sediment was performed by frost on the upper two-thirds of the slope, on the lower third an important role was played by weathering and transport by water.

THE LOWER PART OF THE SLOPE

The lower segment is a squarical basin of 5-8° slope. The basin floor evolved in the Pliocene period.

The only Upper-Pliocene monadnock of the basin (468 m) is largely of exposed bedrock. At outcrops frost shattering attacked the rhyolite bedrock. The weak rock rapidly disintegrated. This unsorted (So = 10.3) debris, mixed with fine gravel and sand, covers the bedrock in a layer of some tens of cm.

There is a difference between this and the previous slope segments. The development of this lower segment was independent of them. Its surface was dissected by valleys as early as the Pleistocene and the gelisolifluctional sediments from upper segments were removed across this section. Thus, in this area (III), besides sheet wash, there took place a considerable gully and stream erosion too in the Pleistocene.

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PALEOGEOMORPHOLOGIC SIGNIFICANCE OF REDEPOSITED DOLOMITE IN THE TRANSDANUBIAN MOUNTAINS

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The Transdanubian Mountains can be considered morphologically - within the Carpathian mountain frame - mountains of medium height bordered by Neogene basins. As previous research indicates, for its morphostructure it is a remnant of Upper Cretaceous tropical peneplain which has a faulted-folded crystalline basement and was dismembered into horsts. The mountains is mostly built up of Mesozoic limestone, dolomite, Tertiary calcareous, pelitic and coarse terrigenous sediments and additionally volcanic materials. Remnants of the Cretaceous karstic peneplain with bauxite covers are preserved where Tertiary sediments covered them and preserved them from denudation or during their evolution they were in low basin position. By their age of origin and burial, buried blocks can be referred into Lower Cretaceous or Upper Cretaceous or Upper Cretaceous-Eocene peneplain remains.

By the degree of denudation, exhumed, semiexhumed and buried surfaces of planation can be differentiated and by their orographic and geomorphologic position they are classified into crypto-, threshold, uplifted and summit level horst types (PÉCSI, M. 1970, 1975).

From the Triassic to our days the area of the mountains has belonged to several climatic zones. The quality of geomorphic evolution has differed with the various climatic influences. During repeated burial, transgressions and repeated exhumation landform generations of different nature have been superimposed one upon the other (real tropical peneplains, pediplains, abrasional platforms and their transformed varieties).

During the investigation of the correlative sediments covering semiexhumed and buried horsts and studying their stratigraphic positions, our attention was drawn by the phenomenon that the Triassic dolomite, considered so far a uniform base, is reworked in many cases and vertically divided by several types of bauxite and red clay horizons. This pheromenon is found at localities in the members of the Transdanubian Mountains such as in the Bakony Mountains (JUHÁSZ, Á. 1978), the Zsámbék basin and similar stratigraphic position is exposed in deep boreholes in the southern foreland of the Gerecse Mountains (VÉGHNÉ NEUBRANDT, E.-FÁYNÉ TÁTRAY, M.-MENSÁROS, P.-BALÁZSHÁZY, L. 1978) on buried horsts at about 600 m depth.

The redeposited dolomite divided by bauxite horizons is considered an independent formation by the evidence of its regional distribution. It is to be emphasized that it is found on Upper Cretaceous-Eocene buried surfaces and undoubtedly points to pedimentation. It can be stated that in the late Cretaceous humid tropical planation was discontinuous. The redeposited dolomite formation gives evidence of semiarid, arid climatic oscillation, the periodicity of tropical planation at that time.

The recognition of the stratigraphic position of redeposited dolomite is primarily of practical importance. In the mountain forelands and intramontane basins below the explored bauxite horizons further horizons are expected to be found. This sets a new trend of research. The data justify the complex geological-geomorphological evaluation and simultaneously neccesitate the control of explored bauxite occurences.

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REPEATEDLY BURIED AND EXHUMED RELICT FORMS

Explanation of geomorphological surfaces

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ABSTRACT

Geomorphological surfaces and their dating are indispensable tools for the reconstruction and staging of long-term relief evolution. The origin of geomorphological surfaces (erosional surfaces, pediments, terraces etc.) arranged in a step-like fashion above one another are explained in highly different ways by DAVIS, PENCK, KING and the followers of climatic geomorphology. Views generally coincide, however, in the highest surface being the oldest and the lower ever younger. This principle is valid of morphogenetic units that have practically permanently uplifted or have not subsided to a critical extent during their long period of development. Deviations from the principle were considered exceptions by some. More and more macrostructural-morphological units are found to prove the validity of the principle with geogenetic evolution of repeated erosional and burial periods. As a result of this relief evolution, old relict surfaces have various elevations and are occasionally preserved or only reshaped or transformed to various degrees. All the geomorphological surfaces and their ages and terminology are demonstrated in tables, profiles and maps.

* * *

Repeatedly buried and exhumed surfaces are found at various elevations in both the Hungarian Mountains and the Alpine-Carpathian mountain system. It is perhaps not exceptional that valleys occur which were cut in the Tertiary, later buried and exhumed in the Quaternary. In addition, in the mountain system, generally uplifting in the Upper Cenozoic, geomorphological surfaces (raised beaches or fluvial terraces) are naturally more numerous and their ages are mostly inversely related to stratigraphic order. In Hungary, for instance, the Transdanubian Mountains have a peneplanated relief with remnants of bauxite. Subsequently, the peneplain was dismembered into horsts and grabens of various elevation the surfaces of which were again buried and totally or partially exhumed primarily in the Tertiary (in the Eocene, Oligocene and locally also in the Miocene). In the margin of the Transdanubian series of horsts the gemorphological surfaces formed in the Late Cenozoic (Miocene and Pliocene raised beaches, pediments, 6-7 fluvial terraces) were mostly preserved by travertine layers from subsequent erosion.

The Transdanubian Mountains of tectonically folded-faulted type consists of horst series dissected by trench-like basins built up mainly of Triassic calcareous rocks. In these mountains several generations of geomorphological surfaces* can be identified; out of them the oldest one has undergone repeated burial and exhumation and in the course of the evolution acquired highly variable orographic positions (PÉCSI M. 1970, 1975, 1984). Its interpretation only became possible by the detailed investigation of the morphogenesis of the mountains. The results obtained so far are summarized as follows:

1. The Mesozoic horsts of the Transdanubian Mountains which have, under thin Upper Cretaceous or Tertiary sediments, bauxite-bearing tropical paleokarst forms, can be considered Cretaceous tropical peneplain remnants from the geomorphological point of view. According to their orographic position these *buried horsts* may also occur in uplifted plateau position, in lower-lying step or threshold positions. Nevertheless, their erosional surfaces as primary morphogenetic forms existed as early as in the Cretaceous and in the course of the subsequent repeated burial and exhumation the surfaces were not subject to considerable change of form *(Fig. 1,* types B, C and D*)*.

2. It is also common that during repeated exhumation only the sedimentary cover was removed and the *exhumed paleokarstic peneplain* represents the geomorphological surface recently in summit or incidentally in piedmont position *(Fig. 2)*.

3. There exist a lot of horsts covered by Eocene limestone and Oligocene clastic sediments, on the surface of which sediment movement caused not only retouching but also certain transformations. In this case the original erosional surface of horst is considered a *younger,* (e.g. Oligocene) *partially reshaped geomorphological surface with paleokarst* (Fig. 1, type A).

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* In the sense of the erosion cycle theory of DAVIS, W. M. on the gradually rising terrain the highest geomorphological surfaces are oldest while at lower they tend to be ever younger. Similar interpretation is given by W. PENCK's concept of equilibrium morphological evolution, i.e. in the margin of the continuously rising mountains ever younger pediments are formed below each other.. Similarly, the terraces of the continuously rising mountains or the raised beaches of uplifting shores can be interpreted as geomorphological surfaces of ever younger age underlying each other.

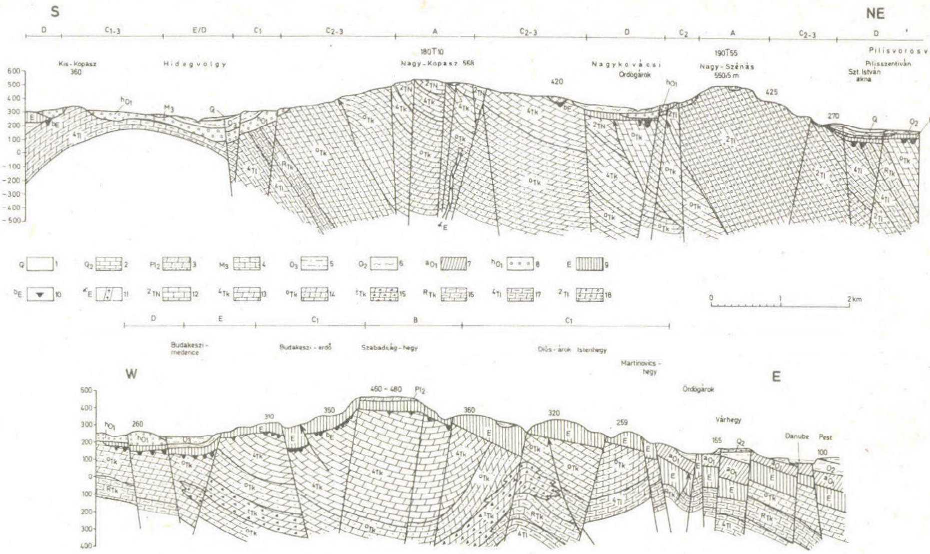


Fig. 1 Geomorphological types of the graben and horst mountains in the Buda Mountains (after PÉCSI, M. and WEIN, GY.)
A = Exhumed planated horsts in uplifted position, B = Buried surfaces of planation in uplifted position, C = Horsts in foothill position: 1. totally buried, 2. semi-exhumed, D = Buried surfaces of planation in graben position, E = Glacis d'erosion; 1 = Pleistocene loess and blown sand, 2 = Pleistocene travertine, 3 = /Upper/ Pliocene sand, clay travertine, 4 = Sarmatian conglomerate and limestone, 5 = Upper Oligocene sandy clay, 6 = Middle Oligocene clay, 7 = Lower Oligocene marl, 8 = Lower Oligocene sandstone, 9 = Eocene formations, 10 = Eocene reworked bauxite and conglomerate, 11 = Eocene acid dyke, 12 = Upper Triassic 'Dachstein' limestone, 13 = Upper Triassic 'Hauptdolomit', 14 = Upper Triassic coarse dolomite, 15 = Upper Triassic cherty dolomite, 16 = Upper Triassic marl, limestone, dolomite, 17 = Middle Triassic pink-coloured dolomite, 18 = Middle Triassic Dipl. dolomite

4. Sometimes it is difficult to determine the age and extent of transformation of the exhumed *uncovered horsts*. In these cases one may start from the fact that the surface of the Transdanubian Mountains were peneplanated as early as in the Cretaceous, the surfaces of those of lower position only slightly changed during the Tertiary. The uncovered horsts of morphologically higher position could be truncated mainly during the Paleogene and in the course of the Neogene their margins were only pedimented.

5. Each of the *buried* (1), *semi-exhumed* (2) and *exhumed* (3) horsts peneplanated in the Cretaceous may occur at different elevations or may be found side by side in the same height within one mountain *(Figs. 1-3)*. It is also frequent, however that Mesozoic horsts overlain by Paleogene sediments are arranged in a step-like fashion. Consequently, the erosional surfaces of these horst types of different height do not represent geomorphological surfaces of different age.

6. In the intramontane graben-like basins among horsts, the surface of the ancient peneplain with (tracer of) bauxite occurs in crypto-peneplain position *(Fig. 4)* locally under several hundred metre thick Paleogene clastic sediments.

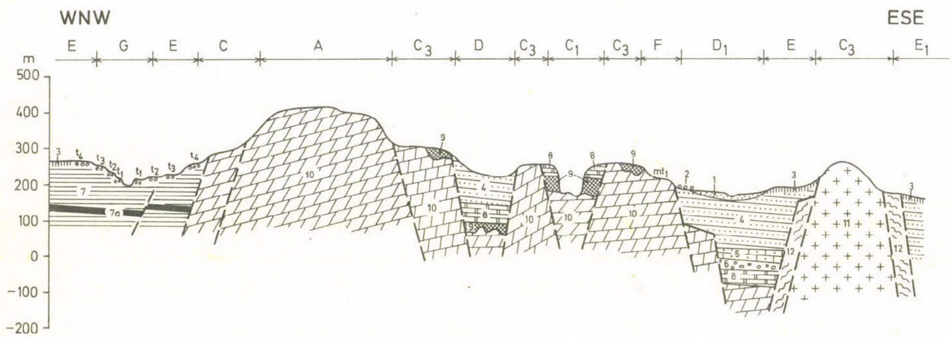


Fig. 2 Geomorphological surfaces of the Vértes Mountains.
A = exhumed horst in summit position, a remnant of the slightly remodelled Cretaceous peneplain, C = horst in foothill position: C1 = totally buried, C3 = totally exhumed, D = buried surface of planation in intramontane grave position: D1 = intramontane graben filled by molasse and alluvial fans, E = glacis d'erosion with terraces: E1 = rock pediment and glacis d'erosion, F = remnant of (Upper Pannonian) raised beach, G = submontane basin with river and glacis terraces. t1-t4 = Fluvial terraces, mt1 = raised beach, 1 = alluvium and meadow soil, 2 = alluvial fan, 3 = loess and loess-like sediments, 4 = Pannonian sandy and clayey formation, 5 = Sarmatian formation, 6 = Miocene gravel and sand, 7 = Oligocene sand and clay formation, 7a = Oligocene lignite, 8 = Eocene limestone, 9 = bauxite (Cretaceous), 10 = Triassic dolomite and limestone, 11 = granite, 12 = (Carboniferous) metamorphic rocks

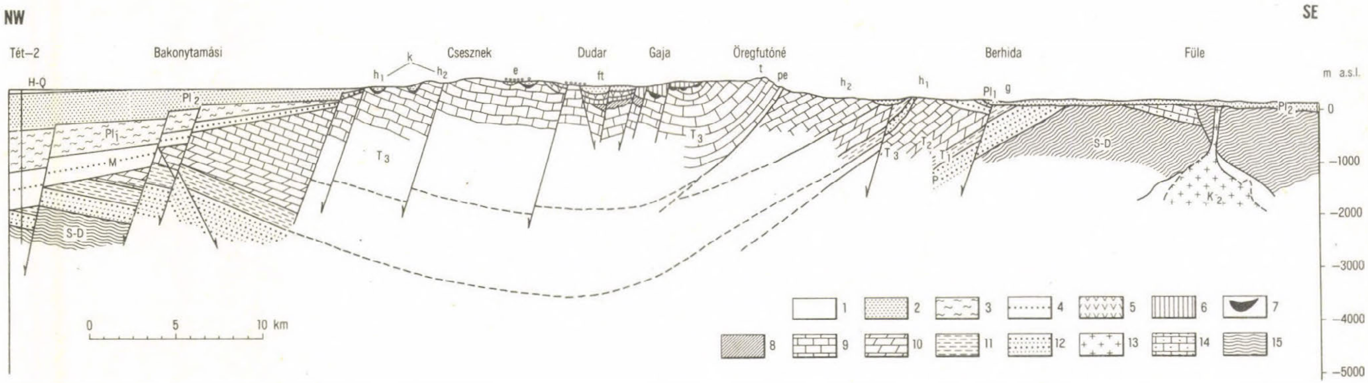


Fig. 3 General geomorphological profile across the Bakony Mountains (after WEIN, Gy. 1969; comp. by PÉCSI, M.)
Holocene-Pleistocene fluviatile sand, gravel and alluvial soils, 2 = Upper Pannonian sand and clay, 3 = Lower Pannonian clay-marl complex, 4 = Miocene gravel and sand layers (including some Upper Oligocene in the Dudar basin), 5 = Eocene coal measures and calcareous strata, 6 = Lower Cretaceous (Aptian, Albian and Cenomanian) limestone and calcareous marl complex, 7 = bauxite deposits and bauxite formations, 8 = Jurassic limestone sequence, 9 = Upper Triassic dolomite and limestone complex, 10 = Middle Triassic limestone, 11 = Lower Triassic aleurolite, marl and limestone complex, 12 = Permian sandstone and conglomerate, 13 = Upper Carboniferous granite porphyrite, 14 = Lower Carboniferous conglomerate and clay shale, 15 = Silurian-Devonian phyllite and crystalline limestone complex, t = uplifted remnant of a tropical peneplain, ft = cryptopeneplain, covered peneplain, e = exhumed peneplain, locally covered by Miocene gravel, pe = piedmont step, h2 = riser of Pannonian raised beach, h1 = pediment, g = Pleistocene piedmont surface (glacis) developed on loose deposits, k = remodelled tropical peneplain in threshold position, Tét1-2 = prospect drillings

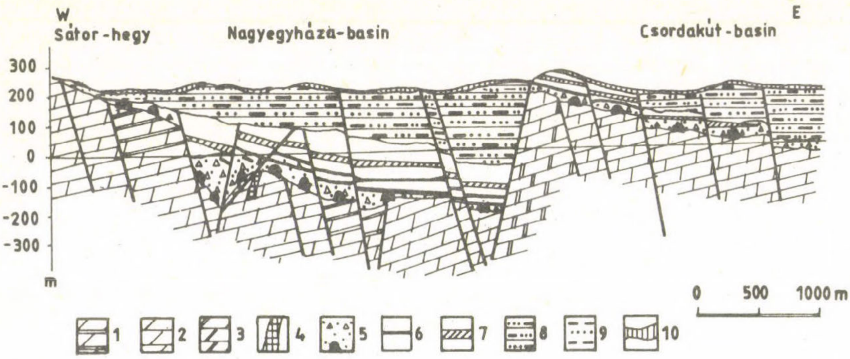
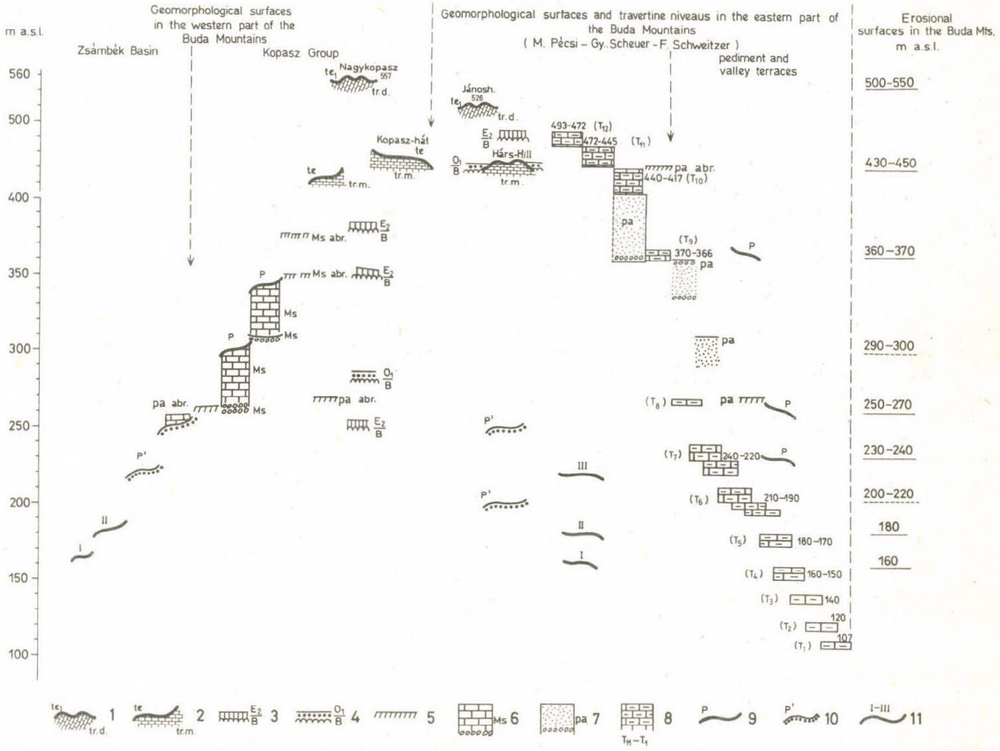


Fig. 4 Representative geologic profile of Nagyegyháza-Csordakút Basin (Véghné et al. 1978).
1 = Norian 'Hauptdolomit', 2 = Ladinian-Carnian dolomite, 3 = Ladinian dolomite, 4 = red calcitic dolomite, 5 = redeposited dolomite, bauxite overlies the ancient karstic peneplain, 6 = Lower to Middle Eocene coal measures, 7 = Eocene limestone, 8 = Upper Oligocene sand and clay, 9 = Pliocene sand and clay, 10 = Pleistocene loess

7. In the mountain margins the ancient raised beaches represent usually a lower geomorphological surface than the erosional surfaces of the uplifted and exhumed horsts. Nevertheless, some instances show that Pannonian marine formations overlie horsts uplifted to 400 to 500 m which were buried for first time in the Paleogene (*Fig. 1*, type B, *Fig. 5*, T11-12); elsewhere the Pannonian travertine overlies directly the surface of the Mesozoic ancient peneplain (Balaton Uplands).

8. The Late Cenozoic geomorphological surfaces in the horst margin of the Transdanubian Mountains raised beaches, piedmont surfaces, river terraces) were mostly preserved from subsequent erosion by the hard layers of travertine. Travertines precipitated from hot karst springs, at the current base level. In the Buda Hills about twelve geomporphological surfaces were preserved from erosion by travertines (*Fig. 5, Table 1*). This phenomenon is characteristic of mountain margins and of some larger valleys. In the valley side terraces a lower sequence of travertines is found (107-250 m a.s.l.). The higher sequence deposited on piedmont surfaces and raised beaches. To determine their age faunal, paleomagnetic and absolute chronological data were used (PÉCSI, M.-SCHEUER, GY.-SCHWEITZER, F. 1982).



<u>Fig. 5</u> Geomorphological surfaces in the Buda Mountains (PÉCSI, M. 1980 - based on data by PÉCSI, M. 1963, 1975; SCHEUER, Gy.-SCHWEITZER, F. 1974; WEIN, Gy. 1977). - 1 = exhumed Mesozoic peneplain in summit position (te_1) on Upper Triassic dolomite (tr.d.), 2 = remnants of exhumed Mesozoic peneplain (te) on Upper Triassic 'Dachstein' limestone (tr.m.), 3 = buried Mesozoic peneplain, remains of tropical karst and bauxite under Eocene limestone (E_2/B), 4 = buried Mesozoic peneplain, bauxite and tropical tower karst 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 (P1), 11 = Pleistocene derasion terraces, tali and gentle slope segments on unconsolidated deposits

Table 1 Main geomorphological surfaces in the Transdanubian Mountains

I. *Remnants of peneplain surfaces*

1. Remnants of Mesozoic peneplains with tower karst:
   - remnant of peneplain with paleokarst in summit position (E-Bakony, Tés Plateau)
   - cryptopeneplain covered by Eocene limestone (Gánt, Nyirád etc)
   - exhumed remnant of peneplain (Keszthely Mountains, W-Buda Mountains)
2. Remnants of Paleogene (partly Mesozoic) peneplains reshaped by Oligo-Miocene pedimentation
   - peneplanated Mesozoic horst covered by Oligocene-Miocene gravel mantle (N-Bakony)
   - summit surfaces with spots of Oligocene-Miocene gravel (W-Gerecse Mountains)

II. *Marginal geomorphological surfaces (Neogene)*

1. Miocene marine terraces (raised beaches)
   - littoral surface covered by Carpathian conglomerate (Bakony Mountains)
   - Badenian littoral surface with gravelly limestone (Visegrád Mountains)
   - Sarmatian marine terraces (Balaton Uplands, Buda Mountains)
2. Pannonian raised beaches and travertine horizons
   - Lower Pannonian (Monacian) raised beach *(No 3)* (Buda Mountains, Diósd-Sóskút, Balaton Uplands
   - travertine *(No 11)* from the upper part of the Lower Pannonian (Pre-Csákvárian?) (Buda Mountains at 500 m a.s.l., Balaton Uplands, travertine at Kapolcs)
   - raised beach(es) from the lower part of the Upper Pannonian (Csákvárian) (*No 2*, occasionally *No 3*) (Vértes and Buda Mountains)
   - travertine horizons (*No 10* and *No 10a*) on raised beach from the middle parts of the Upper Pannonian (Sümegian and Baltavárian) (Bakony: Nagyvázsony, Várpalota, Pula, Buda Mountains: Szabadság-hegy)

III. *Foothill (pediment) surfaces*

1. Main period of Pliocene pedimentation (Baltavárian-Csarnótan), higher level of the pediment surfaces (cca. 5,4-3 million years, KRETZOI, M.-PÉCSI, M. 1982)
2. Formation of Upper Pliocene gravel sheets in the second half of the period of pedimentation (Ruscinian-Csarnótan)
   - highest sheet or terrace *No VIII* in the foreground of the E-Alps
   - Residual gravel terraces of the Kemeneshát, terraces *No VII* and locally by travertine (T: *No 8*)

IV. *Quaternary fluvial terraces and travertine horizons, loesses and slope deposits*

- terrace *No VI* (Lower Villányian), travertine *No 6-No 7* (from the Upper Villányian-Kislángian stage)
- terrace *No V (Lower Biharian), travertines No 5* (upper part of Lower Biharian, of already reverse polarity, about 800,000 to 900,000 years old). The lowest horizons in the Paks old loess, below the PD paleosol, belong here.
- terrace *No IV* (Upper Biharian-Tarkö-Vértesszölös stage) travertine *No 4* (Vértesszölös stage more than 350,000 years).The terrace material and the travertine are both of normal polarity.
- terrace *No III* (R1 and R1-R2); travertine *No 3* (190,000 years);
- terrace *No II/b* (R-W and W1), travertine *No 2b* (100,000 years). The young loess of Basaharc-Mende belongs here.
- terrace *No II/a* (W3), travertine *No 2a;* the young loess series of Dunaújváros-Tápiósüly) (less than 20,000 years);
- flood-plain (terrace *No 1*), travertine (Holocene), less than 11,000 years.

GEOMORPHOLOGICAL SURFACES IN THE MESOZOIC MEMBERS OF THE NORTH HUNGARIAN MOUNTAIN RANGE

The Aggtelek-Rudabánya Mountains, NE-Hungary, is structural morphologically, also *a folded-faulted horst planated in the Mesozoic.* The peneplain with paleokarsts was also buried and exhumed in the Tertiary. The Tertiary crustal movements dismembered it into units developing independently (and eroding to various degrees - *Fig. 6*). Orographically it is a low mountains today.

The general surface evolution is outlined as follows: In the early Mesozoic there was a syncline; from the Upper Triassic it turned into mainland and until the Middle Cretaceous it was planated under tropical subhumid climate. The low tropical peneplain with paleokarsts was dismembered along major faults at the end of the Mesozoic and became a pediment zone enclosed by more elevated crystalline mountains on the N and S. Geomorphological evidence allows the assumption that peneplanation was followed by pediplanation in the Eocene. Subsequently, in the Paleogene and Neogene, the surface was covered by sediments in varying depth.

Beginning from the late Miocene, due to moderate uplift, the mantle of loose sediments has been partly or completely removed. On the resulting surface, during the Pliocene and the Pleistocene pediments of mountain margin and river terraces

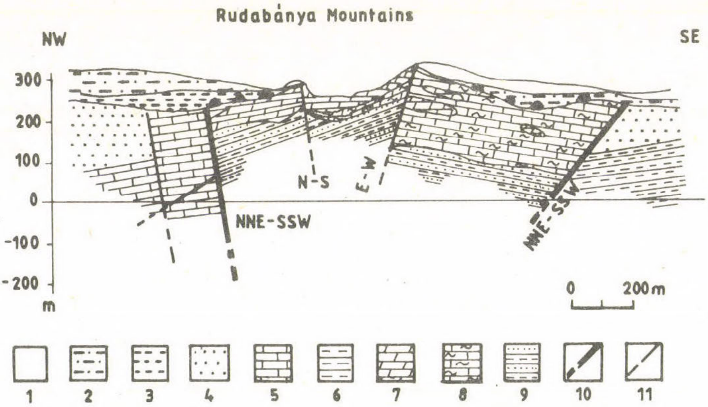


Fig. 6 Transversal section across the Rudabánya mine (by HERNYÁK, G. 1976).
1 = spoil heap, 2 = Pannonian clay, sand and gravel, 3 = Sarmatian-Badenian clay and silt, 4 = Oligocene greenish-grey sand and clay, 5 = Ladinian black shale, siliceous schist and marl, 6 = Ladinian cherty limestone and radiolarite, 7 = Anysian dolomite of 'saccharoidal' texture, 'Gutenstein' limestone, 8 = Campilian grey, laminated limestone and shale, 9 = Seisian greenish and purple sandstone, shale and anhydrite, 10 = reverse fault plane, 11 = normal fault

were formed. The above outlined history of geomporphic evolution has brought about the following landforms or geomorphological surfaces *(Fig. 7)*:

a. *exhumed planated horst in summit position,* which underwent *intensive karstification* (Aggtelek Mountains, Martony Mountains);

b. *medium elevated planated horsts* of which loose Paleogene sediments were entirely removed during the Tertiary and the Quaternary (central part of the Rudabánya Mountains);

c. *semiexhumed planated horst reshaped by pedimentation* with Oligocene or Miocene cover in mosaically varying depth (e.g. margin of the Rudabánya Mountains);

d. during the Pliocene on the Tertiary loose sediments of buried horsts pediments were formed and they functioned as initial surfaces for the Pleistocene valley dissection and were eroded into intervalley ridges. Along the major valleys three to four terraces were shaped; the higher ones are covered by travertines.

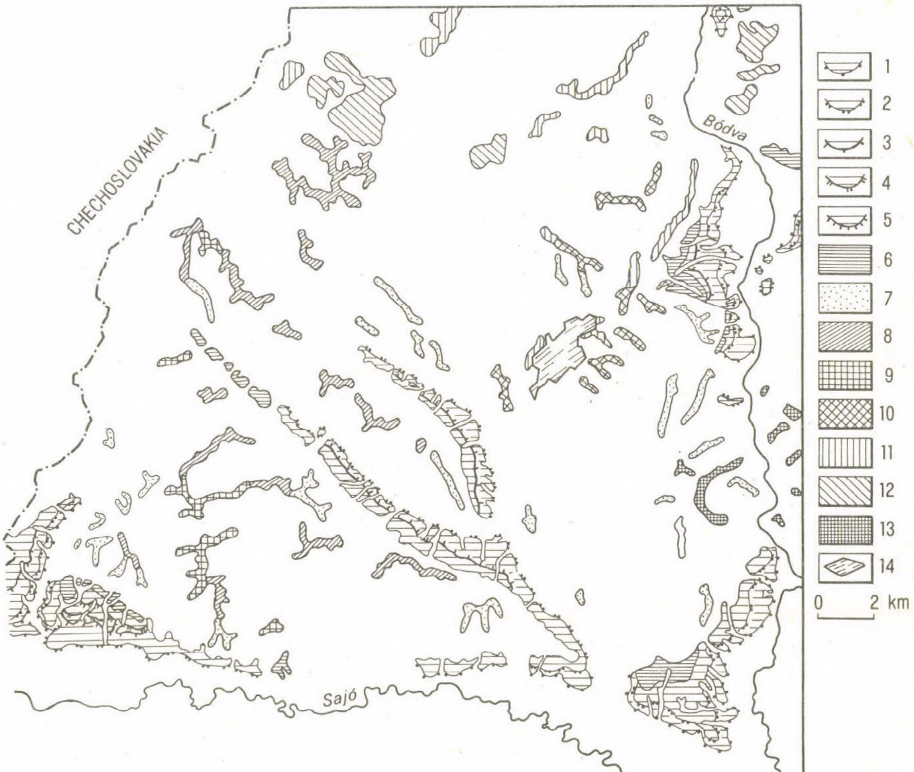


Fig. 7 Main geomorphological surfaces of the Sajó-Bódva Interfluve. 1 = terrace No II/a, 2 = terrace No II/b, 3 = terrace No III with travertine horizon, 4 = terrace No 4 with travertine horizon, 5 = terrace No V, 6 = Upper Pliocene pediment (locally red clay accumulation), 7 = Low interfluves, derasion step flats and remnants of older pediments, 8 = higher summit levels of hills or interfluves (initial surfaces for valley dissection in the Quaternary), 9 = remnants of Neogene peneplain, 10 = semi-exhumed planated horst surface remodelled by pedimentation covered by Paleogene sediments), 11 = surfaces of medium uplifted planated horsts (exhumed during the Tertiary and Quaternary), 12 = totally exhumed planated horst in summit position with intensive karstification, 13 = repeatedly buried and exhumed peneplain remnants built up of Paleozoic sediments, 14 = mine area

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BURIED MESOZOIC FORMS IN THE TRANSDANUBIAN MOUNTAINS

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ABSTRACT

By the origin of forms, PÉCSI, M. (1975) defined the Transdanubian Mountains as a series of peneplanated horsts of slightly folded-imbricate structure with a close pattern of faults. Its surface had been eroded to a uniform low peneplain by the Upper Tertiary. The karstic peneplain was mostly formed on Triassic dolomite and limestone. The geologic and geomorphologic position suggests that peneplanation continued from the Upper Jurassic to the Middle Cretaceous for most of the mountains. Cone and tower karst rose above the low peneplain and they are now covered by lateritic regolith and, in many places, by bauxite. From the Middle Cretaceous the peneplain was inundated by sea. The dismembering of the peneplain, started in the Upper Cretaceous, went on in the Tertiary. The ruins of peneplain which underwent further subsidence in the Tertiary and gave way to basin formation in their places are called cryptopleneplains (PÉCSI, M. 1970). From the analyses of exposure it is seen that the exposures only differ in the cover sediments, and, thus, were classified according to the overlying material: buried cryptopeneplains covered by Middle Cretaceous or Upper Cretaceous or Lower Eocene.

* * *

PALEOGEOGRAPHIC CONDITIONS TO TROPICAL CONE KARST FORMATION

At the beginning of the Triassic geosyncline period in the area of the present Transdanubian Mountains sandstone, dolomitic sandstone and dolomitic marl were the main lithofacies. Subsequently, from the Upper Scythian limestone and dolomite became dominant. Marl strata only deposited in the Karnian and Rhaetian. The *predominant rocks* in the mountains *are Karnian-Norian 'Hauptdolomite' and Rhaetian 'Dachstein' limestone.* In some parts sedimentation continued in the Jurassic too (BÁRDOSSY, Gy. 1977). According to FÜLÖP, J. (1971) in the lower part of the Liassic first littoral, than neritic and finally bathyal facies are found. It was followed by slow regression. The Jurassic sequence of a total 400 m depth is almost completely absent in the base of tropical weathering products, only in the SW-Bakony Mountains some fragments of Liassic sediments preserved from erosion were found in the bauxite base. The Jurassic sequence may have extended over there, although it is completely absent in the E-Bakony and the Vértes Mountains, the proximity of Jurassic series makes it probable that once they also covered this area.

The problem with the tropical karstic peneplain is the beginning of its formation; whether it started as early as the Upper Triassic or only commenced in the Late Jurassic. The investigations by FÜLÖP, J. (1964) indicate that the Late Jurassic and Cretaceous sea only reached the axial zone of the Transdanubian Mountains and did not extend over the southern peneplanated parts. From the Upper Triassic the S flank of the geosyncline was uplifted and became land.

The segment of the mountains which was not inundated by sea from the Upper Triassic or the late Jurassic, *was exposed to tropical terrestrial weathering for about 100 m.y.* Terrestrial erosion took place in the area affected by the Jurassic and Lower Cretaceous transgressions for more than 10 m.y. (BÁRDOSSY, Gy. 1977). *On the surface of Triassic accumulations of primarily calcareous rocks an extended peneplain with cone and tower karst forms* evolved (SZABÓ P.Z. 1956, PÉCSI, M. 1980).

Among other evidence, paleomagnetic results and plate tectonics principles suggest that peneplanation took place in the marginal zone of the African continent and the mountains acquired its present position only in the Upper Cretaceous and the Paleogene (WEIN, Gy. 1978, PÉCSI, M. 1980, MÁRTON, P.-MÁRTON, E. 1984).

By the Middle Cretaceous the S part of the Transdanubian Mountains had been eroded to a karstic peneplain situated at lower elevation than its environs. From the surface of the higher crystalline mountains tropical weathering products (red clay and laterite) were redeposited over to it.

DISMEMBERING AND BURIAL OF THE PENEPLAIN

Climatic conditions went on to favour tropical peneplanation for a long period, from the Upper Cretaceous, however, intensive tectonic movements put an end to the era of tranquility and, at the same time, to regional peneplanation. The general uplift in the Upper Cretaceous-Paleocene (the mountains were mainland from the late Cretaceous to Upper Eocene) is interpreted (DUDICH, E.-KOPEK, G. 1980) that the mountains were built up of blocks moving at different rates and separated by faultlines. Dismembering into grabens and horsts continued through the Tertiary too. In the opinion of PÉCSI, M. (1970) the surface of the Transdanubian Mountains occupied a pediment position between higher crystalline mountains from the Paleogene and functioned as a geosyncline, while the Mesozoic peneplain was sculptured by pedimentation.

The further geomorphic development of a segment of the Mesozoic peneplain depended on whether is was located on an uplifting or on a subsiding horst. *If the subsiding planated horst was inundated by sea and the sediment mantle has been preserved* *to our day, both the peneplain and the overlying tropical weathering products (including bauxite) have survived.*

MORPHOGENETIC TYPES OF HORSTS

Evaluating the geomorphic development horsts, PÉCSI, M. (1969, 1970) identified four types:

1. The planated horsts which repeatedly subsided during the Tertiary; the remains of the peneplain were buried under deep sediment and became *cryptopeneplains*.

2. Some remains of the peneplain were uplifted into summit position, but are covered by Eocene or Oligocene sediment mantle. They are *horsts in summit position with remains of covered paleokarstic peneplain.*

3. On other occasions, the *planated horst in summit position have been partly or completely exhumed.*

4. Horsts in summit position uncovered by sediment are also common. They were buried once or twice, on their surfaces, however, there are only traces of the cover layer or paleokarst preserved.

In this paper only the first two types are tackled, where the remnants of peneplain covered by weathering products are mantled by a dated cover layer.

TYPES OF BURIED PLANATED HORSTS

A common feature of buried planated horsts is that they formed on surfaces of Upper Triassic dolomite and Dachstein limestone. Another common trait is represented by the tropical wheathering products deposited in the depressions of the cone karst surface. The ages of cover layers are, however, different. It seems instrumental to classify the horsts according to the age of cover.

1. *Buried horsts covered by Lower Cretaceous sediments.* The sediments deposited by the Aptian-Alban seas directly overlie the bauxitic weathering products (at Alsópere and Tés). During the transgression, the loose bauxite was not destroyed, as it was a tranquil ingression. The peneplain formed on Dachstein limestone and were overlain by clay and marl. The fragments of peneplain covered and preserved by marine sediments acquired a higher position due to the movements and tropical planation extended again over large surfaces and considerable lowered the surfaces of blocks mantled by Middle Cretaceous sediments too. Bauxite beds were only preserved on horsts in lower geomorphological position in the Upper Cretaceous (FÜLÖP, J. 1966):

2. *Buried horsts covered by Upper Cretaceous sediments.* They had been affected by peneplanation until the Senonian transgression. The fragments of peneplain with cone karst and bauxite were first preserved under littoral sediments with clayey, coal-bearing and marly interbeddings, subsequently overlain by marl and limestone mantles at Halimba, Sümeg, Ajka and Kolontár - FÜLÖP, J. 1966). The sediments of the Halimba basin overlie bauxite without unconformity. There

are intercalated dolomite and limestone gravel in the bauxite itself; in the upper part there is an enrichment of them and microscopic grains of dolomite are also dispersed in it (BÁRDOSSY, Gy. 1977). Above this transitional zone, a freshwater-lacustrine series and a sequence with coal seams follow. No similarly gradual transition has been observed in exposure either in Hungary or abroad.

3. *Buried horsts covered by Eocene sediments.* Most of the buried horsts studied in exposures belong here. In areas with an Eocene cover, sedimentation starts with paludal deposition along seashores. During the Lower Eocene ingression, bauxite terrains were covered with clayey, coal-bearing amd marly deposits. Lower Eocene transgression was limited in area and inundation became completed in the Middle or Upper Eocene (at Gánt and in the Budakeszi basin).

At the end of the period of denudation, before paludal deposition upon the uppermost of the series locally redeposited bauxite and bauxitic clay accumulated (at Iszkaszentgyörgy and Gánt - BÁRDOSSY, Gy. 1977). Evidence is given by large bauxite gravels and boulders as well as the bedding parallel to the cover.

4. *Exhumed and repeatedly buried horsts covered by Oligo-Miocene sediments.* In the Transdanubian Mountains remnants of peneplain are also known the Upper Cretaceous surfaces of which are covered by younger, Tertiary coarse gravel and occasionally by conglomerates. The most typical occurence is in the Buda Mountains (on Nagy-Hárshegy). Here the cover is Lower Oligocene 'Hárshegy' sandstone. In other parts of the mountains, bauxite beds overlain by Miocene gravels are also known (at Nyírád). Here exhumation in the Tertiary was followed by repeated burial. In the NW margins of the Bakony Mountains the bauxite and laterite mantle is covered by Oligocene clayey-sandy sediments. In the environs of Fenyöfö subsequent to the accumulation in the Eocene, the surfaces with bauxite were overlain by Oligocene sand.

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LANDSCAPE TOPOLOGY AND EVALUATION OF THE BALATON 'RIVIERA'

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ABSTRACT

In their previous papers (MAROSI, S.-SZILÁRD, J. 1975, 1979) authors have given detailed ecological descriptions and evaluations of the landscape types along Lake Balaton and in the Somogy Hills. In their present study they undertake to present a complex landscape typological description of the north shore region of the largest lake in Central Europe (almost 600 km^2 in area). The natural potentials of this landstrip, commonly called the 'Balaton Riviera', are also evaluated. Here authors ignored the alluvial flats in the 'Riviera', reflecting azonal, hydromorphous and semihydromorphous effects, and utilized for various purposes. Landscape typology is based on the concept and terminology of PÉCSI, M.-SOMOGYI, S.-JAKUCS, P. (1972).

* * *

The 130.2 km^2 area of the 'Riviera' (basically sloping flats on the north shore of Lake Balaton) are landscape typologically considered as some moderately dissected *piedmont surface with rendzinas and locally various zonal soils and with a deep ground-water table.*

Regarding lithology, the Riviera presents a rather variable picture. The *Paleozoic* rocks of the basement commonly form outcrops. Most frequently Permian red sandstone occurs (covering an area of 16 km^2). *Mesozoic* formations extend over substantially larger surfaces. Triassic dolomite has the largest extension (30 km^2). In addition, various marls, Sarmatian and other limestones represent calcareous rocks. The youngest deposits of marine origin, the *Pannonian sandy-clayey* sediments, only occur on some spots. Older rocks are locally overlain by *Quaternary*, mainly proluvial, foothill talus material, deluvial loess-like deposits. Their mantles of various depth are parent materials for soil formation.

Due to the lithological differences, tectonic movements and the effect of planation and selective erosion, the *relief* of the Riviera is varied too (PÉCSI, M. 1969). *Two basic surfaces* are identified at 120-150 m and at 160-180 m a.s.l. They are structurally preformed as evidenced by the dips of strata in many places. The surfaces slope towards Lake Balaton and rise above the lake in a wave-cut margin, the *abrasional platform* at 112-116 m, which is succeeded by a *system of lacustrine elevated beaches* of three-fold division. A primary feature of the multifaced *slope conditions* is *southerly exposure* involving radiation and thermal surplus favouring intensive farming (vineyards and orchards). Gentle stable slopes are generally predominant.

Among the *forms of microrelief,* flat derasional valleys are to be mentioned. Several forms of various width are associated with erosional valleys: tali and alluvial fans as well as terrace-like 'valley shoulders'. Typical microforms are the cryoplanation steps, the small, conical or frustrum-cone-shaped forms resulting from selective erosion; they are outcrops of porphyroid sills. Man-made forms are some terraces, deep-cut tracks in loess, stone quarries, sand and clay pits.

Of *subsurface waters* the *free groundwater* is 1-3 m below the surface on alluvial terrains and low raised beaches; on highly elevated beaches it is at depths of 5 to 8 m. At the higher levels the position of the groundwater table adjusts to aquicludes. Both high and deep water tables occur. Both aquifer (karst) water and free groundwater flow towards the lake basin and rises to the surface as partly permanent, partly intermittent springs along fissures and bedding-planes. Post-volcanic overflowing carbonic acid springs are common.

The karst springs of the adjacent Balaton uplands take a leading role in the water-supply of the Riviera as well as that of the lake shore zone (BARANYAI, S. 1980). Continuous water-supply will be secured when the regional water-works and the conduit network, now under construction, are built.

It is characteristic of the *climate* in the Riviera (BÉLL, B.-TAKÁCS, L. 1974) that from SW to NE there is an 100 hour increase in the number of hours of sunshine and, at the same time, it is the western part which receives an extra 100 m precipitation. The number of days with precipitation is remarkably higher in the west, but this part is also windier and cooler. In the vicinity of Lake Balaton it is the Riviera which enjoys the best shelter from the wind and the warmer character due to slope exposure has its ecological impact. As a function of relief dissection, vegetation cover and soils, various micro- and topoclimates have emerged.

Natural vegetation is hornbeam-oak forest in the W and *Quercus cerris* in the E, with a transition towards steppe vegetation in the easternmost corner. In accordance with lithological endowments the partly secondary karst-scrub forests with *Cotinus coggygria* occur. Cultivation reduced by now areas covered with natural vegetation - replaced by orchards and arable fields. The present forests are for the most part secondary, degraded stands.

Soils, which are always the complex reflections of the momentary ecological conditions, show a W to E *zonation.* Where lithological factor is ineffective, there is a complete series from lessivé brown forest soils via brownearth variations to chernozems. The series of zonal soil types, however, has largely been modified by cultivation: chernozem dynamics is observed in every soil type. In addition, the anthropogenic influence is manifest elsewhere in truncated profiles and on surfaces eroded to the parent material. It is of interest to note that on rendzina-covered limestone and dolomite terrains, zonal soil types immediately appear as soon as some ten centimetres of loessy-sandy mantles occur. The calcareous chernozems have a low humus content, slightly crumby structure, a well-developed lime-film horizon and some $CaCO_3$ accumulation in a lower concretion horizon. These soils are suitable for the cultivation of a wide range of crops. Their water circulation is adequate, though only a small portion of the precipitation is retained by the soils because of the negative effect of the shallow loessy parent material and the underlying dolomite, particularly observed on hillslopes. Locally dolomitic debris hinders cultivation.

Chernozem brown forest soils of mosaical occurence are of lesser spatial extension than chernozems. Their use is similar to the parallel types on the flats of the south shore. They are associated with unconsolidated deposits of various depth, but cultivation is also made harder by proluvial interbedded debris.

The group of *brownearths* here comprises Ramann's brown forest soil on loess as parent material and rust-brown forest soil on sandy base sediments of soil formation as well as their variations of less or more prominent steppe soil character. Ramann's brown forest soil is common on larger terrains of the Keszthely bight, and on the alluvial fan of the Vár-völgy (Castle valley). It is generally found on parent materials of loess and dolomitic debris. The *A* horizon has been converted into chernozem in many places, but the *B* horizon is represented by well-developed red brown sandy loams rich in dolomitic debris; it is only below the *BC* horizon that $CaCO_3$ concentration is observed. The amelioration of these soils by fertilizers of calcareous matrix and organic manure is desirable in order to improve their humus content and structure and influence their water and nutrient balance in a favourable direction.

For most of the *rust-brown forest soils* on sandy parent material the transformation process into chernozem has started owing to human intervention. Their *A* horizon is, at present, of crumb-blocky structure; slight traces of some lime-film are also observed in the upper part of *B* horizon; humus content is intermediate. The even now distinct structure constituted of polyhedra and large blocks is a clear indication of forest soil dynamics. This soil. due to both its nutrient and water cycling, provides favourable conditions to the cultivation of a wide range of crops, but large-farm utilization my also be hindered here by its occurence in mosaic-like small spots.

The *lessivé brown forest soils* extend over relatively large areas, primarily in the W-Riviera and on the sloping margins of the Keszthely Mountains, where bedrocks of limestone and dolomite are mantled by Quaternary debris and loessy-sandy deposits. In most profiles human impact is observed in the degree of erosion and the 'cultural' structure mainly of the uppermost, ploughed horizon. Deeper in the true *B* horizons the very cohesive loamy clay with clay films and prismatic structure are most typical. Therefore, it is difficult to cultivate; loosening at depth is necessary. It is an unfavourable feature of these soils that, owing to improper humus composition, nutrients are washed into the *B* horizon, where they are fixed (phosphorous in the first place) and only a part of them remains available for the plant. The use of fertilizers combined with micronutrients is needed. It is more to the purpose to use this soil as orchards or vineyards rather than as arable land.

Rendzinas of various depth have a common feature of being heavily calcareous and humic. Those of thin fertile layer are not suitable for agricultural use; their pedologically inert layer is unable to store water, their small colloidal fraction contains $CaCO_3$ and their capacity for nutrient uptake is practically zero. These soils can be best used for afforestation.

The *agricultural utilization* of the Riviera is organized in the framework of state farms, cooperatives, and - in a relatively great extent - private farms, part-time gardening. The latter two particularly, but also the whole of the agriculture in the Riviera in general, are engaged in vine and fruit growing.

The agricultural large-farms in the area of historical wineproducing regions maintain a high standard of production and supply foreign and home markets with products of high quality. The well-organized and rentable production systems are not yet typical for most of the private vineyards and for some of the collective farms. Well-considered measures and proper systems of interest should be introduced to reconstruct vineyard over expanded areas. It would be useful to broaden the framework of collective farms at the lower levels of cooperation, i.e. involving more independence in decision-making.

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A MORPHOGRAPHIC DESCRIPTION OF THE TRANSDANUBIAN MOUNTAINS

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ABSTRACT

The methodological study includes the morphographic analysis and synthesis of the Transdanubian Mountains, a karstic block mountains of faulted and imbricate structures. It has a basic morphographic (orographic) characteristic of slight vertical and horizontal dissection and low orographic position. The low Mesozoic mountain range gradually rises above the surface of the neighbouring hills and plains; steep slopes, abrupt forms and marked marginal faults are only local phenomena. For the evaluation the author used maps of relative relief and valley density (Figs. 2 and 3) drawn on 1:25,000 scale topographic map base. With a goal-oriented classification of relative relief and valley density values, the morphographic data for the Transdanubian Mountains analyzed at micro-, meso- and macroregional ünits are summarized in Table 1. For horizontal and vertical dissection it is a moderately to heavily dissected hilly macro-region, while only values for valley density indicate a 'true' mountains of medium height.

* * *

OROGRAPHY OF THE MACROREGION

The *major morphographic parameters of the Transdanubian Mountains* - horizontal dissection expressed by valley density and differences in elevation expressed by relative relief - point to *a moderately to heavily dissected hilly microregion.* Average relative relief in the mountains is very low: 68.2 m per km^2; it is approximately the same as in the Transdanubian Hills (73.8 m per km^2). It is a consequence of low vertical dissection and low orography that relative relief values higher than 200 m per km^2 are only measured in 1.8 per cent of its area (125 km^2) and the 'truely' mountainous areas with higher than 100 m per km^2 relative relief (1365.5 km^2) do not make up a quarter of the total area (19. per cent - *Table 1*). (The mesoregions and microregions of the mountains are shown in *Fig. 1*).

58.3 per cent (4040.6 km^2) of the Transdanubian Mountains belongs to territories with relative relief typical of hill regions in Hungary, i.e. between 30 and 100 m per km^2, while

22 per cent (1522.9 km²) can be referred to the class of *flat plains* by its relative relief below 30 m per km² *(Fig. 2)*.

The horizontal dissection of the mountains is much heavier, it approaches the value for *'true' mountains of medium height* (as this class is conceived in Hungary). It is manifest in both the development of its valley network (18,937.4 km in length) and average valley density (2.7 km per km² - *Fig 3*). Average valley density here is higher than in the Transdanubian Hills (2.02 km per km²).

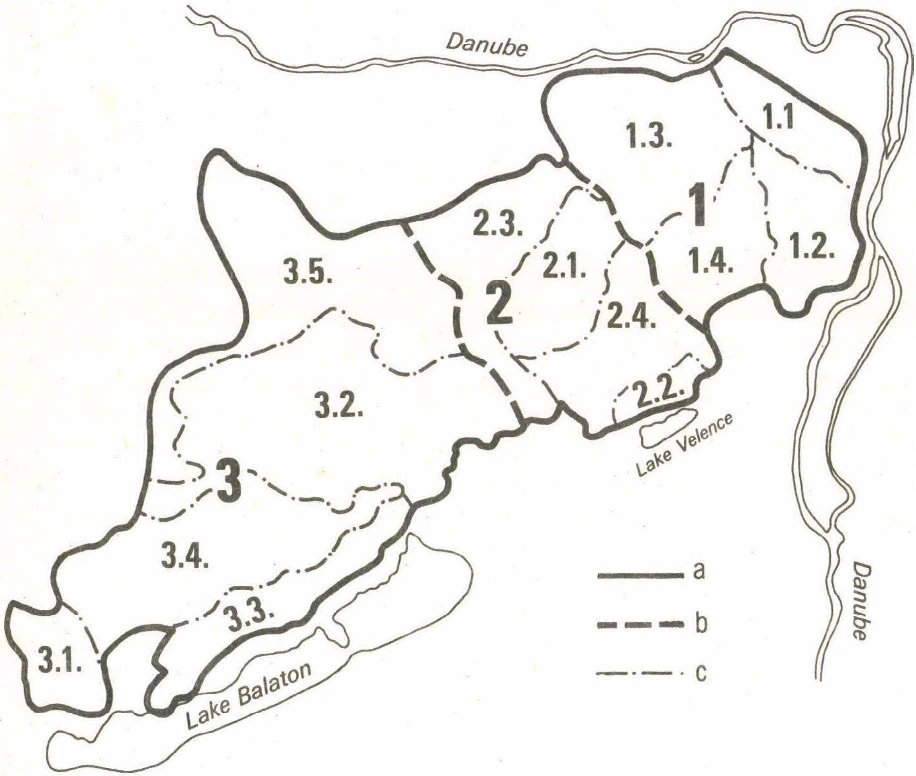

Fig. 1 Landscapes of the Transdanubian Mountains (after PÉCSI, M.-SOMOGYI, S. et al. 1980)
a = boundary of macroregion; b = boundary of mesoregion; c = boundary of microregion
Landscape units: 1. = Dunazug Mountains: 1.1. Pilis Mountains; 1.2. = Buda Mountains; 1.3. = Gerecse Mountains; 1.4. = Bicske-Zsámbék basin; 2. = Vértes-Velence Montain Group: 2.1. Vértes Mountains; 2.2. = Velence Mountains; 2.3. = Vértesalja Hills; 2.4. = Velence Mountains and environs; 3. = Bakony region; 3.1. = Keszthely Mountains; 3.2. = North-Bakony; 3.3. = Balaton Uplands; 3.4. = South-Bakony; 3.5. = Bakonyalja Hills

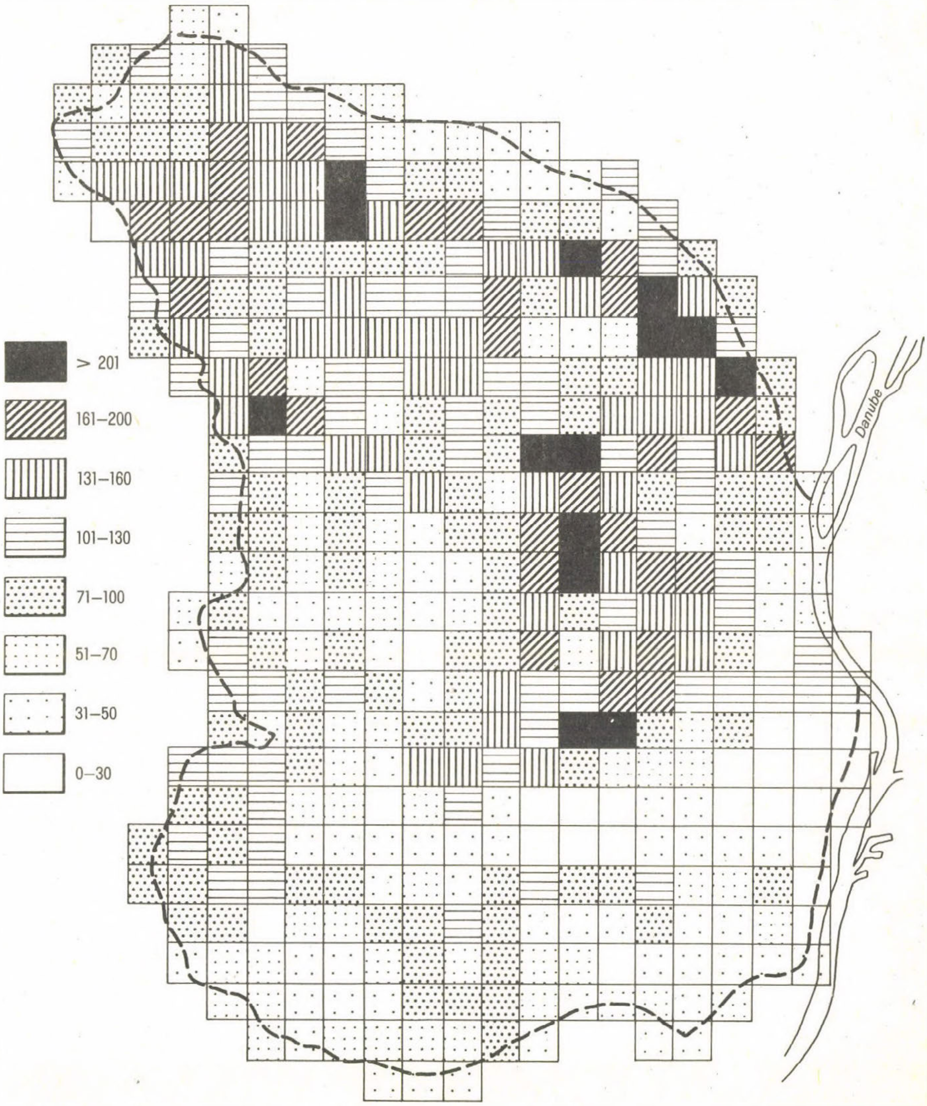

Fig. 2 Map of relative relief categories for the Buda Mountains (by ÁDÁM, L. after the relief map by KERESZTESI, Z.-KERESZTESI, Zs.-MOLNÁR, M.-TIEDERLE, L.)
Relative relief in m per km²

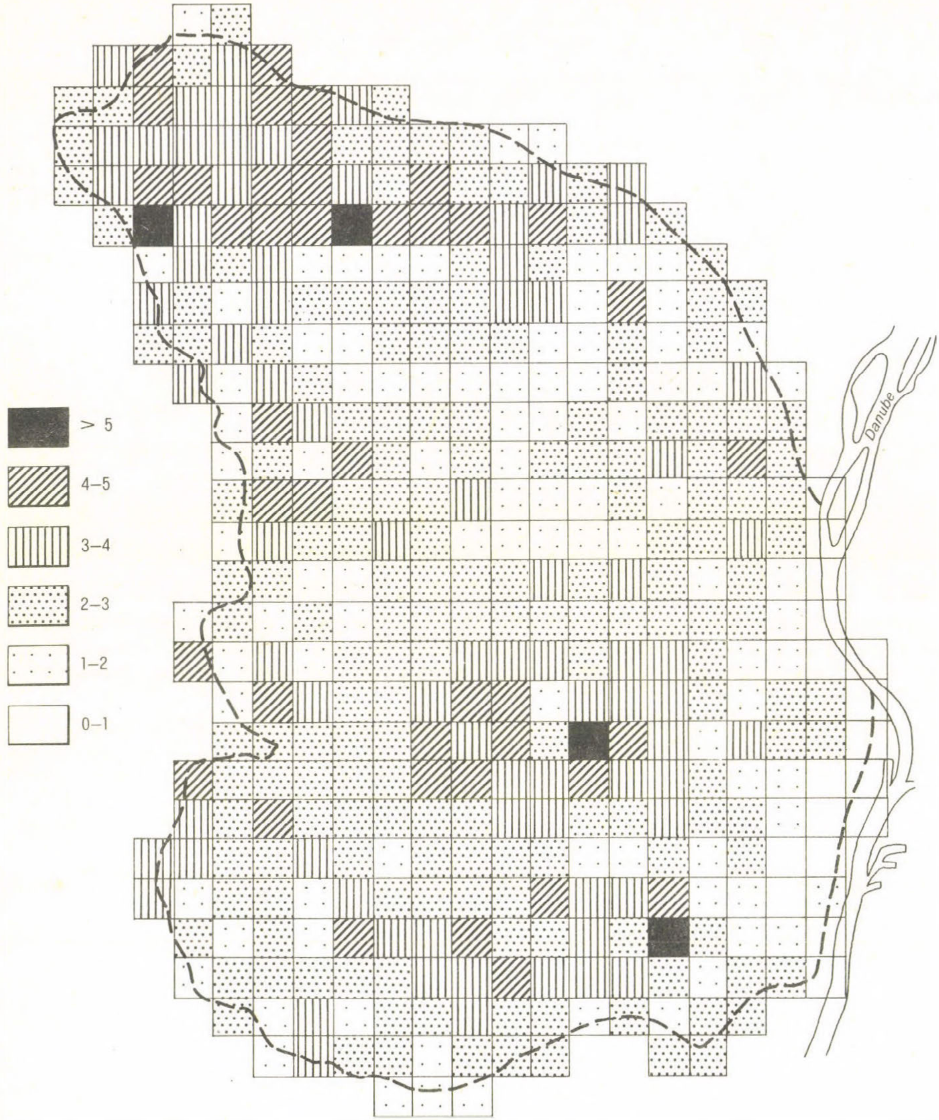

Fig. 3 Map of valley density for the Buda Mountains (by ÁDÁM, L. after the valley density map by NEMERKÉNYI, A.)
Valley density in km per km²

Accordingly, 60,4 per cent (5185 km^2) of its area has *intermediate valley density* (2-4 km per km^2) and with the heavily dissected surfaces of 4 km per km^2 valley density they make up 69.2 per cent (4,795.6 km^2) of total area. The ratio of areas with slight horizontal dissection and low valley density (0-2 km per km^2) is 30.8 per cent (2129.4 km^2 - *Table 1*).

In about 60 per cent of the moderately dissected mountainous area (4300 km^2) morphographic endowments allow crop cultivation and in 10-15 per cent (693-1039 km^2) orchards and stockbreeding are profitable.

Since the hills encircling the mountains are of considerable extension (2759.7 km^2) and their morphographic parameters have lower values, the averages and percentages of the more dissected mountains are somewhat reduced and the resulting overall picture seems *less articulate*, rather indistinct. The orographic picture, however, is not essentially altered by concentrating on "mountains" in strict sense, neglecting the marginal hill areas. *Table 1* demonstrates that, in this latter case, the value for the average relative relief (81.9 m per km^2) and for average valley density (2.87 km per km^2) would increase a little, but surfaces with less than 100 m per km^2 relative relief constituting 71.4 per cent (2976.4 km^2) of mountainous areas as well as areas of *little to medium* (0-2 and 2-3 km per km^2) valley density with a share of 63.1 per cent (2628.7 km^2) would still remain in the category of hill region. By orographic parameters only 30 per cent of the mountainous terrain of the Transdanubian Mountains in a narrow sense can be referred to the class of *"true" low mountains*.

MORPHOGRAPHIC EVALUATION OF MESO- AND MICROREGIONS

The degree of dissection of the mountains varies by meso- and microregions by the specific features of lithology, structure, orography, hydrography and destruction.

The Dunazug (Danube Bend) Mountains. The most heavily dissected mesoregion within the Transdanubian Mountains is the Dunazug Mountains. Both its relative relief (87.6 m per km^2) and average valley density (2.9 km per km^2) are the highest. *31.8 per cent* (526.2 km^2) of its dissected planated surface of horsts with karst phenomena belongs to areas with relative relief higher than *100 m per km^2*, 4.7 per cent (77 km^2) of which has relative relief over *200 m*. Only 37.8 per cent (792.6 km^2) of the mountains belongs to surfaces with low relative relief (below 70 m per km^2), while 20.4 per cent (337.6 km^2) is made up by areas of medium relative relief (70-100 m per km^2). *On 8.8 per cent* (172.2 km^2) *valley density is high* (above 4 km per km^2), and areas with *medium valley density* (2-4 km per km^2; 1134.9 km^2) are also *extended* (68.5 per cent).

Of the microregions of the Dunazug Mountains the Pilis Mountains have the highest values for relative relief. Both the average value (129.3 m per km^2) and the maximum (442 m) are the highest here in the whole Transdanubian Mountains. As much as 43.3 per cent (108.6 km^2) of its surface belongs to those with high relative relief (above 100 m per km^2), while the area (42.6 km^2) of terrain with intermediate relative relief (70-100 m per km^2) makes up 19.4 per cent. The share of surfaces with relative relief values above 200 m per km^2 (41 km^2) is also the highest here (18.6 per cent). At the same time terrains with low (0-70 m per km^2) relative relief make up only a third of the area of the mountains (69 km^2; 31.3 per cent - Table 1).

Closely related to the structure and remarkable relative relief of the Pilis Mountains, its horizontal dissection is rather minute. It is manifest in the high values for both drainage development (635.6 km) and average valley density (2.89 km per km^2). On 70.4 per cent (155.1 km^2) of its surface there is medium (2-4 km per km^2) valley density, while on 8.3 per cent (18.4 km^2) high (above 4 km per km^2) valley density is found.

Dissection is great in the Buda Mountains too. Both average relative relief (96.5 m) and its maximum (290 m) as well as average and maximum valley density (2.96 km per km^2 and 5.9 km per km^2, respectively) are prominent. 40.8 per cent (149 km^2) of its horst surfaces are constituted by areas with high above (100 m per km^2) and 24.2 per cent (88 km^2) by those with medium (70-100 m per km^2) relative relief. Valley density is high (above 4 km per km^2) on 12.3 per cent (44.7 km^2) and medium (2-4 km per km^2) on 62.6 per cent (228.3 km^2).

Most of the orographic parametres of the Gerecse Mountains are similar to those of the Buda Mountains (average and maximum relative relief is 93.3 m per km^2 and 275 m per km^2, respectively); with the slight difference that drainage network is somewhat more developed (2181 km) and, consequently, horizontal dissection has a higher value. It is manifest in both the average and maximum valley density (3.05 km per km^2 and 6.0 km per km^2, respectively).

The morphography of the Bicske-Zsámbék basin is described by relative relief (average 41.1 m per km^2; maximum 128 m per km^2) and valley density (average 2.6 km per km^2; maximum 5.0 km per km^2). 61.3 per cent (217 km^2) is hilly surface with slight or intermediate (30-70 m per km^2) dissection, while plains (0-30 m per km^2 relative relief) cover 28.7 per cent (102 km^2) of the area.

The Vértes and Velence Mountain Group. It is the least heavily dissected mesoregion in the Transdanubian Mountains. Its most typical morphographic feature is the slight vertical dissection of relief. Average relative relief is only *50.4 m per km^2,* which is the characteristic value for a very slightly dissected hilly region. It can be explained by the extended slightly dissected piedmonts and hills around the mountains (Vértesalja Hills 400.6 km^2) with low relief (on the average 35.6 km^2 and 35.4 km^2, respectively) which considerably reduces the average values and percentages for the mountainous portions of the mesoregion. Consequently, surfaces with less than *100 m per km^2* relative relief have the lowest percentage here in all the mountain range; their share is only *9.4 per cent* (121.2 km^2). Areas with relative relief over *200 m per km^2* are even less significant altogether *0.1 per cent* (2.0 km^2). *Slightly* dissected surfaces (below 70 m per km^2) extend over 1035.5 km^2 area *(80 per cent).*

The well-developed drainage network (3672.3 km) and average valley density (2.8 km per km^2) make its horizontal dissection much heavier. Of *10.9 per cent* (140.9 km²) of its area *great valley density* (above 4 km per km²) is typical, while of *60.9 per cent* (787.8 km²) *intermediate* (2-4 km per km²) is characteristic and only 28.2 per cent (364.9 km²) has low valley density (below 2 km per km²).

Of the microregions only the Vértes Mountains of horst structure shows major dissection. Its average relative relief (89.6 m per km²) is only a little below the neighbouring Gerecse; its average and maximum valley density (4.02 km per km² and 7.4 km per km², respectively) is highest in the whole Transdanubian Mountains.

34.7 per cent (109 km²) of the area belongs to surfaces with relative relief above 100 m per km², but medium dissected (70-100 m per km²) terrains (84 km²) are of considerable extension (26.8 per cent). In connection with its well-developed drainage network (1260 km), great (above 4 km per km²) valley density is typical of 35.4 per cent (111.1 km²) and medium one (2-4 km per km²) of 59.4 per cent (186.3 km²).

By low relative relief (the average value is 64 m per km²), the Velence Mountains falls into the class of medium dissected hills. Of the total area 60.9 per cent (50.7 km²) is slightly (0-70 m per km²) dissected, while 31.7 per cent (26.3 km²) is medium dissected surface and only 7.4 per cent (6.2 km²) is with relative relief above 100 m per km², which is typical of low mountains.

The Vértesalja Hills and the environs of the Velence Mountains are mostly terrains of low relative relief (average 35.6 m per km² and 35.4 m per km², respectively), plains (0-30 m per km²) and slightly dissected hills (30-50 m per km²). Horizontal dissection, as reflected by average valley density (2.8 km per km² and 2.1 km per km²), is more remarkable. The slightly dissected surfaces provide favourable slopes for agriculture. More than 90 per cent of their area belongs to surfaces of 0-5 per cent and 5-12 per cent slope classes. Their total area is 69.4 per cent of the mesoregion (897.2 km²).

The Bakony region. This assemblage of microregions of various morphographic character is slightly dissected both vertically and horizontally. Its average relative relief *(65.9 m per km²)* and average valley density (2.6 km per km²) are around the average values for the whole of the Transdanubian Mountains *(Table 1).* Its orographic parameters are also those of an overwhelmingly low mountains; the elevation above sea level does not reach 300 m, the highest point is only 704 m.

The best indication of the slight vertical dissection of the mountains is the fact that relative relief over *200 m per km²)* is measured in only 1.2 per cent (46 km²) of its large area (3974.6 km²); higher than *100 m per km²* relative relief is only characteristic in 17.9 per cent (714.1 km²) of its total area. *18.2 per cent* (725 km²) of the mesoregion belongs to areas with *intermediate* (70-100 m per km²) relative relief and *63.9 per cent* (2535.5 km²) to those with *low* (below 70 m per km²) relative relief. 23.2 per cent (919.6 km²) is a plain with relative relief below 30 m per km². Its horizontal dissection is less prominent than in the case of the other two mesoregions. 34.9 per cent of the surface is characterized by *low* (below 2 km per km²) and 56.9 per cent by an *intermediate* (2-4 km per km²) valley density; the percentage of heavily dissected terrains is only 8.2 (324.5 km²).

Of the microregions of the Bakony area, relief is highest in the Keszthely Mountains. First of all, it is manifest in the average value for horizontal dissection (93.6 m per km^2), with those for the Buda and the Pilis Mountains the highest in the Transdanubian Mountains. Accordingly, the percentage of mountainous surfaces with relative relief above 100 m per km^2 is highest here (after the Pilis Mountains) covering 43.3 per cent (126 km) of the small planated mountains. Besides them, however, the extension of medium dissected (70-100 m per km^2) areas (52 km^2) is also remarkable (17.9 per cent). By average valley density (2.67 km per km^2) horizontal dissection is intermediate in the Bakony region; for 67.4 per cent (196.1 km^2) of the area medium (2-4 km per km^2) valley density is characteristic.

By its morphographic parameters the Keszthely Mountains is followed by the North-Bakony excelling, first of all, with horizontal dissection. After the Vértes Mountains it has the second highest values for average (3.2 km per km^2) and maximum (6.2 km per km^2) valley density in the Transdanubian Mountains. The development of drainage network (4058.9 km) is indicated by the fact that 15.3 per cent (199.3 km^2) of the surface dismembered into planated blocks has valley density above 4 km per km^2 and 65.5 per cent (853.5 km^2) that of 2-4 km per km^2. Average relative relief (77.6 m per km^2) shows slight vertical dissection (0-70 m per km^2) for most of the mountains (53.1 per cent); values above 100 m per km^2 are measured only in 23.7 per cent (309 km^2) of the area.

Orographically the Balaton Uplands is even more homogeneous than the North-Bakony. Drainage development is moderate (1066.7 km), horizontal dissection is slight and average valley density (1.8 km per km^2) is low. 63.4 per cent (375.7 km^2) of the surface, which is also slightly dissected vertically (average relative relief is 74.3 m per km^2) has little valley density (0-2 km per km^2) and on 78.4 per cent (464.7 km^2) relative relief is 0-100 m per km^2.

The least dissected mountainous area in the Bakony region (and also in the Transdanubian Mountains) is the South-Bakony. Both average relative relief (56.1 m per km^2) and average valley density (1.97 km per km^2) are the least. Orographically it reminds of the least dissected microregion of the Transdanubian Hills, the South-Baranya Hills (average relative relief 56.7 m per km^2 and average valley density 1.9 km per km^2). 70.5 per cent (615.5 km^2) of its surface of planated blocks has low relative relief (0-70 m per km^2), while of 56.9 per cent (496.7 km^2) little valley density (0-2 km per km^2) is typical; relative relief is above 100 m per km^2 in 122.1 km^2 (14 per cent) and valley density is above 4 km per km^2 (only 2.5 per cent).

The Bakonyalja is the microregion with the highest dissection in the Transdanubian Mountains. Related to its developed drainage network (2826.5 km), primarily horizontal dissection is outstanding reflected in the average (3.09 km per km^2) and maximum (5.9 km per km^2) valley density. 70.6 per cent (646 km^2) of its rolling surface with limited relief (average relative relief 44.3 m per km^2 and the maximum one 135 m per km^2) has intermediate (2-4 km per km^2) valley density, while on 85.5 per cent (782.6 km^2) dissection is slight (0-70 m per km^2).

The morphographic evaluation of the Transdanubian Mountains with the help of maps of relative relief and valley density provides particular information of the vertical and horizontal dissection of the mountain range. Supplemented with maps of slope categories and hypsometry, it is useful for the geomorphological, climatic, soils and vegetational regionalization of the unit, for a geomorphological synthesis as well as for the delimination of agricultural and sylvicultural ecological sites of similar endowments.

Pécsi M. (ed.)
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RECENT RESERCH ACHIEVEMENTS AND A TYPOLOGY OF VOLCANIC MOUNTAINS IN HUNGARY

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ABSTRACT

This paper summarizes the achievements of detailed field work carried out over the last thirty years, compares the results with earlier held views and presents the methods elaborated for this research. These latter are 1. the study and comparison of landform in relation to geological structure, lithology and bedding and 2. detailed analyses of drainage patterns. The analysis of drainage patterns provides valuable information for the reconstruction of volcanic forms, since the main lines of the original (incipient) drainage network are preserved. Drainage patterns characteristic of the various types of volcanoes are presented while the direct and indirect impact of primary volcanic forms and their governing function in denudation are demonstrated. The original forms and the sequence of erosion in the Tertiary volcanic areas are outlined with regard to the extent of post-volcanic tectonic movements and their major impact on relief evolution. It is on this basis that the volcanic mountains of Hungary are classified.

* * *

Although mountains of low to medium height only comparise about 20 per cent of the area of Hungary, some two-thirds of them are of Tertiary volcanic origin. Consequently, volcanological and volcano-morphological research have been prominent topics of geological and geomorphological investigations in Hungary. *Geologists* have collected considerable information over the last one hundred years and produced many maps on the structure of volcanic mountains in Hungary, while J. CHOLNOKY was the first to present a comprehensive *geomorphological* evaluation of all the volcanic mountains in the Carpathian region. His comprehensive volcano-geomorphological approach was based on the presumption that primary volcanic forms dominated all the mountains of volcanic origin: he believed that he had recognized volcanic cones, calderas and even craters, and compared them, generally very appropriately, to active volcanoes. B. BULLA

(1962) denied the existence of such primary volcanic forms; in his opinion the present volcanic mountains have been denuded to 'peneplained mountains of rolling surface', and in this interpretation is supported by S. LÁNG (1967) on the basis of more than twenty years of field experience that covers most mountains in Hungary.

In the 1950s detailed field work led A. SZÉKELY to conclude that although *primary volcanic forms* had been transformed into denudational forms as early as the Tertiary, but *did not disappear altogether.* The heavily truncated remnants of main eruption centres may still be recognized as peaks, cones or high summits and the ruins of former caldera margins rise as arcuate crests above other mountain ridges. Most of the mountains are, however, erosional forms (Härtling) or structural features (horst) or combinations of two (erosional horsts). Moreover remnants of former lava flows may still be observed in several places, while subvolcanic forms have been exposed as the very result of intensive denudation. Consequently, landforms must be analyzed in combination with geological structure, lithology and bedding, as cones of similar shape may prove to be a truncated eruption centre, an erosion cone or an exhumed laccolith (SZÈKELY, A. 1964, 1983).

The *direct impact* of primary volcanic landforms on present features is much more significant than the existence of volcanic remnants, since they may play a governing role in denudation. Thus former major eruption centres, although in a heavily eroded form, may rise conspicuously above surfaces of denudation.

As a matter of course, the first drainage lines followed primary volcanic slopes (consequent streams), but, subsequently, on the lower-lying surfaces between the main eruption centres (in the intercolline basins and cols) drainage patterns corresponding to the shape and slope conditions of these surfaces evolved. It has to be emphasized that in our research the *detailed and comprehensive evidence yielded by the drainage patterns is of the utmost importance.* While areas of high relief underwent denudation and lost their original shape as the valleys cut deeper and broadened out, new systems of tributary valleys also developed. The original drainage network, however, has survived in its major lines, although the evidence for this is indirect.

The drainage pattern in itself is a source of valuable information for the reconstruction of the original volcanic forms, since it preserves the main lines of the initial drainage network (SZÉKELY, A. 1983). Major eruption centres are generally picked out by a radial pattern; the inner slopes of calderas have dendritic or centripetal patterns, while their outer slopes exhibit radial patterns *(Fig. 1).* Lava and pyroclastic terrain of ridges and foothills is dissected by parallel valleys, the foot-slopes of cones, parasitic cones and near-surface subvolcanic features such as laccoliths are typified by annular drainage, while arcuate valleys are observed on the sides of cones or domes. Reflecting the diversity of original volcanic forms, such patterns may also appear in combination as in the case of a slope with small parasitic cones, where parallel and arcuate drainage patterns may be combined. Thus, original

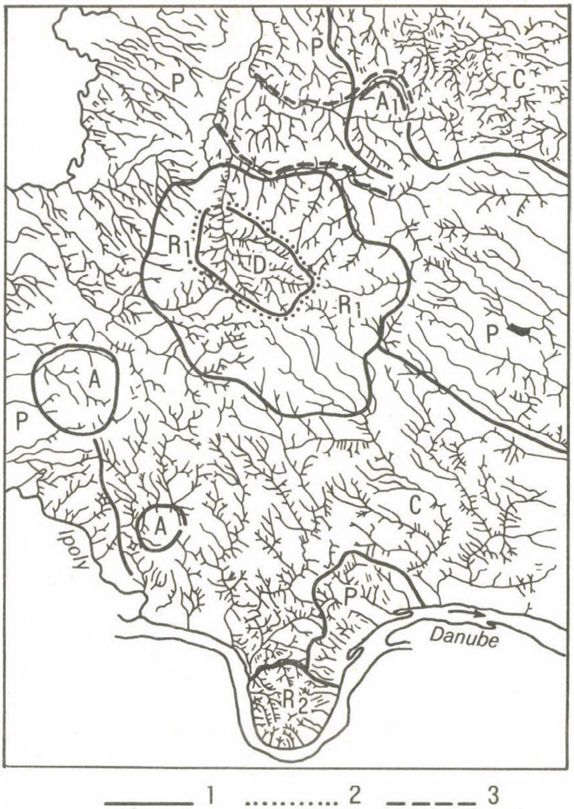

Fig. 1 Drainage patterns in the Börzsöny Mountains from aerial photographs (by CZAKÓ, T., interpreted by SZÉKELY, A.)
1 = boundaries of drainage pattern types with genetic interpretation; 2 = remnants of the inner caldera margin; 3 = remnants of the hypothetic outer relict caldera; D = dendritic drainage within the relict caldera; R = radial drainage; R1 = on outer slopes of the caldera; R2 = on slopes of the relict volcanic cone; P = parallel consequent drainage; A = annular drainage; A1 = twisted annular drainage on the margin of former parasitic cone (eruption centre); C = parallel and twisted sickle-shaped drainage combined

volcanic forms are reflected in the relief, especially in drainage patterns, or millions of years after their original forms have been destroyed.

Vulcanism, however, is always accompanied by *structural movements* whether of a synvolcanic or postvolcanic nature, which alter the original forms as well as modifying the whole relief. Indeed, postvolcanic tectonic movements have *played* a decisive and *governing role*, in the evolution of volcanic mountains in Hungary due to the intensive crustal movements, involving *vertical displacement in excess of 2000 m* that have occurred since the decline of volcanic activity in the Upper Miocene.

Firstly, the volcanoes of the Intra-Carpathian basin had subsided even before the cessation of volcanism; according to SZÁDECZKY-KARDOSS, E. et. al. (1959) this occurred abruptly, due to the collapse of the emptied magma chamber and in the opinion of KUBOVICS, I.-PANTÓ, Gy. (1970) gradually, with the compaction of the underlying sediments. (The first hypothesis is contradicted by the borehole evidence of BAKSA, Cs. et. al. 1977 and also by geophysical measurements.)

Moreover the lower parts of the volcanoes were protected from erosion by the inundation of the Upper Badenian sea, and surfaces of lesser elevation are still protected by a Badenian sediment cover. In several places these sediments still reach a thickness of 300 m to 450 m.

Under these circumstances, the *intensive denudation* of the volcanoes only started subsequent to the gradual uplift of the mountains and parallel marine regressions during the Upper Sarmatian and the Pannonian periods. In other words, the volcanic mountains of Hungary are much younger than the Mesozoic block mountains, and have been eroded for much shorter period of time and by much less intensive processes. As a result, conditions did not favour the formation of such extensive planation surfaces in the volcanic mountains as occur in the block mountains, and only marginal and piedmont surfaces of varying width could evolve. The *systems of sediments* is best developed in the volcanic mountains (PINCZÉS, Z. 1978, SZÉKELY, A. 1969, 1978, PÉCSI, M. 1965, 1970), since the original surface and lithology (thin-bedded composite volcanoes) were most favourable for rapid sculpturing. During the millions of years of denudation even the highest volcanic centres have been heavily eroded and, mostly since the Upper Pliocene, dissected without planation. As a result, the volcanic forms have not been entirely obliterated.

There were *three major stages of volcanic activity* in what is now Hungary during the Tertiary. 1. The first period was one of small-scale *initial volcanism* during the Upper Eocene (45 m.y. B.P. - all the following dates are based on K/Ar dating). Regarded by recent geological and lithological evaluation as a volcanic arc on a plate margin, the resulting andesite mountains have been heavily eroded and vulcanism survives only as subsidiary traces.

2. The *main period of volcanic activity* is placed in the Middle Miocene (19 m.y.-12 m.y. B.P. - about 95 per cent of eruptions determining the present forms are between 16 m.y.-14 m.y. old), when the Intra-Carpathian volcanic range was produced. In Hungary the Northern Mountain Range dates from his period, has a length of more than 200 km, and stretches from the Visegrád Mountains to the Tokaj (Zemplén) Mountains. In the Bükkalja and particularly in the Tokaj Mountains intense volcanic activity continued into the Upper Miocene and, as a consequence, more original volcanic forms has been preserved in this areas. Most of the material produced during this main stage (about 80 per cent in the Middle Miocene) was andesite and associated pyroclastics, with some acidic rhyolites rhyolitic tuffs, and dacite.

3. The *final stage of basaltic volcanism* is younger, and it is dated to the late Pliocene (4 m.y. to 2 m.y.) and the

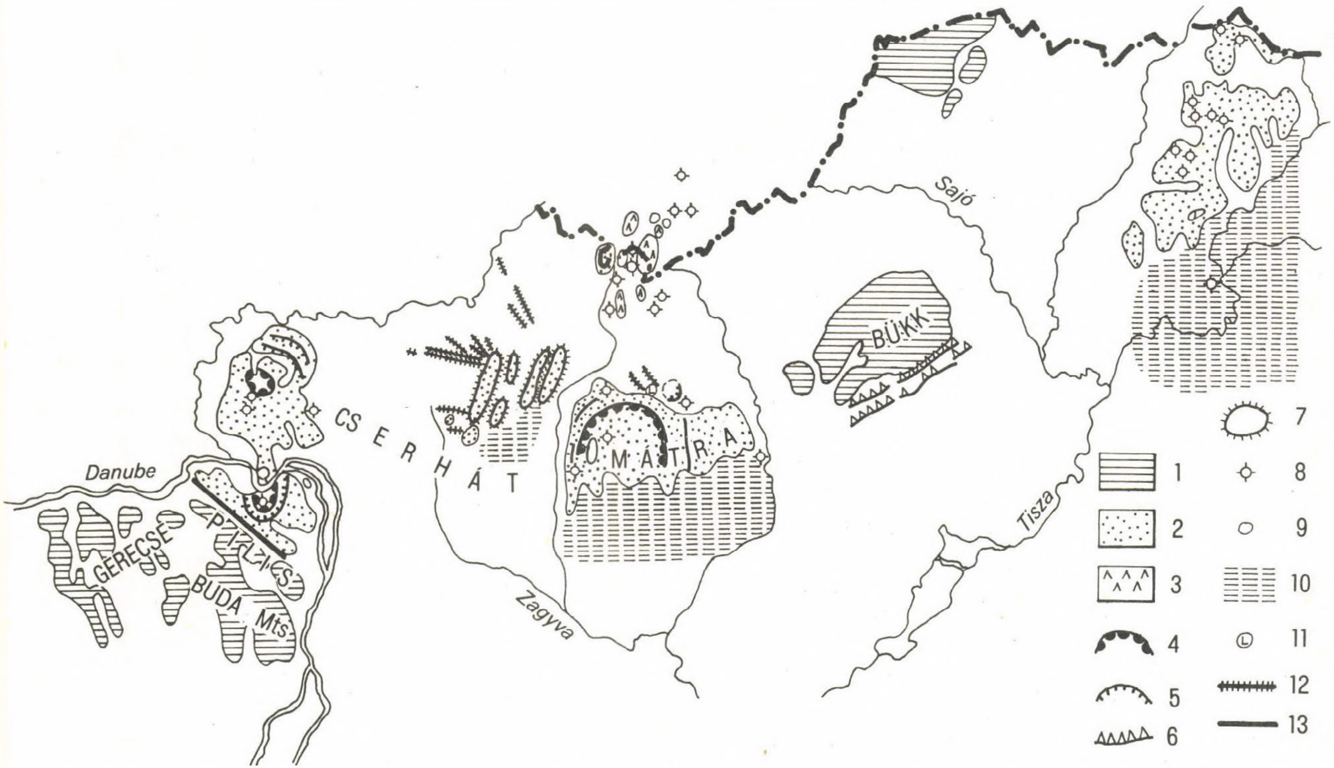

Fig. 2 Structural morphological types in the Hungarian Mountains with special regard to volcanic mountains (by SZÉKELY, A.)
1 = Mesozoic mountains of horst series; 2 = Miocene volcanics (mostly andesite agglomerate and tuff and secondarily rhyolite and rhyolitic tuff) on the surface; 3 = Late Pliocene basalt; 4 = remnants of the inner caldera margin; 5 = hypothetic relict outer caldera margin; 6 = remnants of rhyolite and dacite tuff; 7 = horst series of volcanic material; 8 = volcanic cone remnants; 9 = vent remnants; 10 = buried volcanic forms; 11 = laccolith; 12 = dyke; 13 = main structural lineament between Mesozoic rocks and Miocene volcanics

early Pleistocene (2 m.y. to 1 m.y.). It was again of lesser intensity and produced basaltic mantles and cones only in Transdanubia, to the W of the Bakony Mountains and S of the Little Plain (4 m.y. to 1 m.y.) and in the environs of Salgótarján (2 m.y. to 1 m.y.). But compared to the andesite mountains these are only subsidiary elements.

In the Intra-Carpathian volcanic range *relief types* are controlled by original volcanic forms, post-volcanic tectonic movements and the denudation processes governed by them.

The original forms could only survive the millions of years of erosion in heavily reshaped and truncated forms. Nevertheless, in the central zone, the indirect influences of primary volcanic forms are demonstrated in the following types *(Fig. 2):*

I. *Remnants of volcanic mountains* are in various stages of resculpturing, depending on their age, altitude, position, lithology and original forms.

1. *Relict volcanoes (paleovolcano) with double calderas* are exemplified by the Dunazug relict volcano (the Visegrád Mountains). The older volcanic cone is about 15 km in diameter, with a collapsed centre probably due to a heavy explosion. In the resulting caldera another explosive cone, the Keserü-hegy paleovolcano, about 6 km in diameter was built up (BALLA, Z. 1978) on which another caldera was formed by a smaller explosion *(Fig. 3)*. Arcuate ridges, with steep inward and gentler

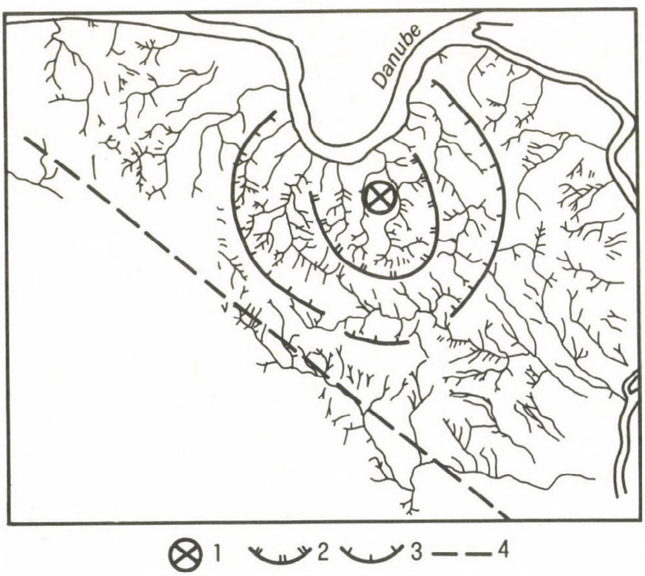

Fig. 3 Network of watersheds in the Dunazug Mountains drawn from aerial photographs (by GÁBRIS, Gy.)
1 = hypothetic relict eruption centre in the inner caldera; 2 = margin of inner caldera; 3 = margin of outer caldera (arcuate drainage on the inner side, radial on the outer side and arcuate on the W); 4 = main structural lineament; boundaries of Mesozoic sediments and Middle Miocene volcanics

outward slopes, attest to the margins of both calderas. The inner sides of the relict calderas are indicated by conspicuously arcuate annular drainage patterns of asymmetric valleys, while the outer slopes are marked, by centripetal drainage and the western foot by an arcuate valley *(Fig. 3)*.

These relict composite volcanoes are mostly built up of andesite agglomerate with embedded volcanic bombs which increase in diameter from the margins (some tens of cm) to the centre (8-10 m) and also with depth in the andesite series (from 200 m to 1000 m). Here in the inner caldera heavy hydrothermal weathering is observed.

The N margin of the caldera was separated by the Danube bend at Dömös and, thus, topographically now belongs to the Börzsöny Mountains. The Danube gorge at Visegrád is both antecedent (PÉCSI, M. 1959) and epigenetic. The Danube initially followed a sinuous course on a surface of Upper Badenian Leitha limestone, but following the post-Pannonian uplift of the mountains, cut down through this surface (PÉCSI, M. 1959) onto the buried stratovolcano beneath, where Leitha limestone has been preserved up to 400 m a.s.l.

2. The Börzsöny Mountains represent a denuded *volcano with central caldera*. The Central Börzsöny is dominated by the remnants of a single *stratovolcano* of 12-14 km diameter and originally about 1200 m height (the High-Börzsöny paleovolcano - BALLA, Z. 1978). The erosional caldera of 4-5 km diameter at its centre has evolved from the erosional widening of the one-time central crater, while the volcanic cone has been heavily eroded and tilted to the WNW. A *remarkable asymmetry (Fig. 4) characterises* the whole mountain range today, with steep,

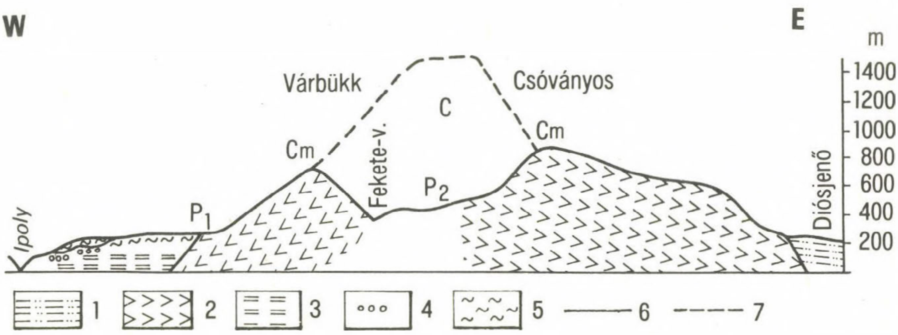

Fig. 4 W to E profile across the Börzsöny Mountains
1 = Carpathian schlier; 2 = Lower Badenian andesite (stratovolcano series); 3 = Pannonian sand and clay; 4 = Pleistocene terrace gravel; 5 = loess-like slope deposit; 6 = fault; 7 = reconstruction of the paleovolcano (based on data by BALLA, Z.); C = caldera; Cm = caldera margin; P = pediment; P_1 = on the outer margin of the caldera; P_2 = within the caldera

eastern and gentler western slopes. Unambiguous geological evidence of this asymmetry is to be seen in the position of the volcanic cover layers (Upper Badenian) at 300 m altitude on the W side, while at the same altitude base layers (Carpathian) occur on the E side.

The asymmetry is also obvious in the *pediments,* which are better developed, and longer and gentler in the upper segments to the W than to the E. Pediments also occur within the caldera, although here they are dissected by deep valleys owing to their higher altitude.

The caldera form is much better preserved than in the Dunazug paleovolcano, with more discernable margins that almost form a full circle. Within the caldera regular *dendritic* drainage is seen, while the outer slopes are typified by a radial drainage pattern with parallel valleys on the W side (CZAKÓ, T.-NAGY, B. 1974). At the base of the composite volcano towards the N and NE runs the sickle-shaped Kemence-patak valley. Beyond it, however, the two ranges of the N-Börzsöny are relict sommas of two subsequent older paleovolcanoes (BALLA, Z. 1977).

In summary, the Börzsöny Mountains were built up during three major consecutive volcanic phases in a relatively short period of the Lower Badenian, since they were subsequently overlain by Lower Badenian marine sediments. Each phase saw the production of a new caldera within the previously existing one which are therefore of ever decreasing dimensions in extension and height. Younger volcanic activity destroyed most of the older forms; and the relief is presently dominated by the heavily eroded ruins of the youngest volcano.

3. *Relict composite volcano with a semicircular caldera* - as in the W and Central-Mátra Mountains. In contrast to the Börzsöny, volcanism in the Mátra lasted with some interruptions for millions of years, (Carpathian volcanism is 16 m.y. old and the late Lower Badenian is 12 m.y. old). There were three distinct volcanic stages of andesite-rhyolite production and an additional fourth and final stage of more alkaline basaltic andesite volcanism (BAKSA, Cs. et. al. 1977). In the Lower Badenian a composite volcano of about 30 km diameter and 300 m in height was built up over a relict, mostly submarine Carpathian volcano. Today in the W-Mátra it is this Lower Badenian volcanic ruin that is predominant.

In this vast volcanic cone, in all probability also through explosion and subsequent collapses, a large caldera-like de*pression* of about 16 km diameter formed and this was followed by minor acidic volcanism with the production of rhyolites and ryholitic tuffs and intensive hydrothermal activity. As a result, the rocks of the caldera were largely decomposed and erosional resculpture promoted. There then followed the final stage of basaltic andesite volcanism which overwhelmed with its deep lava covering previous volcanics in many places. The latter, thus, remain prominent in the present relief.

The *S part of the caldera* subsided together with the Great Hungarian Plain and at present is overlain by 400 to 700 m of Pannonian deposits. At the same time, the *N part* undergone gradual *uplift* together with the Carpathians and because erosional activity has there by been intensified, subvolcanic laccoliths and dykes have been exposed along the N margin.

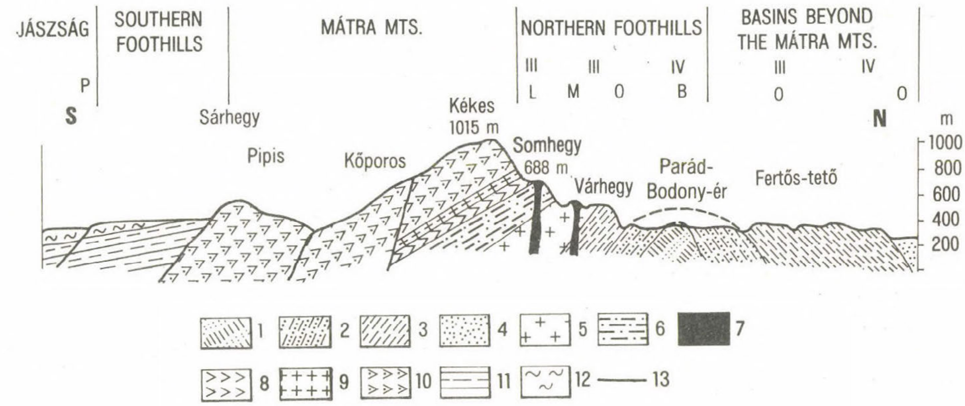

Fig. 5 General profile across the Mátra Mountains (by SZÉKELY, A.)
1 = Middle Miocene 'apoka' (schlier); 2 = Upper Ologicene (Lower Kattien) 'apoka' (schlier); 3 = Upper Oligocene (hard) sandstone; 4 = Upper Oligocene (Upper Kattien) loose 'apoka' (schlier); 5 = Lower Miocene sediments (variegated clay; loose sandstone, Lower Rhyolite Tuff, brown coal seams); 6 = Carpathian schlier; 7 = subvolcanic remains exposed (dykes, laccoliths); or remains of older Miocene lava flows; 8 = Lower Andesite Series (end of Carpathian); 9 = Middle Rhyolite Tuff; 10 = Badenian volcanics (andesite, andesite agglomerate and tuff); 11 = Upper Pannonian sand and clay; 12 = Pleistocene deposits (alluvial fan, talus, slope deposits); 13 = fault-line. P = pediment; L = laccolith; M = Lower Miocene lava flow remains; O = Upper Kattien sandstone escarpment; B = erosion basins on the Mátralába

Asymmetry is strongest in the Mátra because of the uplift to the N and the subsidence to the S (SZÉKELY, A. 1964, 1969, 1978 - *Fig. 5*). To the N strata underlying the volcanics are located several hundred metres higher (Carpathian schlier at 400-500 m) than the strata overlying the volcanics to the S) Upper Badenian, Sarmatian and Pannonian at 200-250 m). The effect on the relief is that the steep slopes clearly expose the structure of the composite volcano, while the S slopes are long and gentle. The situation is similar to that observed in the Börzsöny along an E to W section.

Planated surfaces also show a striking asymmetry, particularly the best developed, young (Upper Pliocene-Pleistocene) *pediments* (SZÉKELY, A. 1964, 1969, 1978), which generally extend over several kilometres, although along the N foot of the steep slopes of the composite volcano gentle glacis d'erosion could form. Here too pediments extend far into the caldera.

The drainage pattern provides major evidence as to the original volcanic structure *(Fig. 6)*. Within the half-caldera the dendritic drainage is asymmetrical and extends more to

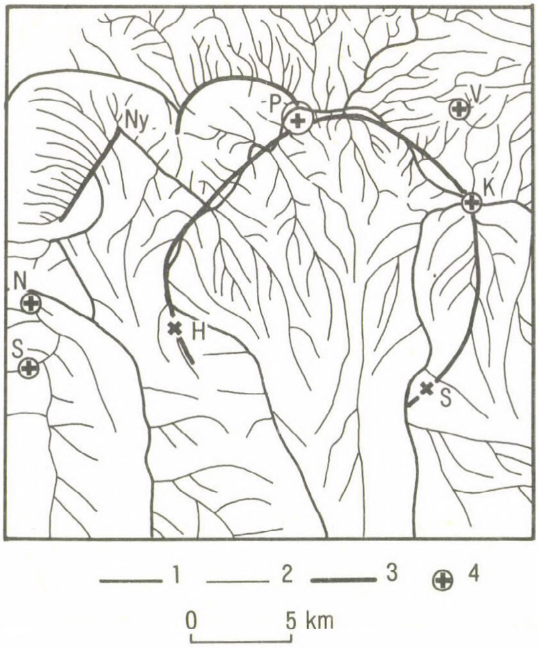

Fig. 6 Watershed network of the Mátra Mountains (by GÁBRIS, Gy. from aerial and space images)
1 = main watershed; 2 = watershed; 3 = volcanic (tectonic) structures; 4 = dome; K = Kékes, V = Vár-hegy; P = Piszkés-tetö; T = Tóthegyes; H = Havas-tetö; Ny = Nyikom-tetö: N = Nagy-Hársas; S = Somlyó

the W than to the E. On the outer caldera margin radial drainage forms a semicircle to the W and N, towards the Zagyva river.

4. In contrast to the above described denuded calderas (where the caldera form is more or less still recognizable), *relict calderas* do not present the characteristic caldera form. They are found at Recsk, Mátralába, in the remains of the Upper Eocene volcanics and have been reconstructed from a dense network of borehole information (FÖLDESSY, J. 1980).

5. *The centrolabial stratovolcano system* of the Tokaj (Zemplén) Mountains. Here the heavily truncated remnants of volcanic cones are aligned along rift systems, and more original forms are generally preserved than in other areas, since volcanic activity lasted longer, into the late Miocene and early Pannonian (14-9.5 m.y. B.P.). The oldest segments to the NE have been most heavily effected by erosion. Recent research indicates submarine vulcanism initially. To the S in the younger (Upper Miocene) volcanics, more original forms; primarily eruption centres, remnants of composite volcano cones and lava flows, are preserved.

Volcanic rocks are also found in great variety. While in other areas acidic lavas are only subsidiary elements, here mainly rhyolite and locally dacites and associated tuffs are major rock types. In addition, postvolcanic activity and ore mineralization were most prolonged here with important geomorphological implications. Relief inversions are also characteristic, where lava flows, resistant to erosion that filled former valleys now stand out as ridges, white limnoquartzites deposited in depressions form flat top rises.

As a result of prolonged volcanic and postvolcanic activity, *the greatest diversity and best preservation of* original and resculptured *volcanic forms* is found in the Tokaj Mountains. In contrast to the above uniform giant stratovolcanoes, in the Tokaj Mountains there was no dominant central volcano, but rather a series of volcanoes of various size (centrolabial type) which gives a distinctive feature to these mountains with their generally radial or centrifugal drainage pattern.

The mountains are tilted slightly to the E; this asymmetry, however is much less striking than in the cases of the Mátra and the Börzsöny. Pediments are best developed on the gentler E side and extend further into the mountains (PINCZÉS, Z. 1978). The individual volcanoes or volcano groups are separated by broad basins with wide, extensive pediments. The W, E and S margins of the mountains are *marked by major fault systems* and the volcanics extend further beneath several hundreds of metres of Pannonian-Quaternary deposits.

6. *Volcanic horst series* of the E-Cserhát Mountains. This area was originally part of the W margin of the vast W-Mátra stratovolcano and was separated from it by the subsidence of the Zagyva graben after the Upper Badenian. Simultaneously the Volcanic-Cserhát itself was dismembered. The Upper Badenian transgression and associated sediments affected the whole Volcanic-Cserhát. Most of the surface was also inundated by the Sarmatian sea.

During the most recent uplift from the Pliocene on *four mountain zones were further elevated* by NNE to SSW faults. Today these surfaces form a *series of asymmetric horsts* partly or totally stripped of their postvolcanic sedimentary mantles to form (buried, semiexhumed, exhumed or residual surfaces). The *three separating grabens* have preserved the postvolcanic sequence in their basins, in which splendid examples of Upper Pliocene-Pleistocene *pediments* occur and determine the character of the relief.

The W margin of the Ancient Mátra was further shaped by *postvolcanic crustal movements* resulting in the present *horst-graben structure* which is broadly similar to that of the Mesozoic horst series in the Transdanubian Mountains (e.g. the Gerecse and Buda Mountains). Only the volcanic rocks, however, are preserved, as the forms have been destroyed by denudation.

Here the drainage pattern does not indicate primary volcanic forms, but is adjusted completely to the postvolcanic structures. The water-courses follow the graben basins and occasionally with mostly rectangular changes of direction, break through the series of horsts *(rectilinear drainage)*.

II. *Remnants of volcanic mantles* are composed of flat, structurally preformed surfaces in various states of denudation and dissection depending primarily on their age, relative height and resistance.

7. *The relict lava mantle* of the E-Mátra. The more extensive, S portion has subsided together with the Great Plain basin and has been buried under several hundred metres of Upper Miocene and Pannonian deposits. The whole volcanic body was tilted to the S and has produced a striking *asymmetry* of relief, drainage and planated surfaces.

A regular *parallel*, consequent and asymmetric *drainage* has emerged with short and steeply sloping valleys towards the N and longer, more gently sloping ones towards the S, adjusted to the relief of the lava mantle. With the subsidence of the Great Plain foreground the mantle was dissected into parallel deep valleys and intervalley ridges (relict volcanic mantle), but the correspondance between strata on both sides of valleys can easily established. The ridges are of a thick andesite cover which controls relief forms and presents itself as a dissected planated, structural surface.

8. *Remnants of lava mantles*. The young (Upper Pliocene) basalt lava mantles have not yet been dissected by valleys and the flat plateaus preserve the original structural form the lava mantle. Only the margins have retreated, but here are not yet lowered nor have they been dissected. The most beatiful and largest is the Medves of 13 km^2 along the N border of Hungary, the original extension of which was 16-18 km^2; the thickness of the basalt ranges from 10 m to 100 m, depending on the relief of the underlying material.

9. *The relict tuff mantle* (dissected tuff mantle) of rhyolite and dacite tuff scarps of the Bükkalja. During the major volcanic stage of the Middle Miocene the Bükkalja was buried under more than 10 m of rhyolite and dacite tuffs associated with a fissure of eruption located to the S under the Great Plain. The highly variable resistance of the tuffs to erosion is decisive in the morphology of this area. Thus, during subsequent denudation the two most resistant ignimbrite layers were eroded into a marked double scarp preserving the loose tuff lying below *(Fig. 7). The forms* of the tuff mantle in the Bükkalja *are primarily determined by these two parallel scarps.*

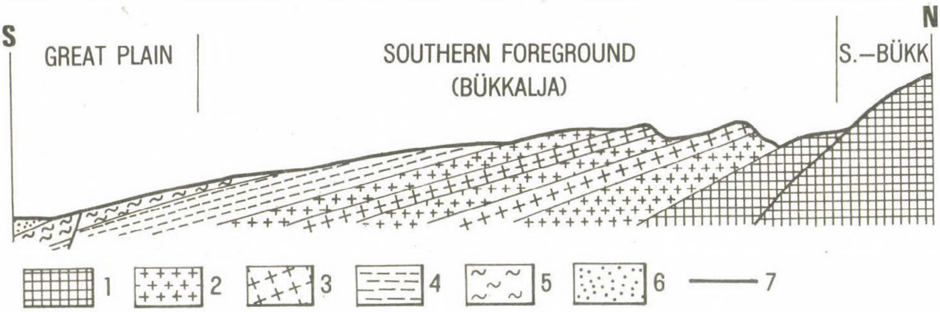

Fig. 7 General S to N profile of the S tilted tuff mantle of the S foreground of the Bükk Mountains (Bükkalja)
1 = Triassic basement; 2 = Miocene rhyolite and dacite tuffs; 3 = ignimbrite; 4 = Pannonian clay and sand; 5 = Pleistocene deposits; 6 = Holocene deposits; 7 = faults

With the late Pliocene subsidence of the Great Plain the tuff mantle was tilted to the S and was dissected into ridges and broad parallel valleys, by streams running from the Bükk Mountains giving the main valleys a parallel alignment, while the tributary valleys were preformed by the scarps. Thus, the area has a rather regular *dendritic drainage pattern* conforming to the relief structure.

III. *Types of volcanic hills.* The various types of individual volcanic hills are different in form and in the influence they exert than the above types of volcanic mountains. Volcanic hills rise individually or in groups above the surfaces of Hungarian hill regions or plains in the Hungary. The author has identified 15 volcanic hill types (relict volcanic cones, denuded volcanic cones, vent remnants, remnants of volcanic cones, etc. - see legend to *Fig. 2* Nos 10 to 24 in SZÉKELY, A. 1983).

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LANDSLIDE TYPOLOGY IN HILLY REGIONS OF NORTHERN HUNGARY

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ABSTRACT

In the course of geomorphological mapping in the hills between the Bükk and Tokaj (Zemplén) Mountains, N-Hungary during the last one and a half decades, the need arose for a more detailed investigation of landslide processes. In the 2000 km^2 hill region located between the rivers Hernád and Sajó and on the right bank of the Sajó, landslide processes not only play and important role in the general evolution of surface forms, but due to their frequency (the number of active slides in the area is around 150), they tend to impede economic activity. On the grounds of the study of landslide processes, taking into account the earlier attempt to develop a typology, a new genetic system of classification has been elaborated. In the following, this system, together with some important characteristics of the landslides in the region under study, will be presented.

* * *

CLASSIFICATION OF LANDSLIDES ACCORDING TO SLIP PLANE

The most important part of the definition of landslides formulated by various authors is the statement that the sliding masses are separated, from the stationary environment along a markedly noticeable surface or slip plane. "Rapid movements of sliding rocks, separated from the underlying stationary part of the slope by a definite plane of separation, are designated as landslides in the stricter sense." (ZÁRUBA, Q.-MENCL, V. 1969, p. 1.) "Landslides are relatively rapid movements of slope forming materials in which failure takes place on one or more discrete surfaces that limit and define the failed mass." (BRUNSDEN, D. 1979, p. 161.) "The solid mass suffers rupture failure along the plastified basement, and performs a sliding movement along a slip plane." (PÉCSI, M. 1971a.)

Starting out from the above fact it seems logical that in a *genetic classification of landslides the basis for typology should be the slip plane.* This is the principle observed by the literature on ground mechanics, and a number of geomorphological studies also distinguish the main types of landslides on the grounds of the character of the slip plane (KNOBLICH, K. 1967; LAATSCH, W.-GROTTENHALTER, W. 1972). This idea has also received attention in the Hungarian geographical literature on the classification of landslides by M. PÉCSI (PÉCSI, M. 1971a). In other systems of classification the slip plane plays an indirect and subordinate role when distinguishing the different types (e.g. KETTNER, R. 1960; HUTCHINSON, J. M. 1968; ZÁRU3A, Q.-MENCL, V. 1969; BRUNSDEN, D. 1979), where the principle of classification is based on the classical works of SHARPE, C. F. S. (1938) and VARNES, D. J. (1958) which start out from the various degrees of deformation in the moving mass. In addition, there are systems that approach the problem from quite different viewpoints (e.g. URBANEK, J. 1969 - types based on energy flows).

In our system of classification the four main criteria are related to the slip plane, and the characteristics of the sliding mass come in at fifth place. Thus, this categorization approaches the evolution of landslides from the basic, most essential point; it is genetic in the deepest sense of the word, and approximates most closely the idea of a natural system. The framework of this classification is given in *Table 1* and *Fig. 1.*

1. The *basic question* as regards slip plane refers to the *conditions of its evolution.* The question is whether slopes possess properties that, from the outset, predispose the surface to rupture and evolve into a landslide. In this respect the degree of homogeneity of the slope-forming rocks is decisive.

In non-homogeneous (e.g. bedded rock) it is usually the surfaces separating the beds with different cohesion and internal friction angles that develop into slip planes. Thus, at such cases *slides with preformed planes* evolve. The preformed slip planes, according to the geological conditions, are plane or nearly plane surfaces. These slides therefore, comprise mainly the translational slides described by HUTCHINSON and BRUNSDEN. In the course of such movements the rotation of the moving mass is generally insignificant, although there are instances (see point 2) when its extent may be considerable.

In *homogeneous rock masses* when the shear forces exceed the shear resistance, the slip plane evolves only at the instant of movement, depending on the spontaneous balance of forces. These syngenetic slip planes are arched, mostly paraboloid surfaces, which can be simplified and replaced in slope stability calculations by a cylinder. The mechanism of motion of syngenetic slides is characterized by rotation that is opposite in direction to the movement. The types called rotational slips (HUTCHINSON), deep-seated slides (BRUNSDEN) or slides on cylindrical surfaces (ZÁRUBA-MENCL) fall into this category.

Table 1 A genetic system of slides (by J. SZABÓ)

ACCORDING TO				According to the consistence of the sliding mass
Conditions of evolution	Place (relative height = m)	Angle of inclination (α) (β = inclination of the slope)	Character of material	
OF THE SLIP PLANE				
PREFORMED	$m > 0$ (slope slide)	$\alpha > \beta$ (slip of stratum)	solid	solid plastic fluent
			plastic	solid plastic fluent
		$\alpha \sim \beta$ (mantle-like slip)	solid	solid plastic fluent
			plastic	solid plastic fluent
		$\alpha > \beta$ (fall type)	—	—
	$m \sim 0$ (slice slide)	—	solid	solid plastic fluent
			plastic	solid plastic fluent
SYNGENETIC (slumps)	$m > 0$ (above base point)	—	—	solid plastic fluent (?)
	$m \sim 0$ (base point)	—	—	solid plastic fluent (?)
	$m < 0$ (below base point)	—	—	solid (?) plastic fluent (?)

in case of solid material:
- hill slide
- block slide

in case of plastic material:
- undulating slide
- carpet-like slide

in case of fluent material:
slump mudflow

- not interpretable

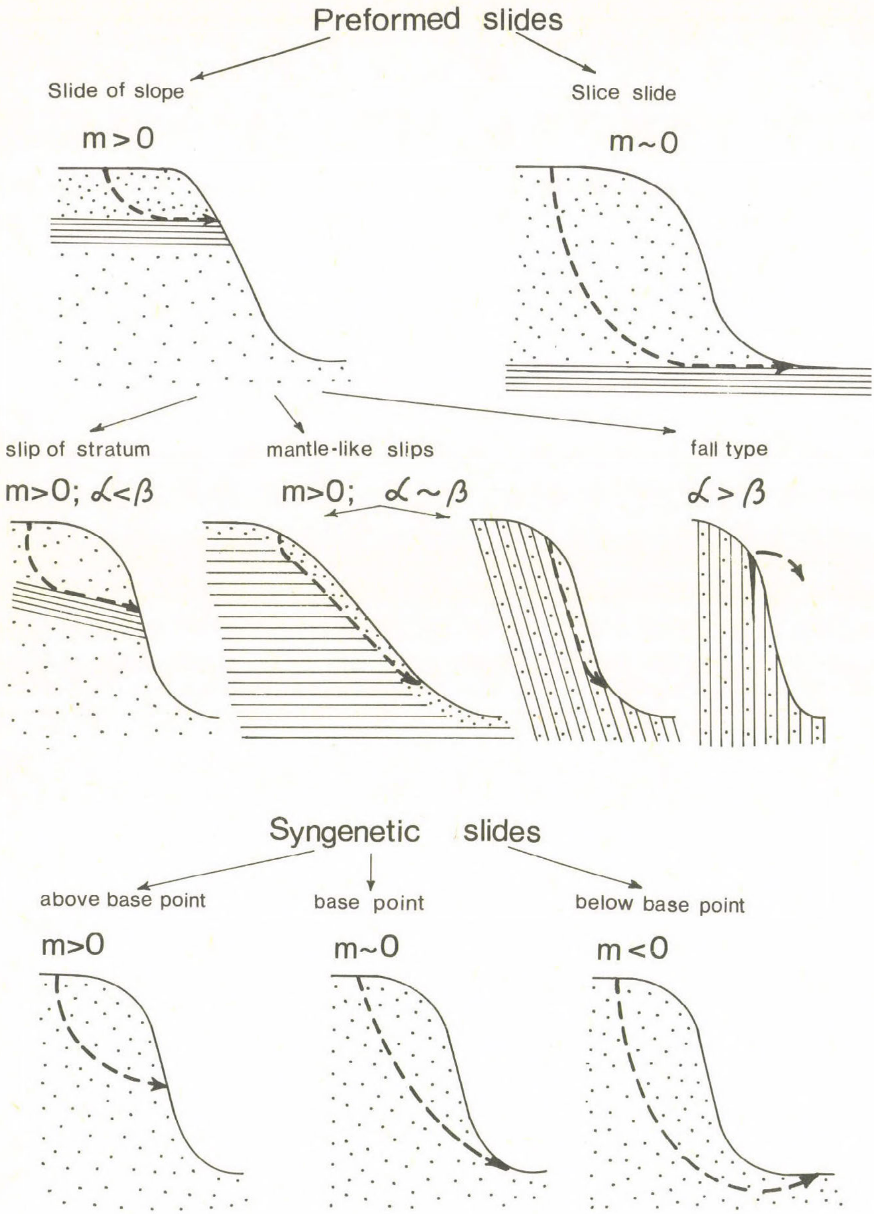

Fig. 1 Survey of the main types of landslides

2. The second main question refers to the *location of the slip plane,* i.e. its position relative to the foot of the slope or base point.

There are essentially *two possibilities* for the *relative height (m)* of the preformed plane ($m \sim 0$ and $m > 0$). If the If the *slip plane is located in the vicinity of the base point* ($m \sim 0$), we speak of deep slides in the majority of these cases, because a considerable degree of *rotation* can be observed in the sliding mass which separates into slices. The slides along the banks of the Hungarian reach of the Danube near Dunaföldvár fall into this category (PÉCSI, M. 1971b). If the *slip plane is located in the upper part of the slope* ($m > 0$), the sliding mass is thinner and the bulk of the slide covers smaller or larger segments of the slope (*slope slide).*

The *slip plane of syngenetic slides* may be located not only above ($m > 0$) or at ($m \sim 0$) the base point, but in some cases, *below the base point* ($m < 0$). Characteristic of slip planes below the base point is the bulging or squeezing out of the surface at the front of the slide. A nice example for this has been presented by ZÁRUBA and MENCL (1969). With syngenetic slides above the base point retrogressive movements are frequent and multiple and successive rotational slips are, thus, formed. Very good examples of the latter were described by G. REICHELT (1967) in a report on landslides near Wutach.

3. The third essential criterion concerns the location and gradient (α) of the slip plane. This, of course, can refer to preformed-plane slides (on nearly plane surfaces) and even to the case of $m > 0$. It can, in general be assumed of the slip plane that $\alpha \geq 0$; since the stability of slopes built up of reverse sloping beds ($\alpha < 0$) is generally high, landslides are not characteristic in such circumstances. In view of the process under study the most important point is the *relationship of the value to the gradient of the slope* (β).

a. If $\beta > \alpha$, then the slope intersects the layers, the bassets outcrop on eroding slopes. The stability of such slopes is low, since the layers outcropping at oblique angles have no support, they can slide easily. On the grounds of their character these can be referred to as *stratum slips.*

b. If $\alpha \sim \beta$, the *layers articulating the rock series* (planes of rupture, cracks) are *parallel to the slope,* thus, the layers running to the foot of the slope, or below that, can support themselves. Slides can evolve only if there are layers near the surface whose angle of internal friction can get considerably decreased under the given conditions (e.g. uptake of water). In such cases the material with decreased stability is unable to keep balance with the tangential force exerted by the weight of the material lying upslope, and landslide is released. To *this type belong the slides of accumulational slopes on which debris or regolith of even thickness has been accumulated.* Here the preformed slip plane will be not one of the planes of separation or bedding planes of the rock in stand-up formation but a rock surface underlying the regolith and parallel with the slope.

This type is called *mantle-like slip.*

c. In the case $\alpha > \beta$ the sloping conditions are relatively stable. The possible movements are no longer slides but rather *falls.*

4. The fourth question refers to the *material along the slip plane.* This problem can arise only with movements along preformed slip planes, since in syngenetic slides the sliding and stationary masses, as well as the surface of rupture are of identical character. In preformed slides the essential condition is whether the surface or rupture is a hard ūnweathered or a soft water absorbant material (and if internal friction varies with water uptake).

If two solid materials are in contact, the movement is determined by the value of friction (δ). On the other hand, if at least *one of the materials is plastic,* or if between the two rock beds there is interleaved *a thin plastifying layer then, in view of the movement, the angle of internal friction (φ) of this latter material will be decisive* (KNOBLICH, K. 1967). Since, in general, $\delta > \varphi$, the probability of the release of a slide is increased and, because of the low value of φ, the index of displacement (CROZIER, M. J. 1973) will be generally higher in such cases.

5. The morphological traits of slide types obtained from a multivariate examination of the slip plane is determined to a great extent by the consistency and mechanical composition of the material of the *sliding* mass. The morphological traits related to material quality may, in some cases, even mask the characteristics of the form-producing basic mechanism. This, however, may be regarded as subsidiary phenomenon, and in a genetic classification it is the basis of the movement that must be grasped, especially if the aim is the elaboration of methods for the prevention of slides. On the other hand, without any knowledge of the nature of the moving material no morphology of slides can be imagined. *Three types of rock consistency are of relevance when distingiushing slides: solid, plastic and brei-like (fluent).* The most typical material involved in slides are those that can readily assume all three states (e.g. clays). Since the drawing of a boundaries between different consistency states is often problematic (sometimes even in time),the evolution of transitional types is a general phenomenon. This condition, naturally, gives rise to difficulties in distinguishing slides from other types of movement. In any case, the types distinguished on the ground of the slip plane fall into morphologically very different subtypes due to the differing consistency of the sliding mass. On the grounds of the main consistency types the following variants are to be reckoned with:

a. Slides in solid (or elastic) materials correspond to movements categorized under the name rock slide. Subcategorization may be based on whether the material remains in one block in the course of movement to produce *hill-slide* or whether it is fragmented into smaller parts producing *block slide.*

b. The classical type of landslide is constituted by the *movement of plastic materials.* In the course of movement such materials are frequently fragmented further and secondary scarps may be formed as well as chaotic surfaces, where depressions without outlet are formed behind the fallen and congested mass of material *(undulating slides)*. The other basic possibility is that, in the course of movement, the plastic material remains essentially in one piece and slides down the slope as a carpet, in which case the surface may hardly be damaged *(carpet-like slip)*.

c. In viscous, fluent material the sliding phenomena are combined with flow, and it is the viscosity of the material that decides which of the two types of movement is dominant. The flow action is frequently started by the onset of a slide, while the slide is subsequently prolonged by the presence of flow phenomena and assumes a tongue-like shape (flow slides - HUTCHINSON; or mudslides - BRUNSDEN). In addition, the width/length ratio (W/L) gradually decreases. The frequency of occurence of the types included in the system outlined here is strongly divergent, which in fact produces theoretical possibilities that do not occur in nature. On the other hand, it is obvious that actual slides are not always "pure" types; in individual landslides materials of various consistencies may be mixed, the ratios of which may vary in time as well. Thus, although the majority of slides are actually complex forms, a genetic investigation must be concerned with the constituents of the complex.

LANDSLIDE TYPES IN THE SAJÓ-HERNÁD INTERFLUVE

Of the three decisive preconditions for slides to occur (i.e. favourable relief, geological conditions and climate) it is primarily the *geological conditions* that are the fundamental factor in the region under study. The greatest part of the surface of the region, is covered by loose Miocene-Pliocene marine, lacustric coastal and fluvial sediments that reach a thickness of over 100 m and which alternative repeatedly - clays following sands following gravels and so on. The valley sides intersect these beds at different levels, and the *majority of the evolving slides are therefore bound to the boundaries of the various strata which constitute preformed slip planes* along those outcrop boundaries where m 0.
On the valley sides that evolved during the Pleistocene the various slope processes have led to the accumulation of slope sediments of considerable thickness, which *start sliding over the underlying* sediments to give *slip planes generally almost parallel to the slope* $(\alpha \sim \beta)$. These are characteristic examples of mantle-like slides.

Relief conditions are less favourable for the generation of slides. The majority of slopes - primarily east of the Bódva River (Cserehát) - are relatively gentle with angles mostly in the range 5-17% and are themselves indicative of the important role that former *landslides have played in the evolution of the terrain surface*. The effect of former slides is mostly manifested in the irregular undulating nature of slopes (V-VIth category slopes - M. J. CROZIER, 1984).

The *climate of the region* tends towards moderate aridity, altough during more humid years when precipitation exceeds 900 mm and above all during the wet winters conditions are created that favour landslide processes. Since mean annual precipitation is highly variable a *definite episodicity is manifest within the seasonal character* (peak movement in early spring) *of these processes*, also discontinuous in space and time (J. URBANEK, 1968).

From the geological structure of the region it follows that *syngenetic slides are infrequent*. Those that occur are mostly small and are mainly *due to human interference* (e.g. cuts for roads). They evolve at places where the material comprising the steepened slopes is homogeneous.

The majority of slides are *bound to preformed slip planes consisting of plastic material and located above the valley floors, the position of which is characterized by the relationships* $\alpha < \beta$ *(stratum slip) and* $\alpha \sim \beta$ *(mantle-like slip). The materials involved in the slips are plastic* and in form they are of *undulating or carpet-like character*, depending on the slope conditions and the thickness of the sliding masses. The sliding of fluent (brei-like) materials sometimes occurs but flows more characteristic evolve at the foot of slides in plastic material which remain active for longer periods and result in elongation of the forms.

The majority of the slides in the area under study are characterized by relatively low tenuity and displacement indices (CROZIER, M. J. 1973). The former reflects the relative lack of the flow forms, whereas the latter is related to the considerable amount of material remaining of the surface of the slides, which is an important uncertainty factor, and enhances the probability of further recurrence. *Undulating slides possess higher classification indices* (D/L ratio) than carpet-like forms, but the values, in the majority of cases, are fairly low for these too, (they rarely exceed 5%). The erosional and accumulational zones are clearly separated on their surfaces in rhythm sequence *(Fig. 2)*. On the upper part the prevelance of erosional features is manifest in the form of scarps and depressions without outlet and dammed behind the slidden masses and often filled with water; progressing downwards, the characteristic forms are earth pads pressed up and superimposed upon one another, articulated by transverse fissures and towering over the original surface. A transitional zone is invariably found in the middle of the slides composed of a mixture of erosion and accumulation forms.

A fairly frequent phenomenon that occurs in the area is of a *slip plane formed not on clay* but on an underlying coarser saturated aquiferous layer.

Carpet-like slips occur both among stratum slips and mantle-like slips. Since large clay blocks remain intact on the surface during the slide, they cause relatively less damage to the slope, while the forms produced decay more rapidly. The lesser agricultural damage they cause is also exemplified by their classificational index, which is in general only 1-2%. Nevertheless, their role in surface evolution is important on account of their ability to transport considerable amounts of material. Their small "D" (deep) value allows wetting from above, when the material becomes viscous and, when slump-mud flow processes also take place.

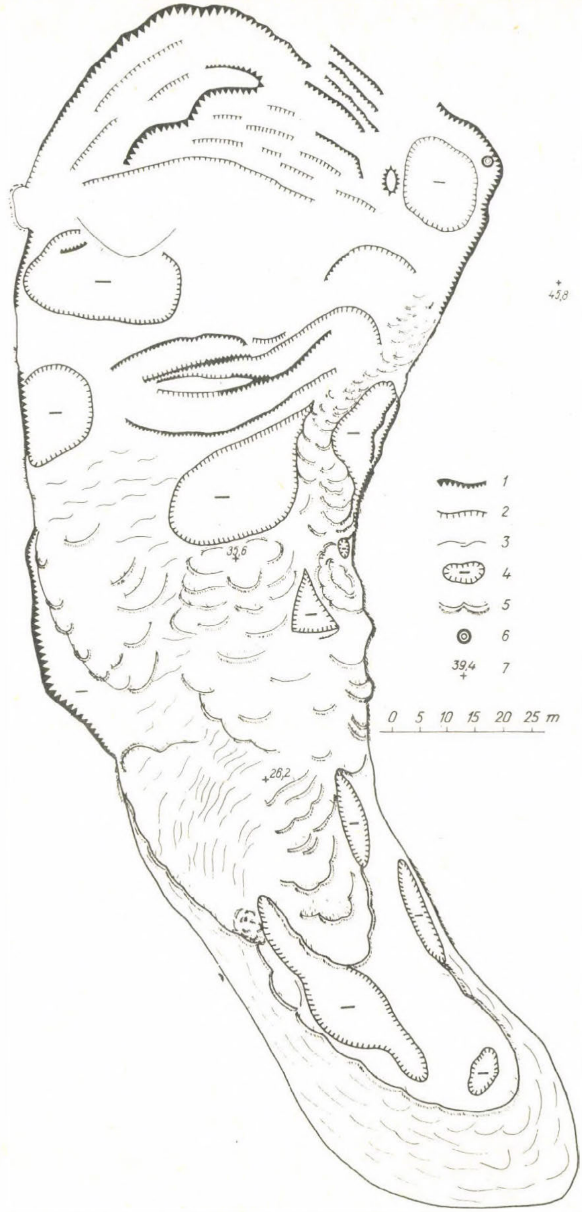

Fig. 2 Morphological units of the slide near Alsószuha
1 = main scarps higher than 1 metre; 2 = main scarps lower than 1 metre; 3 = surface scarps; 4 = closed depressions; 5 = superimposed earth pads; 6 = borehole sites; 7 = identification points

On comparing undulating with carpet-like slips, it can also be stated that *the traces of undulating slips* are more common since they are more enduring in the landscape. With carpet-like slips the case is just the opposite: the frequently generated carpets rapidly merge into the surface and so remain relatively unnoticed.

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GEOMORPHOLOGICAL MAPPING IN ALLUVIAL PLAIN AND THE ASSESSMENT OF ENVIRONMENTAL QUALITY

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ABSTRACT

Relief (including microrelief) is an important component of the agricultural value of the physical environment. In plains even small differences in relative relief may have major consequences for the physical geography of the area and generate various ecotopes with implications to land use. Along the lower Hungarian section of the Tisza river all the ecologically significant geomorphological types have been delimited and mapped with regard to both their origin and ecological endowments. Old channel forms are further classified by morphometry and vegetation cover. For the exact delimitation of forms aerial photographs proved to be useful. The boundaries of forms are represented on maps of 1:10,000 scale. The same units function as areal references during the whole procedure of the assessment of environmental quality. The legend of geomorphological maps used in Hungary has been amplified. The relative scores given underline the decisive control of relief over the value of areas for agricultural use in alluvial plains primarily manifest in the influence on water availability.

* * *

ASSESSMENT OF PHYSICAL ENVIRONMENTAL QUALITY IN LOWLANDS

Although almost two-thirds of Hungary is lowland, the assessment of enviromental quality in research to date has been mostly restricted to mountainous or hilly country and methods are only available for areas of this kind. Without adaptation or complementing they cannot be used for the assessment of lowlands the comprehensive evaluation of which is, however, strongly urged by the present economic situation. The most valuable agricultural lands are on lowland surfaces and represent one of the most important of the natural resources in Hungarian economy.

Agricultural land made up 70.6 per cent of the area of Hungary in 1983, and although this value is decreasing - due to the land protection measures of recent years at a dimishing rate - by some 0.3 to 0.1 per cent per year, the importance of evaluating the environment tends to grow. When any proposal is made to transfer a particular cultivated area to non-agricultural use it is essential to know the relative environmental value of that land when making the decision (PÉCSI, M. 1980.). Relative evaluation helps prevent the expropriation of precious land for new roads, for new industrial plants, for open cast mines and even for recreational use.

The complete procedure of the assessment (elaborated at the Geographical Research Institute Hungarian Academy of Sciences). Based on field-work the 1:10,000 scale geomorphological map of the test area was drawn and the available physical geographical information was collected. Through the application of the first rating method (GÓCZÁN, L. 1981) the factors of the physical environment (relief, groundwater, soils and climate) were evaluated individually and in an integrated manner for the general purpose of agricultural use. The other (automated) method (LÓCZY, D. 1984) helped us set up the order of crops reflecting land capability for the units of the test area. The 'suitability indicators' of crops were tabulated in a modified coding system. The results were evaluated by geomorphological types in order to be available for decision-makers in the various sectors of the national economy.

The main groups of factors in the assessment of environmental quality for the purposes of crop cultivation (GÓCZÁN, L. et al. 1984):

1. topographic endowments,
2. surficial rocks,
3. mineral resources (for purposes of comparison),
4. climatic conditions,
5. surficial and groundwater,
6. soils and
7. natural vegetation.

PHYSICAL GEOGRAPHY OF TEST AREA

The test area of about 50 km^2 is located along both banks of the Tisza, *in the Lower Tisza region*, covering the administrative area of the village Mindszent *(Fig. 1)*. A minor portion of the area on the W belongs to the Danube-Tisza alluvial plain. The lowest point is 75. m a.s.l. and the highest (in the Danube-Tisza Interfluve) is 88 m a.s.l.

The test area has a moderately continental *warm-dry* climate with much less cloudiness (slightly above 50 per cent) than the national average and with summer droughts. Average precipitation during the growing season is around 300 mm and mean temperature is 18 °C for the same period.

Most of the area has been converted into a *cultivated landscape*. The *remnants of the natural vegetation* appear as groves along the active river channels, as willow and poplar groves (willow, black and white poplar or ash) on the high flood-plain. Bramble and nettle are also typical in the undergrowth at sites of clearing as well as some aqueous and swamp plants in the filled meanders and 'kubikgödör'-s (navvy pits) along the leeve.

Almost all the lowland hydromorphous soil types of Hungary, from the young alluvium of channels to the meadow alluvial or meadow soils occur. The most spread *nine soil subtypes* are the following:

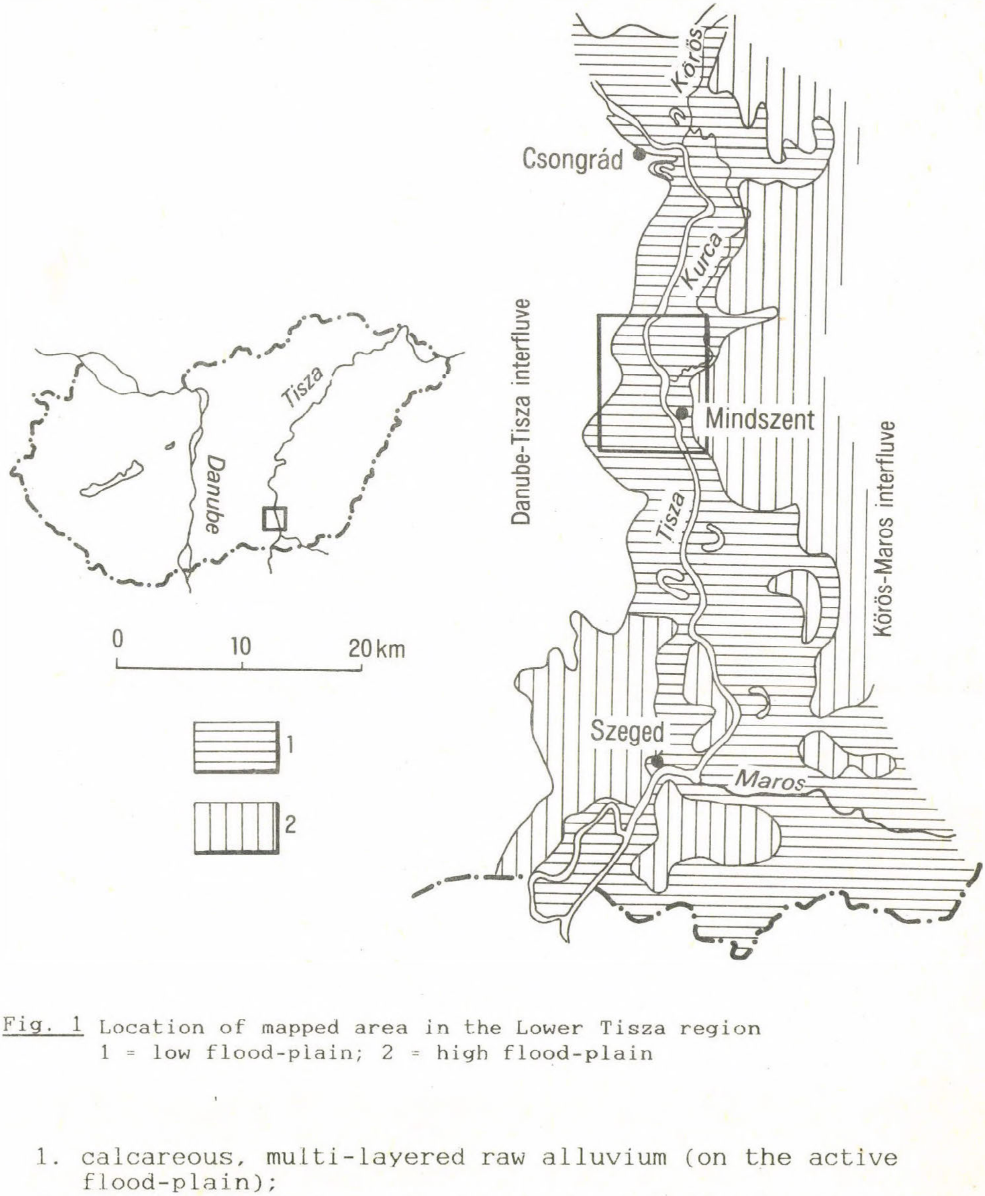


Fig. 1 Location of mapped area in the Lower Tisza region
1 = low flood-plain; 2 = high flood-plain

1. calcareous, multi-layered raw alluvium (on the active flood-plain);
2. calcareous meadow alluvial soil (immediately beyond the levees);
3. non-calcareous meadow alluvial soil;
4. calcareous meadow soil;
5. non-calcareous meadow soil;
6. medium deep meadow solonetz with chernozem dynamics (salt-affected soil generally unsuitable for cultivation as arable land - in the NW of the test area);

Fig. 2 Geomorphological map of the environs of Mindszent (N)

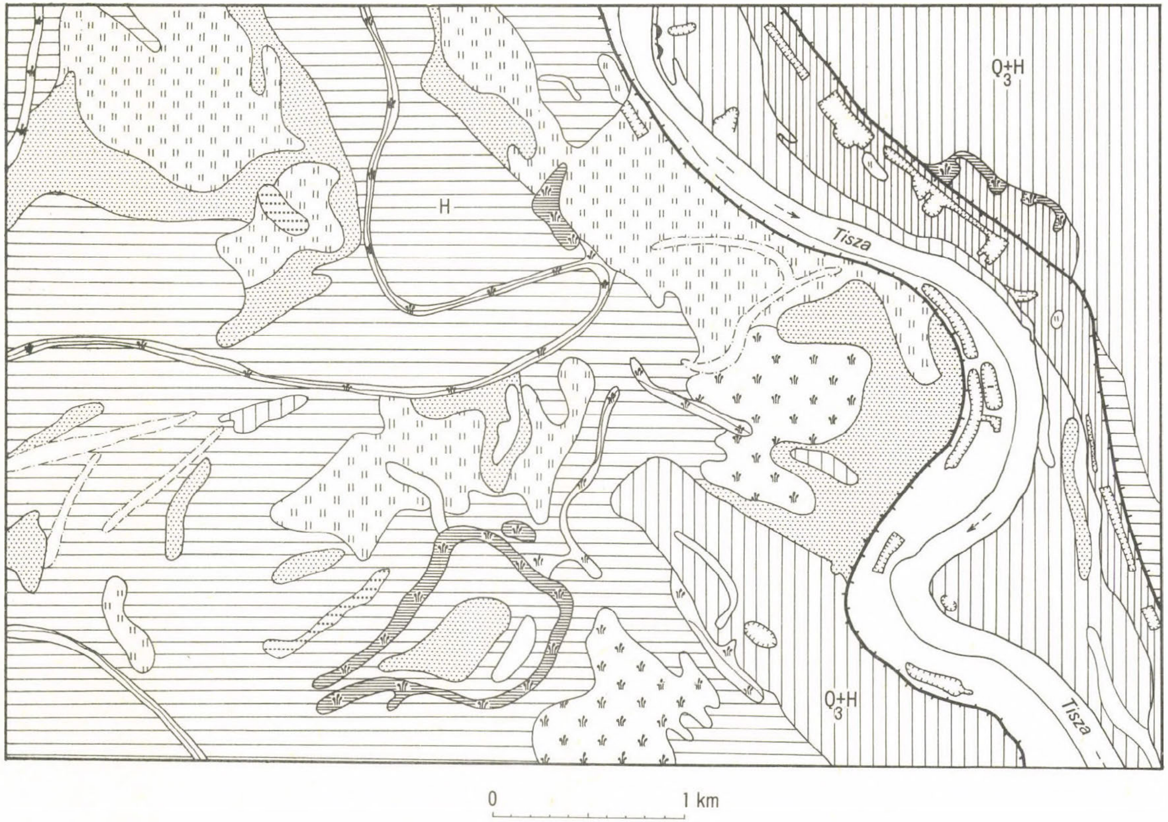
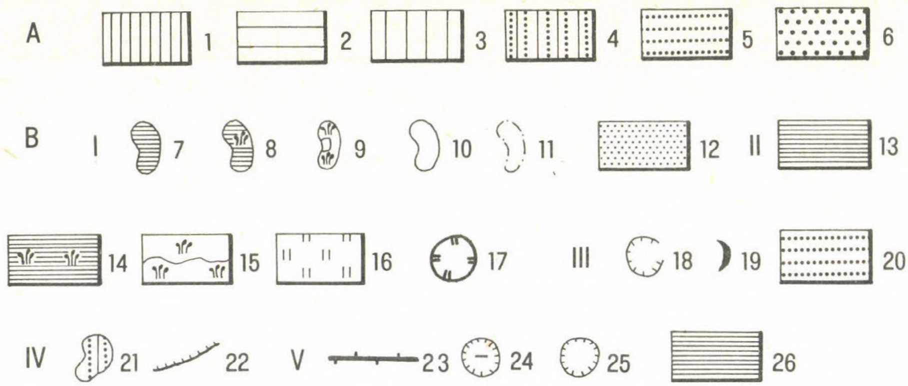


Fig. 3 Geomorphological map of the environs of Mindszent (S)



Groups of landforms: 1 = active flood-plain; 2 = low flood-plain; 3 = high flood-plain; 4 = hummocks mantled by Pleistocene typical or alluvial loess; 5 = Early Holocene fields of cover sand; 6 = Pleistocene alluvial plain covered by sand. Genetic landform types: I. Fluvial forms: 7, 8 = zone of point bars and filled meanders; 9 = filled meander permanently waterlogged; 10 = filled meander seasonally waterlogged; 11 = filled meander with canalized watercourse; 12 = filled meander with groundwater close to the surface; 13 = cultivated filled meander, 14 = meander spurs. II. Lacustrine-paludal forms; 15 = backswamps permanently water-logged; 16 = old lake basins drained by canals; 18 = filled old lake basin with groundwater close to the surface; 19 = enclosed salinic depressions. III. Eolian forms: 20 = wind furrow; 21 = riverbank dune. IV. Forms of complex origin: 22 = Pleistocene loess hummocks; 23 = undercut margin of low flood-plain. V. Man-made forms: 24 = flood protection levee; 25 = navvy pit inundated; 26 = navvy pit without inundation; 27 = artificial lake. Age of landforms: $Q_3 + H$ = shaped up to present; H_1 = Early Holocene; H_2 = Late Holocene; H_3 = recent

7. deep meadow solonetz with chernozem dynamics (salt-affected soil suitable for cultivation as arable land - in the NE of the test area);
8. calcareous humous sand with buried humus layers (on the Danube-Tisza Interluve);
9. brownearth with strong chernozem dynamics.

GEOMORPHOLOGY

The factors of the physical environment were evaluated by *geomorphological units*. In order to delimit these units in a precise way, the *geomorphological map* of the area at 1:10,000 scale was produced and subsequently reduced to 1:100,000 scale *(Figs 2-3)*.

The present surface under study and its broader environs are a result of subsidence from the Tertiary to our days and of the ensuing deposition of the basin. The *relief* as it can be seen today has been shaped by repeated changes of channels. Beyond the zone of point bars and filled meanders enclosed backswamps occur; most of their area is affected by alkalization.

Subsurface layers tend to be ever finer upwards related to flood-plain deposition by the Tisza river. On the active flood-plain alluvial silt and sandy silt accumulate as a consequence of annual inundations, while meadow clay results from the soil-forming processes affecting alluvium on the regulated flood-plain and farther off the river layers of fine silt are deposited. The latter are rich humus and were formed where in the flood-plain mineralogeneous deposition reduced and phytogeneous deposition gained prominence.

In the area the Tisza is the most prominent geomorphic agent since it shifted to the structural graben of the Lower Tisza region in the Early Holocene.

A TOPOGRAPHIC ANALYSIS

In the analysis of lowland landforms first *groups of forms* are differentiated and they are subsequently subdivided into *elements of forms*. Although in the test area on alluvial plain the differences in elevation are minimal, one of the main features of relief is still the minute (horizontal) *dissection* by microforms (due to the alternation of point bars and filled meanders) and it allowed to draw distinctions between the most common landforms. The landforms appearing in a sparse or dense networks and having only slight different elevations (or depths) present dissimilar ecological conditions to crop cultivation - primarily through the differences in groundwater table.

In the distinction between the main groups of landform and the individual landforms, waterlogging and the depth of groundwater table was a primary circumstance to be taken into account. Minor forms were generalized on the map.

In the area under investigation *five groups of landforms* were identified:

- I. Active flood-plain;
- II. Low flood-plain;
- III. High flood-plain;
- IV/A. Low alluvial fan mantled by Pleistocene typical and alluvial loesses;
- IV/B. Fields of cover sand accumulated in the Early Holocene;
- V. Pleistocene alluvial plain covered by sand.

There is a relative richness in *individual landforms*. Modifying the tables of assessment, within the types of low and high floodplain a 'zone of a point bars and filled meanders' was identified, within enclosed meanders the categories of 'more than 50 per cent is permanently waterlogged' and 'less than

50 per cent is permanently waterlogged were introduced. Distinctions were also made by the depths, waterlogging and canalization of meanders. The following *genetic landform types* were established:

I. *Fluvial landforms*

1. Zone of point bars and filled meanders (shallower than 1 m);
2. Major filled meander ($>$1 m deep) with permanent waterlogging;
3. Major filled meander ($>$ 1 m deep) with seasonal waterlogging;
4. Major filled meander ($>$ 1 m deep) with canalized watercourse;
5. Major filled meander ($>$ 1 m deep) with groundwater close to the surface;
6. Cultivated filled meander;
7. Meander spurs.

II. *Lacustrine-paludal landforms*

1. Backswamps with permanent waterlogging;
2. Old lake basins with seasonal waterlogging;
3. Enclosed old lake basins drained by canals;
4. Old lake basin filled by fluvial deposits and plant detritus with groundwater close to the surface;
5. Enclosed salinic depressions.

III. *Eolian landforms*

1. Wind furrow;
2. River-bank dune;
3. Low, flat ridge of cover sand.

IV. *Landform of complex origin*

1. Pleistocene loess hummocks;
2. Undercut margin of low flood-plain.

V. *Man-made forms*

1. Flood protection levee;
2. Navvy pit inundated;
3. Navvy pit without inundation;
4. Artificial lake.

The youngest of relief types is the *active flood-plain* bordered by levees. Its evolution takes place through annual inundations and, consequently, is rather rapid. It has highly variable widths, from 20 m to 1200 m. Deposition during floods makes its altitude above sea level grow year by year; in several places, the active flood-plain lies higher than surfaces beyond the levees.

Most of the test area is *low flood-plain* (75 m to 79 m a.s.l.) of only some thousand years old. It was formed by the Tisza in the Late Holocene, cutting into the high flood-plain surface. Evidence for this is found on the left bank, where the high flood-plain has been dissected into six isolated sections by the river. The individual forms on the low flood-plain are of major importance for agriculture. The relative areal extension of filled meanders is relatively low; their varieties (seasonally waterlogged, with canalized water-course, with groundwater table close to the surface or cultivated) are differentiated. The delimitation of enclosed backswamps on the low flood-plain - which were once occupied by stagnant water - was promoted by the analyses of maps from the time of river regulations.

The *high flood-plain* (80 m to 84 m a.s.l.) is small in area. A contiguous surface is found in the SE of the test area, in other places only fragments are preserved. It is partly covered by point bars and filled meanders.

At the beginning of the Early Holocene fluvial erosion increased and, as a consequence, from the *Pleistocene loess*-mantled surface of the South Trans-Tisza region flood-free ridges were separated. The *hummocks* covered by 'lowland' loess lie at an average 85 m a.s.l., while those mantled by alluvial loessy silt lie at 83 m to 85 m absolute altitude, i.e. at 1 m to 5 m relative height.

Early Holocene ridges of cover sand also occurs in spots. Their material was reworked from the surface of the Danube-Tisza interfluvial alluvial fan.

In the environs of Mindszent the oldest relief type is the *Pleistocene alluvial fan with sand cover* (79 m to 90 m a.s.l.) in the NW corner of the map sheet.

HYDROGRAPHY

The test area being one of the parts of Hungary most affected by drought, the availability of water is rather poor. Water deficit is partly counterbalanced by the Tisza river of large discharge and its tributaries through a well-developed network of canals. Over rather small surfaces the expenses of irrigation are reduced by favourable groundwater conditions. The annual range of groundwater table, also dependent on the regime of the Tisza in its immediate proximity, is generally high in most of the test area. In humid years large amounts of water move over by subsurface flow from the Danube-Tisza Interfluve and the Körös-Maros plain to the Tisza flood-plain. In arid years, however, the draining effect of deeper lying river channels is felt. Average groundwater table is at 2.5 m to 6 m, but considerable range is observed within small areas. If it is below 6 m, groundwater has no influence on plant growth and neglected in evaluation. Cut-off channels (oxbow lakes) are important as water sources. Most of them are connected with the Tisza by networks of canalization.

RELATIONSHIPS BETWEEN RELIEF AND ENVIRONMENTAL QUALITY

The evaluation of environmental factors for general agricultural use resulted in the slightly surprising conclusion *(Figs. 4 and 5)* that the one-time backswamps completely filled by flu-

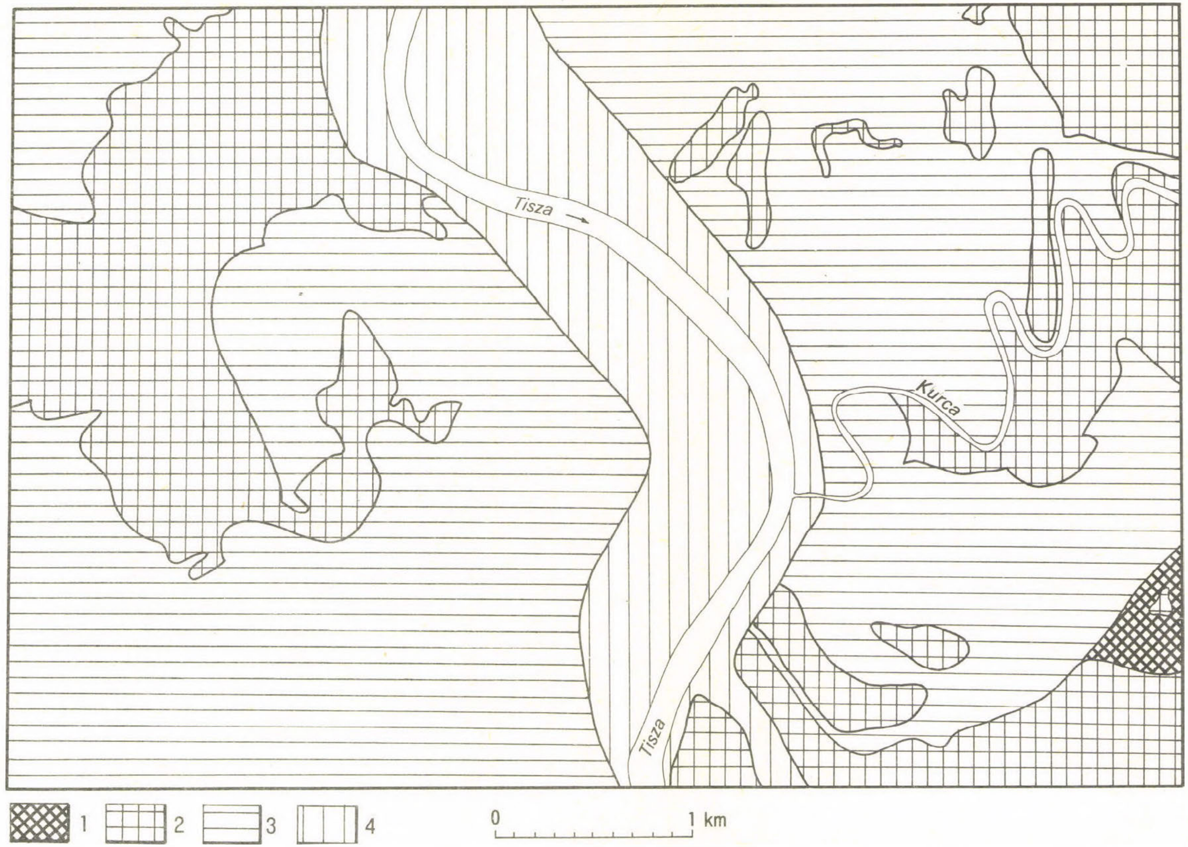


Fig. 4 Map of land capability for crop cultivation (Mindszent N)
1 = the scores for each of major crops are $\underline{r} \geq 7$; 2 = $\underline{r} \geq 6$; 3 = $\underline{r} \geq 5$; 4 = $\underline{r} \geq 4$

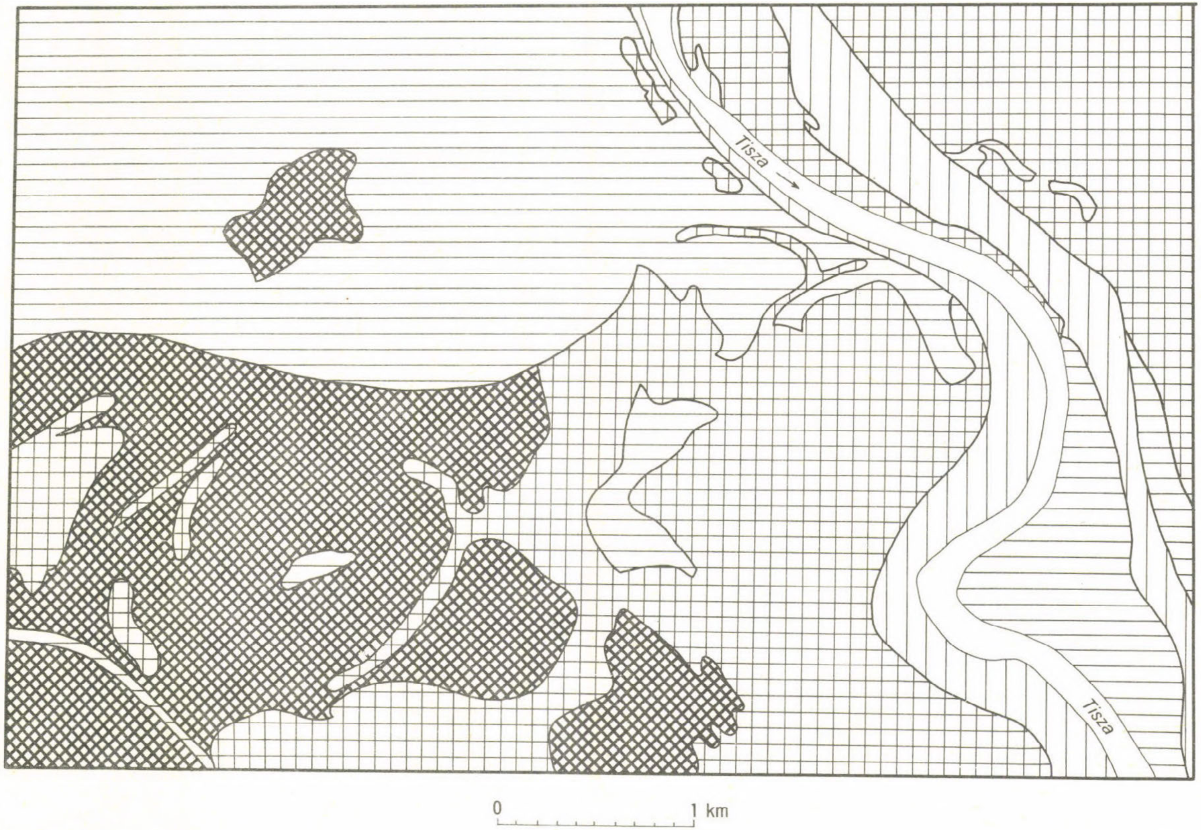


Fig. 5 Map of land capability for crop cultivation (Mindszent S)
For legend see Fig. 4

vial deposits and organic detritus and meander spurs appeared most favourable for such a purpose. The 'ruggedness' of the surfaces of the point bar-filled meander terrain (hindering soil cultivation), abrupt rises in or, on the high flood-plain, the low position of groundwater table present value-reducing features. The zone of point bars and filled meanders in the low flood-plain did not always reach even the scores indicating medium value.

The marginal strips of low flood-plain undercut by the river some isolated spots of the high flood-plain as well as major filled meanders with canalized water-courses were evaluated as having lower than medium quality.

Of least agricultural value are the regularly inundated or waterlogged terrain, filled meanders seasonally waterlogged, backswamps and the sand area of the Danube-Tisza Interfluve covered by the map sheet (altogether about 15 per cent of the test area).

The relative scores given underline the decisive control of relief over the value of areas for agricultural use in alluvial plains primarily manifest in the influence of even minor surface 'ruggedness' on the water budget of soils and the availability of water for plants.

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MAPPING OF RECENT GEOMORPHIC PROCESSES

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ABSTRACT

The factors inducing geomorphic processes are either stable in space and time (lithology and orography) or unstable (climate and human activity). In a given area a wide range of geomorphic processes are observed, primarily due to the diversity of weather phenomena. Methodologically, it is of extreme importance to set up the hierarchy of processes. The typical well-defined processes have to be found for the spatial units. This is aided by the application of air and space images. They serve to delimit the areas (types) with the predominance of processes of different quality. On long and steep slopes used as arable land or vineyard, intensive material transport due to rainwater is typical. It is manifest in gully or rill erosion and sheet wash. Moderate removal of material is characteristic of slopes of intermediate length (maximum 300 m) and inclination of 5 to 17 per cent used as arable land. On the slopes of arable land with less than 5 per cent angle and on the very short slopes gentler than 17 per cent covered by meadow, pasture or vineyard very moderate transport dominates. Deluvial accumulation is overwhelming along the feet of steep slopes and on the margin of valley floors. No change is detected on flat surfaces and this 'neutral' geomorphic evolution is indicated by complete soil profiles.

* * *

GOALS

The study of relief evolution in historical times and its areal representation is a trend of geomorphological research which is in rapid progress in our days. Today the achievements are published in several national atlases, too.

It is not accidental that this kind of research has begun to develop intensively. Human intervention is more and more substantial into dynamic relief equilibria and, as a consequence, these states become upset to some extent. Consequently, in many of the cases, undesirable processes begin to operate or gain in intensitiy. Thus, the investigations may be integrated into *environmental protection* or environmental impact statements.

The international climatological and glaciological research as well as the analyses of secular sea level changes have ever deeply revealed the history of climatic change (BÖHM, R.-HAMMER, N.-STROBL, i. 1983, CHIAO, M.-h. 1976. HANNEL, F. G.-ASCHWEl, I. Y. 1959. HOLLIS, G. 1978, KLAUS, D. 1980, LAMB, H. H.-MÖRTH, H. T. 1978, TOOLEY, M. I. 1974. WENDORF, F. et al. 1977). As the investigations are also concerned with *the analyses of the impact of climatic change,* they have major geomorphological consequences too.

The research into recent geomorphic processes has a *socio-economic significance,* since it determines the areal extension and intensity of the particular processes. At the same time, forecast is also feasible and it draws attention to the occurence and intensification of adverse processes in the area owing to the productive activities of man. The final conclusions of the analyses are the proposals for the optimal use of land, the rational exploitation of or adaptation to the objectively operating processes unalterable by society.

Since recent geomorphic processes are due to particular interactions of physical factors, their investigations are also prominent in *complex landscape ecological research.* The lithology, morphography, macroclimate and microclimate and other components of the landscape are fundamental control of recent geomorphic processes, too. Therefore, they can be considered the geomorphological expression of ecological factors.

The recent geomorphic processes defined and mapped mostly affect agricultural land and occur as varieties of soil erosion or accumulation. With a profound knowledge about them, *the spatially and temporally varying degree of soil loss can be demonstrated in more detail and truer to reality.*

Recent relief evolution can be analyzed in either a *static* or a *dynamic* approach. The static approach registers recent geomorphic events reconstructed from the present landforms. The dynamic approach intends to draw conclusions for earlier geomorphic processes of varying nature and intensity from evidence of climatic changes over historical times. Although mapping is obviously of static characer, the correct way is to apply both approaches in the regional analyses.

METHOD

Mapping is primarily founded on *field observations.* The recognition of processing arising in special weather situations and the estimation of their intensities are only possible in the field. Detailed field-work is also necessary, because the same phenomenon greatly varies in intensity in space and, consequently, manifests itself in different landforms.

The resulting microforms are of relatively short life-time, because cultivation destroys or transforms them. For this reason, they can only be detected by frequently repeated field observations. The number of observations highly increases the reliability of mapped information.

The factors inducing the processes fall into two major groups
1. Among the factors *stable in space and time,* lithology and

orography have to be mentioned. 2. To the group of factors *unstable in time and space* climate and human activity are prominent. It is obvious that they are capable to induce major (quantitative) changes in the (intensity of the) processes. In many cases, however, qualitative changes also ensue.

In a given area a wide range of geomorphic processes are observed, primarily due to the diversity of weather phenomena. Methodologically it is of extreme importance to determine the predominant (typical) and the subsidiary (nontypical) processes and reveal their *hierarchy*. The order of significance varies even within a small region.

A process is called predominant if it has lasting landform evidence in the field or if it is active for most of the year, dependent on climate. *Based on typical processes, the space under study has to be typified.* A fundamentel target of research is to give exact definitions of these types, to determine the parameters of the system of stable and unstable factors which contribute to the formation of the individual types. To achieve this task, as a matter of course, persistent research based on rich experience is needed. We have attempted to set up a system, to outline the major parameters, but it is not regarded a final solution. It was meant to introduce the objectivity of mapping.

Air and space image interpretation is also important in mapping. It is vital to delimit the areas (types) with the predominance of processes of different quality. Remote sensing helps in delimitation. Experience shows that for small areas first of all aerial photographs are useful, while regional studies are best assisted by space images.

Field observations are easily parallelled by the aerial photographs of the same area. The expression of the various processes on photographs can be established. When the types are identified, the aerial photograph may play a fundamental role in the areal extrapolation of a phenomenon studied in lesser detail.

SPATIAL SYSTEM OF TYPES

The NW-Transdanubian test area of 850 km^2 *(Fig. 1)*, by its diverse lithology, topography and socio-economic utilization, gives opportunities to recognize numerous processes and to identify several types.

Through the integration of the factors stable or unstable in space and time mentioned above, a characteristic system of processes is observed. The names of types always indicate the predominant (typical) process.

On long and steep slopes used as arable land or vineyard, *intensive material transport* due to rainwater is typical. It is manifest in gully or rill erosion and sheet wash (PÉCSI, M. 1975). Influenced by changes in rainfall intensity and local antrophogenic factors, several secondary or subsidiary processes can be identified.

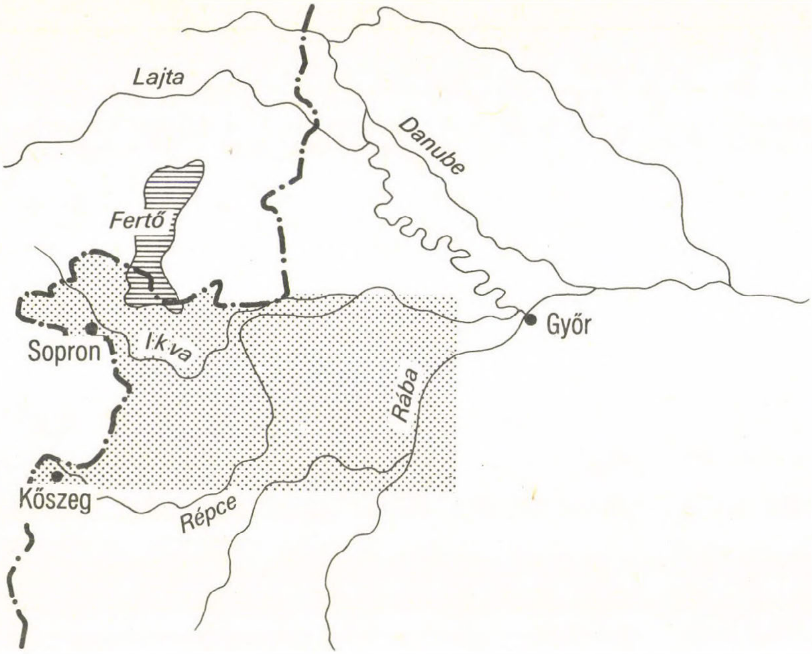

Fig. 1 Location of the investigated area in NW-Hungary

With decreasing intensity, the rate of material transport also lessens. Below an (as yet unspecified) lower limit of rainfall intensity, temporary deluvial accumulation is possible too. The material starts to move downslope, but stops above the valley floor and is moved further onto the valley floor or its margin during the next rainfall. Intensive material transport is primarily a result of rainfall. In function of lithology, the regelation of the transitional seasons (spring and autumn) may also induce gelisolifluction. During hyperhumid autumns and springs mudflows also occur.

Moderate material transport due to rainwater is characteristic of slopes of intermediate length (maximum 300 m) and inclination of 5 to 17 per cent used as arable land. On loose deposits sheet wash as a kind of intensive areal material transport tends to decline. Rill erosion, which is only active during rainfalls of very high intensity, takes its place. Rill or gully erosion is primarily induced by man-made microforms (e.g. downslope ploughing). On slopes of more than 17 per cent angle and meadow or pasture vegetation and on those above 25 per cent with forest geomorphic processes of similar intensity are common. As a secondary agent deflation is worth mentioning. Wind erosion is mainly induced by the combined effect of dry and windy weather situations and loose sandy surficial rocks. The intermittent accumulation of deluvium on these slopes is also of secondary significance.

In the two mountains of the investigated area (the Sopron and the Köszeg Mountains) this is the typical intensity of erosion *(Fig. 2)*.

Intensive (or moderate) material transport and landslide hazard are typical of the above described slopes if the surface is underlain by layers prone to sliding. The two processes are markedly distinct in time: Landslides are characteristic in Hungary primarily in autumn, winter and spring. In winter they are mostly triggered by the mild spells caused by the relatively warm air masses arriving from the medium to high pressure zone of the Atlantic ocean (mPM) or from the subtropical belt (TM). Intensive or moderate removal of material is active from late spring to early autumn.

There are several secondary processes operating on these surfaces. An order of frequency or intensity can be established among them for each season, influenced by stable and unstable factors. In summer intensive and moderate transport is most common. Although rarely, intermittent accumulation of deluvium is also observed. Partly to the effect of special lithology, in autumn, winter and spring mudflows may be characteristic too. During the period of alternating frost and thaw, geli-solifluciton also has to be taken into account. These latter two processes are also influenced by landslides which mix the silty-clayey formation with the loess-like or sandy cover to some extent. Thus, the soil (and the layers lying immediately below) contain much silt and clay, which promote earthflows or gelisolifluction.

On the slopes of arable land with less than 5 per cent angle and on the very short slopes gentler than 17 per cent covered by meadow, pasture or vineyard *very moderate material transport* dominates. On forested slopes below 25 per cent the rate of erosion is of the same order.

On these surfaces material is seldom carried and only in small amount. Sheet wash and rill erosion only operate during heavy rainfalls. Light to medium rainfalls favour intermittent accumulation of deluvium.

In the immediate southern neighbourhood of the young tectonic basin of Lake Fertö this very moderate transport of material is typical *(Fig. 3)*.

Deluvial accumulation is the dominant process along the feet of steep slopes or on the margin of valley floors. The rate or accumulation depends on the length and angle of slope. It is clearly discernible at the feet of long and steep slopes and on the adjacent flat surfaces, mainly in the summer half-year.

'Neutral geomorphic evolution' (no change) is characteristic of entirely flat surfaces and this is indicated by complete soil profiles. All the slopes below 5 per cent angle with meadow-pasture or forest use should likely be included here where it is due to cultivation. Neutral or quasi-neutral state is observed on the youngest alluvial fan surfaces of loose fluviatile sand and silty sand. During the growing season relief evolution is inhibited by vegetation through the reduction the in-

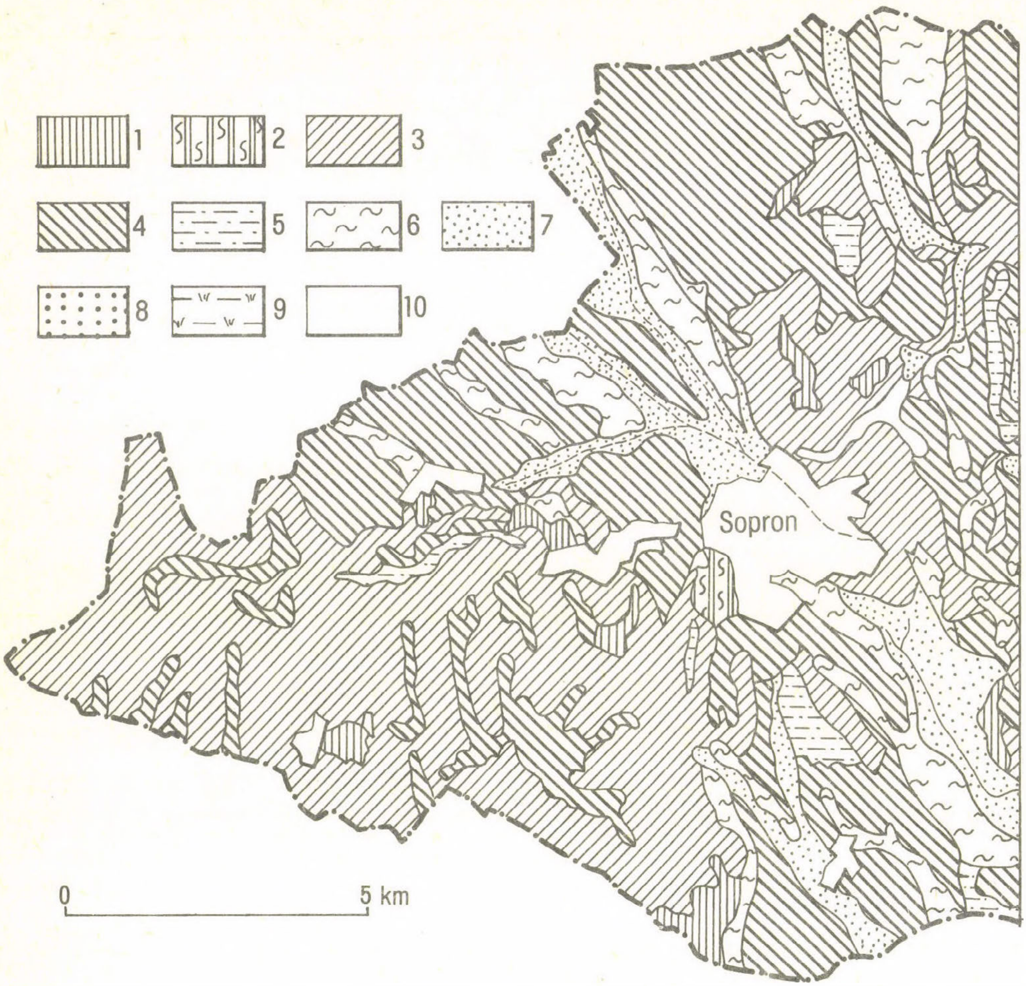

Fig. 2 Recent geomorphic processes in the Sopron basin and environs
1 = intensive material transport by rainwater;
2 = intensive material transport by rainwater and hazard of sliding;
3 = moderate material transport by rainwater;
4 = very moderate material transport by rainwater;
5 = 'neutral geomorphic evolution' (no change);
6 = deluvial accumulation;
7 = fluvial accumulation;
8 = deflation processes;
9 = lacustrine-paludal accumulation in depressions without drainage;
10 = geomorphic processes characteristic of the inner areas of settlements

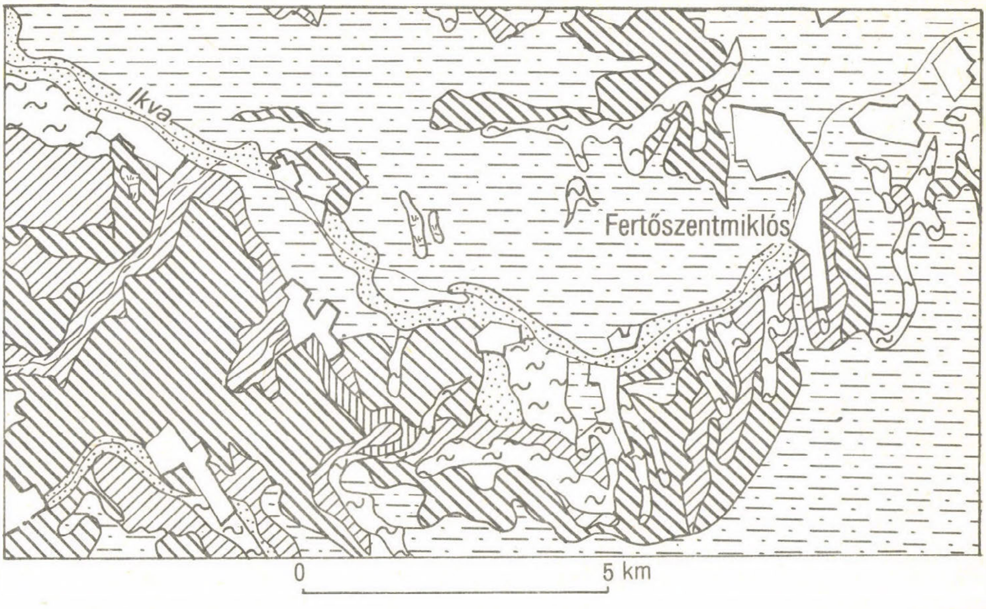

Fig. 3 Recent geomorphic processes in the Ikva region. - For legend see Fig. 2.

tensity of one of the most active secondary processes, deflation. Deluvial accumulation is another secondary process, although on most of the NW-Transdanubian surfaces of 'neutral evolution' (on the vast Late Pleistocene-Holocene alluvial fan of the Rába river extending to N - *Fig. 4*) deflation is the secondary geomorphic process.

Lacustrine-paludal accumulation is predominant on surfaces of no or poor drainage where the groundwater table is close to the surface or which are almost permanently waterlogged because or surficial waters arriving from the connected catchments. Two subsidiary processes are deluvial accumulation of insignificant intensity and biogenic accumulation, which is locally more remarkable. The latter constantly raises surface level through the aggradation of decaying plant fragments.

The subsidiary processes on terrains of *fluvial accumulation* are mostly similar to those listed above. In the period without floods neutral state is probable and this is, first of all, caused by the meadow or pasture use of land. In several cases biogenic accumulation also plays an important role. On arable land, in dry and windy weather situation, deflation should occasionally be taken into account on sandy unvegetated surfaces. Deluvial accumulation is a secondary process which can operate on the margins of valley floors during heavy rainfalls.

The typical areas of *deflation* are the sand surfaces 'inherited' from the Late Pleistocene and Early Holocene. It only

Fig. 4 Recent geomorphic processes on the alluvial fan of the Rába (detail). - For legend see Fig. 2

has major importance on unvegetated surfaces at the beginning and end of dry winters. Subsidiary processes worth mentioning are hardly found, since these surfaces are highly permanent with poor water retention and, thus, material is seldom transported by rainwater.

THE HISTORICAL DYNAMICS OF PROCESSES

The climatic conditions, changeable with time, influence the intensity of geomorphic processes and may even cause alterations in their quality. Some phenomena may (even if temporarily) decline and new ones may arise. To these changes human activity also contributes. Suffice to mention the geomorphological consequences of the appearance and large-scale spreading of arable land, the reduction of forested area and major flood prevention and drainage works.

The intensity changes of geomorphic processes or their temporary breaks or appearances can most reliably be detected by continuous observations. For the geomorphologists, however, the observation network and data base of meteorological or hydrological research, which are capable to monitor the changes for the last 100 years are not available.

The only way is to use indirect methods (such as the records in archives) to reconstruct changes. They mostly inform, however, of the major natural disasters only. There has been a notable experiment to collect data on meteorological events (RÉTHLY, A. 1962, 1970). This historical information is extremely valuable for geomorphological purposes too. This method, however, is not capable to provide a time series, since, as it has already been mentioned, only record the extremities. The advantage of the application of the procedure is that information, although incomplete, for the last 100-150 years even longer time span becomes available.

The intensity changes, temporary breaks and reoccurence of geomorphic processes can be continuously detected in the light of some meteorological parameters. Here data on the amount and intensity of precipitation are of decisive importance, since precipitation influences, directly or indirectly, the overwhelming part of the processes.

The glaciological studies and the analyses of changes of sea (or lake) levels provide excellent information on the major trends of long-term climatic changes. Comparing the results with the precipitation and temperature changes in a region, an approximately true picture is obtained of the nature and rate of climatic change. The monthly and seasonal fluctuations of these two climatic elements satisfactorily describe the periodicity of various processes of material transport by rainwater and of the intensity changes in landslides and karstification. In order to study deflation in a similar manner, it would be of great use to know the variation of wind velocity over a long period. This kind of information, however, is not available for the last 100-150 years. Therefore, we were forced to infer increased or reduced deflation from the particular trends of precipitation and temperature changes. Nevertheless, it is obvious that the dry and warm character of months does not necessarily result in higher wind velocities. In our following case study the dynamic approach of the research into landslide processes is outlined.

In the neighbourhood of the karst region of the Mecsek Mountains, S-Hungary, there are surfaces affected by landslides. In one of them an attempt was made to estimate the dynamics of mass movements during the last 80 years. In the vicinity of the village Orfü, in the W of the mountains, calcareous rocks occur side by side with Miocene strata prone to sliding. The two types of rock are in considerable hydrological connection; a large amount of water flows from the karstic rocks into the sandy layers intercalated between the Miocene clayey formations. The susceptibility of clays or sandy clays to sliding depends on water recharge. The water supply from the karst is a function of the amount of water moving in it and the latter, in turn, is controlled by the atmospheric precipitation. Thus, indirectly the changes in precipitation reflect the trends in the alteration of the amount of water which flows into the strata prone to sliding. The annual and monthly precipitation data series between 1901 and 1980 of the nearest gauge (Abaliget) provided knowledge on the precipitation conditions. Movements generally intensify in the winter half-year or more exactly following favourable weather situations in late autumn and early spring. Consequently, from October to March atmospheric precipitation is of utmost importance. Trends of change with the regression coefficient *a* are shown in *Table 1.*

Table 1 Trends of change of precipitation in the months of the winter half-year by the Abaliget gauge, 1901-1980

Oct.	Nov.	Dec.	Jan.	Febr.	March	Oct.-March
-0.28	0.51	0.18	0.16	0.12	-0.13	0.11

The precipitation values in the six months present a trend of increase (a_{O-M}=0.11). From the mid-1930s to the early 1960s a relatively more humid period is detected *(Fig. 5)*.

In the particular months further regularities are observed *(Fig. 6)*. Opposite trends are demonstrated for two of the autumn months. October gets slightly drier, while November gets much wetter. The rate of humidity change is about the same all through the winter months (December, January and February). In early spring (in March) the change towards aridity is of slower rate than in October. Within these trends characteristic periods of presumably major hydrological or geomorphological role are observed *(Fig. 6)*. Water storage in the karst clearly increased in volume from the mid-1920s until the mid-1960s. It seems likely that in this period water flow towards the Miocene strata, although with a time lag, has also increased and, consequently, landslides must have intensified too.

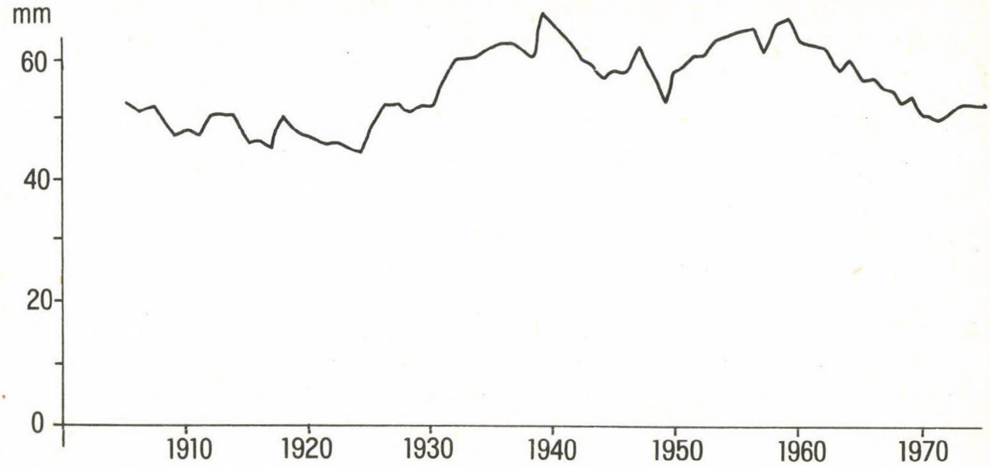

Fig. 5 Trend of average changes in precipitation in the period from October to March

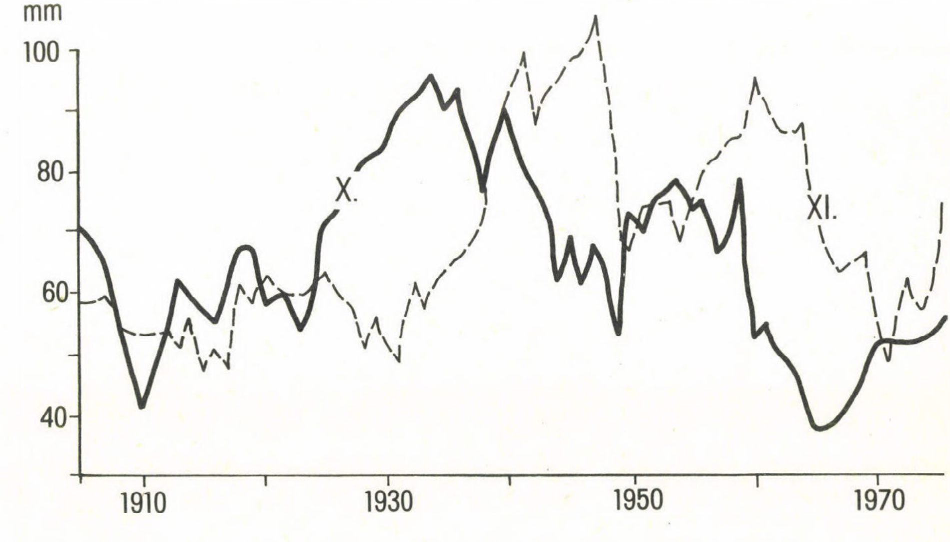

Fig. 6 Moving trend of changes in precipitation in October and November between 1901 and 1980

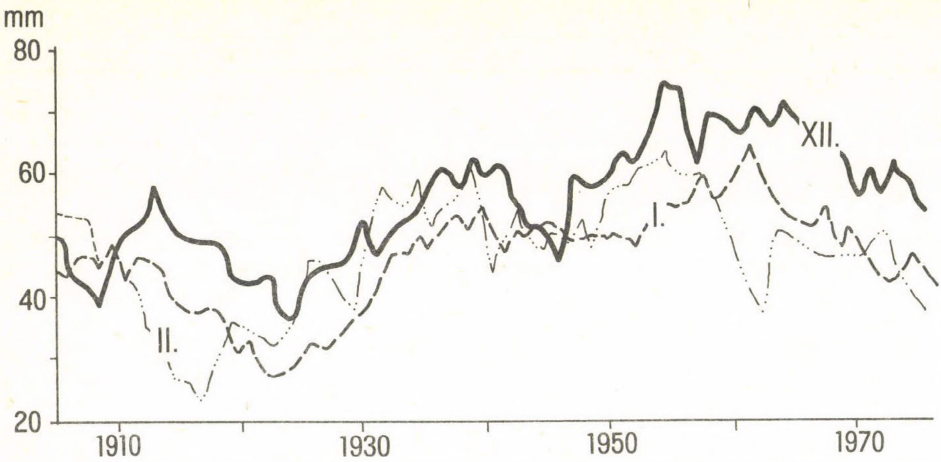

Fig. 7 Moving trend of changes in precipitation in December, January and February between 1901 and 1980

The date of maximum water storage gradually shifted from autumn to winter or early spring: feom the mid-1920s it was in October and by the 1940s it reached November; from the early 1950s to the mid-1960s it shifted through December, January and February to March. This conspicuous climatic trend was certainly manifest in the shifting of the date of maximum landslide intensity in time.

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MAPPING OF SLOPE EXPOSURE

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ABSTRACT

From the alignment of contours and the arrows indicating the direction of slope, the exposure of the surface can be easily read. The slopes in reality and on the map are inclined in uncountable directions between the primary cardinal points (N, S, E, and W) and the secondary ones (NE, SE, SW, and NW) of the compass. Therefore, degree intervals should be established (Table 1). In map construction, in accordance with the maps of slope categories for agricultural use in Hungary, slopes below 5 per cent angle are considered flat surfaces. On maps at scales smaller than 1:25,000 northerly (NW, N and NE), E, southerly (SE, S and SW) and W exposures can only be differentiated. The map of exposure is suitable to represent the spatial distribution of local or microclimates (otherwise expensive to determine). The special local climates remarkably influence recent geomorphic processes active on slopes and play an important role in snowmelt. Map information can be used in agricultural and settlement planning. The map of slope exposure can be digitized and included in a spatial data bank.

* * *

A primary target of geographical research is to reveal the properties of the total environment integrated of the physical and the socio-economic environment and to simulate the qualitative and quantitative interactions operating in it (ANUCHIN, V. A. 1964, CHAPMAN, I. D. 1966, LOVÁSZ, Gy. 1981, PÉCSI, M. 1979 and PÉCSI, M.-RÉTVÁRI, L. 1981).

Topography as an important component of the physical environment strongly influences other environmental phenomena. It exerts an indirect, but major effect on some socio-economic processes. Consequently, *relief research of special purpose can largely promote the understanding of the essence of socio-economic processes.*

METHOD OF MAPPING

The morphometric investigation of slope exposure as an element of relief supplies new data. Moreover, it urges the reformulation of the subject and methodology of morphometry.

The map representation of slope exposure has already been initiated and demonstrated (LOVÁSZ, Gy. 1968, LOVÁSZ, Gy.-SZÜCS, K. 1972). The description of the procedure for various scales and the means of further processing of mapped information and its theoretical and practical usefulness, however, have not yet been outlined. Map construction is based on the alignments of contours and the corresponding directions of slope. The N and S exposures, in the function of slope directions, are matched by contours of W to E strike, while NE and SW exposures are indicated by NW to SE contours, as a matter of course, depending on the direction of slope. Finally, W and E exposures are shown by N to S contours. Between the primary and the secondary cardinal points, there are uncountable transitional directions in reality. 'Pure' exposure is relatively rare. Therefore, the eight classes of exposure should also be given in degrees *(Table 1)*.

Table 1

Exposure	Degree interval
N (S)	337.5° - 22.5° (157.5° - 202.5°)
NE (SW)	22.5° - 67.5° (202.5° - 247.5°)
E (W)	67.5° -112.5° (247.5° - 292.5°)
NE (NW)	112.5° -157.5° (292.5° - 337.5°)

From these data an excellent aid to map construction can be compiled.

The *concept of exposure* is a point to be clarified through a certain compromise. It is defined as the position of slope exposed to any cardinal points and having a minimum angle of 5 per cent. The map of slope exposure belongs to the series of maps which reveal the factors and processes of the physical environment. This series also includes the representation of slope inclination where angles below 5 per cent are considered flat surfaces. In order to accomplish a unified way of representation, this rule is applied, although even a surface of 1 per cent angle can be obviously regarded a slope.

Lithology, structure and Plio-Pleistocene geomorphic evolution produced complicated spatial systems of exposure in many regions and map representation here needs some degree of compromise. In the Hungarian hilly regions of unconsolidated Plio-Pleistocene deposits and of low elevation, the hillslopes of valleys are generally gentle and interfluvial ridges grade into the valley-floor level. Here exposure should be indicated for the lowering head of the interfluvial ridge too, since it is considerable in area. The same applies to the valleys with broad head-valleys. In the case of abruptly terminating interfluvial ridges between deep and narrow valleys, however, the spots of different exposure between valley-walls are so insignificant in area that they can be neglected. In narrow head-valleys in high-elevated mountains or hills, in the majority of cases, the representation of the exposure of minor slopes is also avoided.

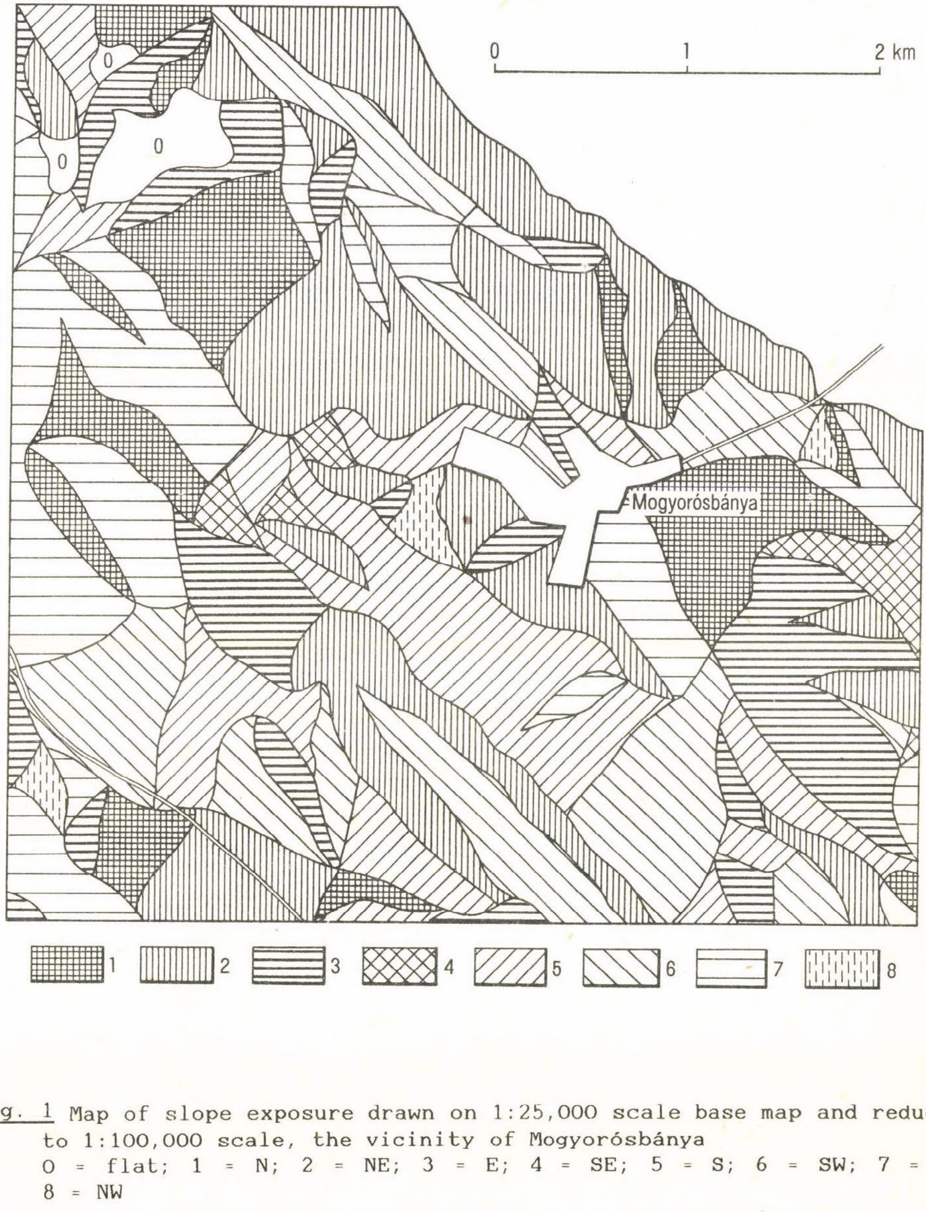

Fig. 1 Map of slope exposure drawn on 1:25,000 scale base map and reduced to 1:100,000 scale, the vicinity of Mogyorósbánya
0 = flat; 1 = N; 2 = NE; 3 = E; 4 = SE; 5 = S; 6 = SW; 7 = W; 8 = NW

It is common that extended slopes are dissected by erosion or derasion valleys or cirques of various size. The exposures or surfaces below a critical minimum value mentioned later are included by map generalization into the larger surfaces.

The number of classes of exposure is a function of scale. The previous experience proves that both the four primary and the four secondary cardinal points exposures can be shown on maps of 1:25,000 or larger (more detailed) scales. It is to be noted that *1:25,000 is a base map scale.* This basic variety can be reduced without much generalization down to 1:10,000 scale *(Fig 1)*. To this reduction the minimum represented area should be determined. The minimum width of spot is proposed to be about 250 m, while minimum length is suggested to be about 500 m. This size is discernible even at 1:100,000 scale. If any of the parameters of the areal spot is below this threshold value, the spot is left out. It should be emphasized again that these parameters are of subjective nature. They may be disregarded if it is required by the purpose of the investigation. If, however, the map is constructed on smaller scale base (for instance, at 1:100,000), certain generalization becomes necessary. Here the joint representation of northerly (NE, N and NW), southerly (SE, S and SW) and E and W exposure classes is suggested.

Much trouble is caused, in the spatial allocation of different exposures, irrespective of scale, by small surfaces of different exposures forming a contiguous area. In order to reflect reality relatively truely the special solutions in the key are suggested:

a. surface of mixed, predominantly northerly exposure;
b. surface of mixed, predominantly southerly exposure;
c. surface or mixed, predominantly E exposure;
d. surface of mixed, predominantly W exposure;
e. surface of mixed exposure.

'Predominant exposure' refers to a more than 50 per cent ratio of the indicated exposure in area.

THE EFFECTS OF EXPOSURE ON LOCAL AND MICROCLIMATE

The investigation of the spatial distribution of different exposures, first af all, contributes to the study of local or microclimates induced by relief. The meteorological network of Hungary is not suitable to give data for the description of local climates - it is not intended to serve this end. It is a fundamental problem that to reveal the types of local climates large-scale equipment, personnel and time of considerable length (several years or tens of years) would be necessary. General microclimate research, for these reasons, has not been launched neither in Hungary nor anywhere else in the world. The existing methods only allow the exploration of small areas (BÉLL, B.-TAKÁCS, L. eds. 1974). It is questionable whether the expenses and mental capacities invested are in proportion to the resulting scientific and practical achievements. The data series of measurements are usually too short and numerically formulated general laws can only be drawn within relatively broad limits. Therefore, for the typification of local climates great difficulties have to be overcome. This situation is remedied by the mapping of slope exposure.

Through the survey of exposure and its spatial distribution, the deviations in temperature from a flat surface (warmer or cooler) are primarily described. It is obvious though that air and soil temperature surplus or deficit does not only depend on exposure, but also on the corresponding slope inclination. On slopes steeper than 17 per cent local climatic modification reaches a remarkable level. *With slope angle and the above presented exposure classes integrated in space, a version can be constructed which shows the areal distribution of the exposures of slopes with more than 17 per cent.*

Consequently, two types of exposure maps exist. One shows the exposure and its spatial distribution for slopes above 5 per cent and the other for those above 17 per cent.

The differences in *air and soil temperatures* on slopes of different exposures are greatest in spring, autumn and winter. The radiation surplus or deficit compared to the flat surface is highest in these seasons.

The maps of exposure do not only provide indirect (non-numerical) data for air and soil temperature but also inform about *wind conditions* influenced by relief. Knowing the prevailing wind direction characteristic of the macroregion, luv and lee slopes are easy to differentiate. Our measurements also indicate major modifications of wind conditions, in function of slope angle, on slopes in wind shelter. While on a hilltop (stubble) at 220 m a.s.l. northerly wind of 8,5 m per s velocity (at 200 cm above surface) was measured, on a SSW slope of 18 per cent angle (stubble) velocity was reduced by 67 per cent at 50 cm above surface and by 86 per cent at 10 cm. At the same locality, in the case of 3.2 m per s northerly wind, velocity reduction was 83 per cent on the lee slope at 50 cm above surface and 96 per cent at 10 cm. In a NNW luv slope with stubble the stronger wind only moderated by 8 per cent at 60 cm and by 20 per cent at 10 cm. With the weaker air movement velocity was reduced by 18 per cent at 50 cm and by 31 per cent at 10 cm. One of the versions of exposure maps informs about the areal extension of this major reduction of velocity in wind shelter. The surfaces where reduction in wind velocity is hardly observed (consequently the hazard of wind damage is higher) can be represented in a similar way.

Temperature modification is naturally restricted to periods of undisturbed radiation conditions, while the changes in wind velocity occur on stormy days. Thus, the two phenomena, although represented on the same map, very rarely appear simultaneously. Vegetation is also a modifying factor. In forests the incidental modifications of air and soil temperatures and of air movements caused by exposure are almost comletely suppressed in the growing season. Stands of cultivated crops (e.g. grain-crops, maize and sunflower) largely modify the elements mentioned in about the last one-third of their growing seasons.

With regard to all these facts, the *map of slope climate* can be drawn which gives some information on the two governing elements (near-surface air temperature and subsurface soil temperature) as well as on general wind conditions compared to the flat surface. This integrated version can be constructed, as experience to date suggests, at scales of 1:25,000 and above, in an approximate way.

Based on differences in slope angle and exposure, the following types of slope climate can be identified:

1. Moderalety warm - southerly slopes below 17 per cent angle;
2. Warm, in wind shelter - SE, S slopes above 17 per cent angle, assuming, as a matter of course, N or NW wind;
3. Moderately cool - northerly slopes gentler than 17 per cent;
4. Cool and windy - northerly slopes above 17 per cent angle.

W and E slopes are primarily classified according to air movement conditions.

5. Windy - E exposed slopes above 17 per cent angle;
6. In wind shelter - W slopes above 17 per cent angle.

The above categories, however, must not be conceived as strict rules. Measurements were made on two E exposed slopes at 9.4 m per s W wind. One of them had a broad valley-floor in its foreground which presented no obstacle to air movement. The other was situated 1.5 km to the E, but in front of it a ridge of N to S strike rose to 80 m relative height. As a consequence of the topographic obstacle in the case of the latter E exposure 50 per cent reduction in velocity is observed at 200 cm in relation to the 'open' position. All these underline that in the delimitation and description of types the relief configuration of the broader surroundings is also to be taken into account.

The influences of slope climates of exposural origin on some physical ecological factors are seasonal or occasional and, consequently, they are to be considered in several investigations in the earth sciences.

THE EFFECTS OF EXPOSURE ON GEOMORPHIC EVOLUTION AND WATER BUDGET

The research into the nature and spatial distribution of *recent erosional processes* has more and more come into the fore in geomorphology. This study has far-reaching links with engineering geomorphology and environmental protection. The types and intensity of recent erosional processes active in a given area are partly controlled by the present topography (e.g. slope inclination and local climates belonging to the individual exposure). Topography basically regulates runoff ratio which may result in erosion or derasion processes. The geomorphic processes on slopes are also highly dependent on the local climate. Therefore, *maps of exposure can be used in the interpretation of geomorphic processes in microregions, too.*

Regarding one of the main problems of *hydrological* and *agroecological* research, the ratio of atmospheric precipitation used by plants, *snowmelt* is of great importance. The intensity

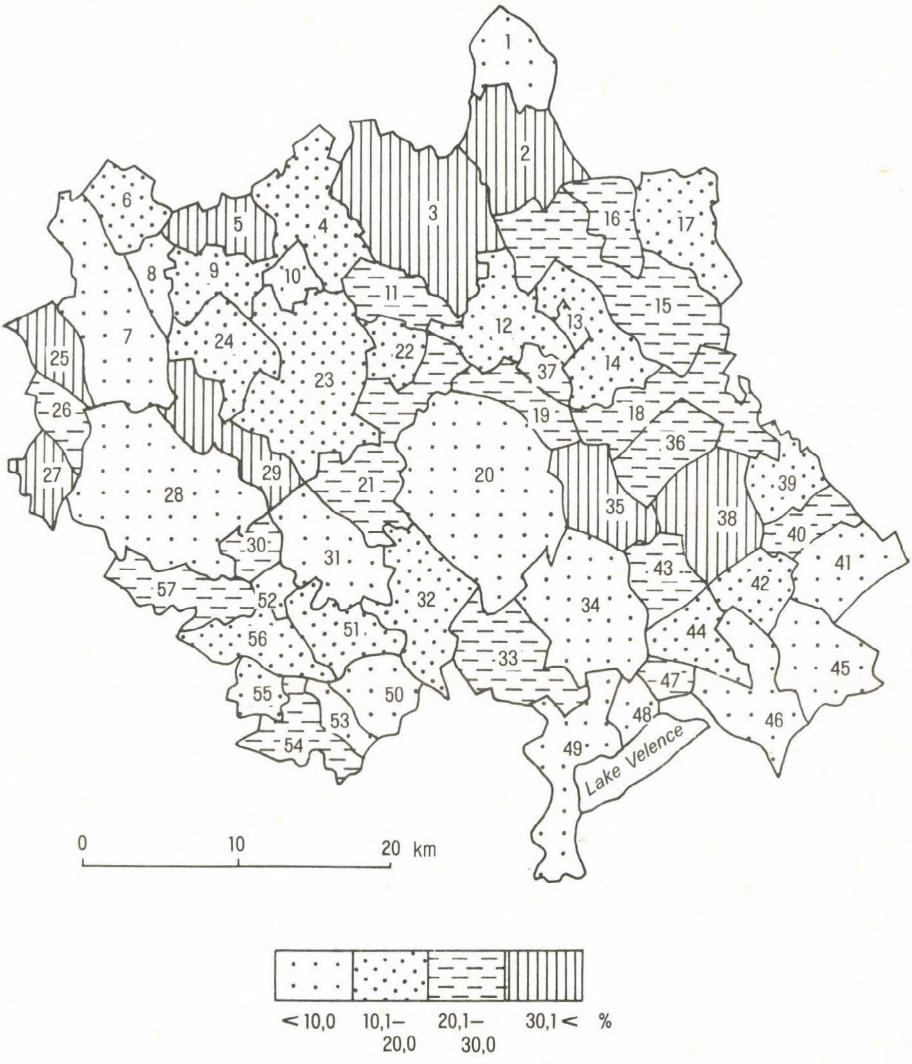

Fig. 2 Percentage of surfaces of northerly exposures in agricultural land

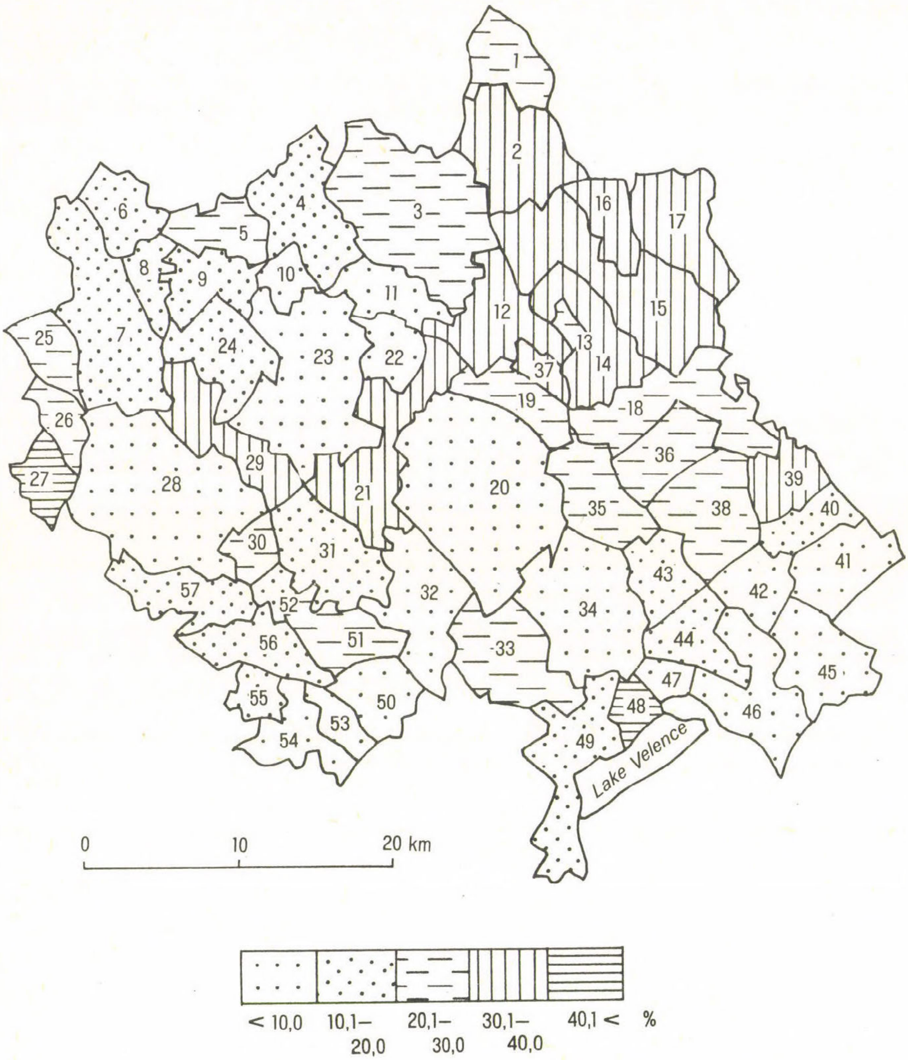

Fig. 3 Percentage of surfaces of southerly exposure in agricultural land

Fig. 4 Percentage of surfaces of easterly exposure in agricultural land

Fig. 5 Percentage of surfaces of westerly exposure in agricultural land

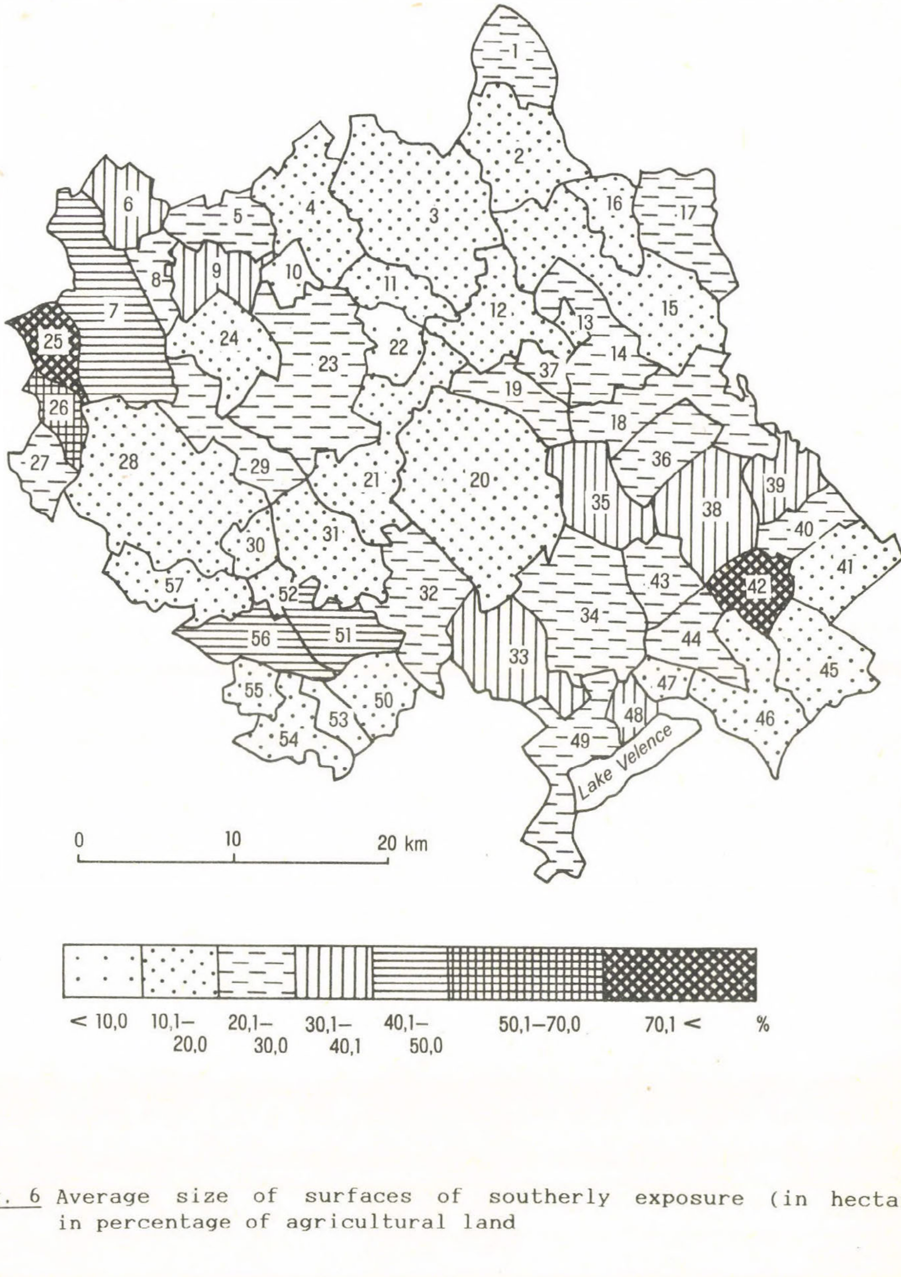

Fig. 6 Average size of surfaces of southerly exposure (in hectares) in percentage of agricultural land

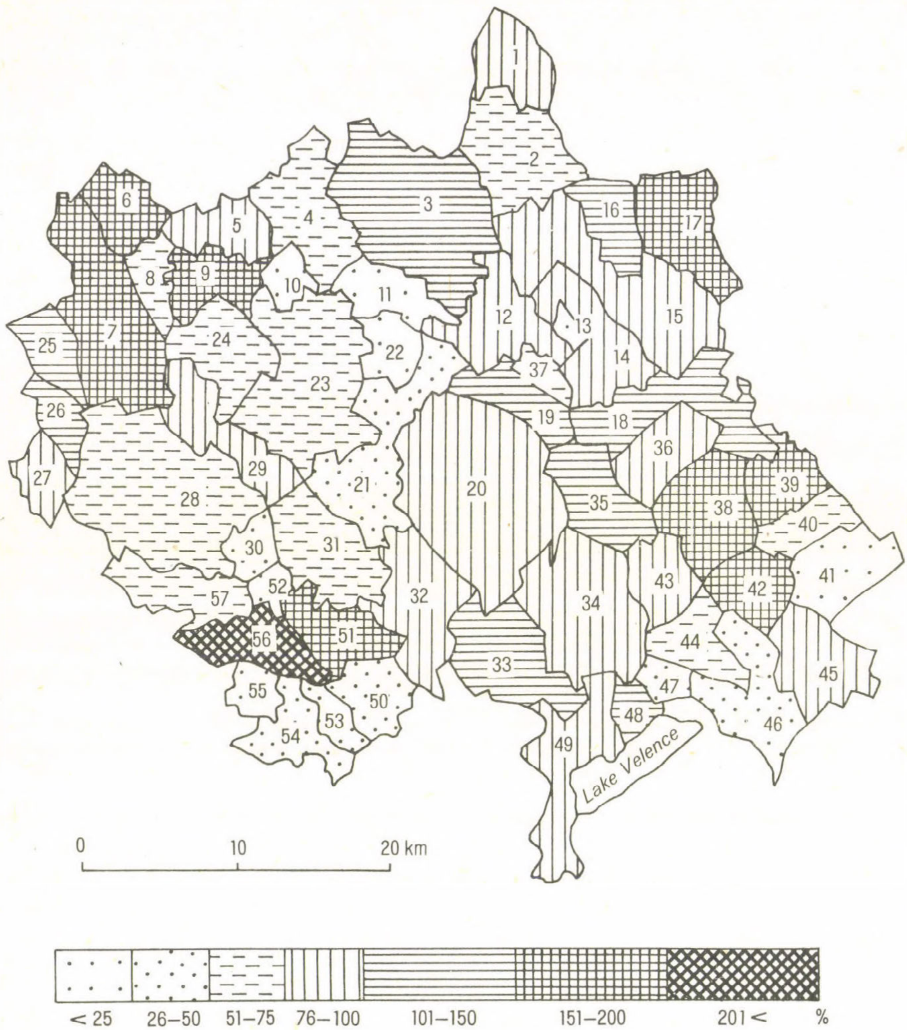

Fig. 7 Maximum size of surfaces of southerly exposure (in hectares)

and frequency of snowmelt depends on slope inclination and direction. It is more frequent and intensive under the weather conditions of slopes of southerly exposure. Indirectly, the water budget of soils is also influenced. The surplus or deficit of soil temperature resulting from exposure also affects the date of sowing and the development of plants. If a certain exposure and slope inclination are coupled with a particular geologic structure, soils are made liable to dry out.

The types of local climates of exposural origin and their spatial distribution promote the regional optimatization of agriculture.

THE ROLE OF THE MAPPING OF EXPOSURE IN SETTLEMENT DEVELOPMENT PLANNING

Due to the specialization of agriculture, in the planning of optimal crop pattern interest has grown in the knowledge of the areal ratios of slopes of different exposure. The data were processed for administrative units (*Figs 2-5*) and areas are distinct where the percentage of one exposure or the other is high or insignificant. For instance, the group of villages where surfaces of southerly exposure have relatively high percentages in area can be distinguished on the map.

In another variety of processing base map information, the average size of the surfaces of similar exposure can be expressed in hectares (*Fig. 6*). It is a direct indication of the areal distribution of the individual exposures. Within the limits of a village, where the size of area and dissection allow, the data base of average value calculation can also be analyzed statistically. The frequency distribution curve for the individual exposures can be drawn and the standard deviations of the most frequent size and average values.

Within the limits of villages surfaces of similar exposure occur in several spots of various size. To represent the largest spot independently is of interest for large-scale farming, since the slope climate characteristic of the given exposure is formed in the largest homogeneous area (*Fig. 7*).

The mapping of slope exposure is a part of the preliminary scientific research founding the *planning of settlement development* (GABOS, Gy. 1979). Through its local climatic effect, this topographic factors has psychological and hygienic functions in settlements. For this purpose, as a matter of fact, mapping at large scales (1:25,000, 1:10,000 or 1:5,000) is most appropriate, since it is truest to reality (LOVÁSZ, Gy. 1983). These investigations also form an organic part of engineering geomorphological research.

It can be concluded that *the spatial analysis of exposure as a factor contributing to special local climates promotes a better understanding of a renewing natural resource.*

As map representation is the best way to show the results, *mapped data may become integrated into a regional data bank.* The information from large-scale survey organized into an information grid can be used for several purposes in regional development (KLINGHAMMER, I.-PAPP-VÁRY, Á. 1973. HÖNA, E. 1977). The spatial patterns mapped can be also included into the automated integrated assessment of environmental quality.

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