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KUTI

agrogeology

László Kuti

Agrogeology

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Agrogeology

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GENERAL ASPECTS OF AGROGEOLOGY

One of the most important components of today's policy of living standard is food economy especially its agricultural sector. It is expected to satisfy the progressively growing needs of the society to the highest possible extent at a time when the advance of civilisation factors (urbanisation, traffic, and industrialisation) occupies relevant farmlands and gradually stricter environmental protection regulations must also be met. These tasks can only be performed by a well-organised agriculture of high professional level taking unequivocally into account the optimal use of the potentials of the specific land.

High-level mechanisation and ideal organisation of work are insufficient to the qualitative use of farmlands but the results of scientific investigations must also consciously be applied.

Agrogeology today

Agrogeology is one of the research sectors of applied geology. It addresses all geological characteristics of the superficial deposits and the related geological processes taking place therein which are of crucial importance regarding agricultural production and sylviculture, influence the plantation of crops and woods and provide information on a number of factors including the sequences constituting the soil, soil forming sediments and parent rocks, the position and quality of groundwater, the salt regime governed by groundwater movement as well as the natural and manmade changes in the regions below the soil horizon affecting the surface as well (after KUTI 1977).

Accordingly, it investigates not only the sediment appearing on the surface and affected by soil development (=soil) but all near-surface sequences taken together as well as the relationship between soil–parent material–groundwater in lowlands and soil–soil forming sediment and parent rock in mountain and hilly areas. Furthermore, it examines also the changes of these systems as a result of human intervention and makes predictions concerning the advantageous or disadvantageous effects of these changes.

Consequently, the most important tasks of agrogeology can be defined as follows:

1. Detailed agrogeological description and specification of farmlands and land units aimed at optimal land use as well as supporting the rational selection of crops and the production system.
2. Investigation of the geological factors of different soil degradation processes (erosion, deflation, salinisation, acidification, desiccation, etc.), prediction of the occurrence of these processes together with the geological chances of their prevention and minimisation.
3. Examination of the agrogeological and water regime properties of the soil–(soil forming sediment)–parent rock–groundwater system characteristic for the given land unit.
4. Research, survey, simulation and prediction of the impacts of soil use as well as agri- and sylviculture on the soil–(soil forming sediment)–parent rock–groundwater or „soil–parent rock–bedrock" system aimed at the prevention and elimination of harmful effects.
5. Investigation of the geological aspects of water regulation and irrigation as well as their impact on the environment.
6. Definition, examination and characterisation of the real soil forming geological sequence.

Searching for international studies of agrogeological investigations it can be stated that the term is used quite rarely and in different concept than in Hungary. Most of the publications that we studied are devoted to investigations aimed at the use of geological information for the research and examination of raw materials appropriate for soil improvement (CHESWORTH et al. 1989, VAN STRAATEN and FERNANDES 1995, VAN STRAATEN 2002).

In Hungary the actual agrogeological investigations were launched by the agricultural reambulation of geological mapping data. However, it turned out quite rapidly that it was not enough. In order to support methodological research it is necessary to investigate some comparatively small areas suitable to focusing on the detailed examination of a specific problem. The establishment of the research system of pilot areas was aimed to meet this objective (Figure 1).

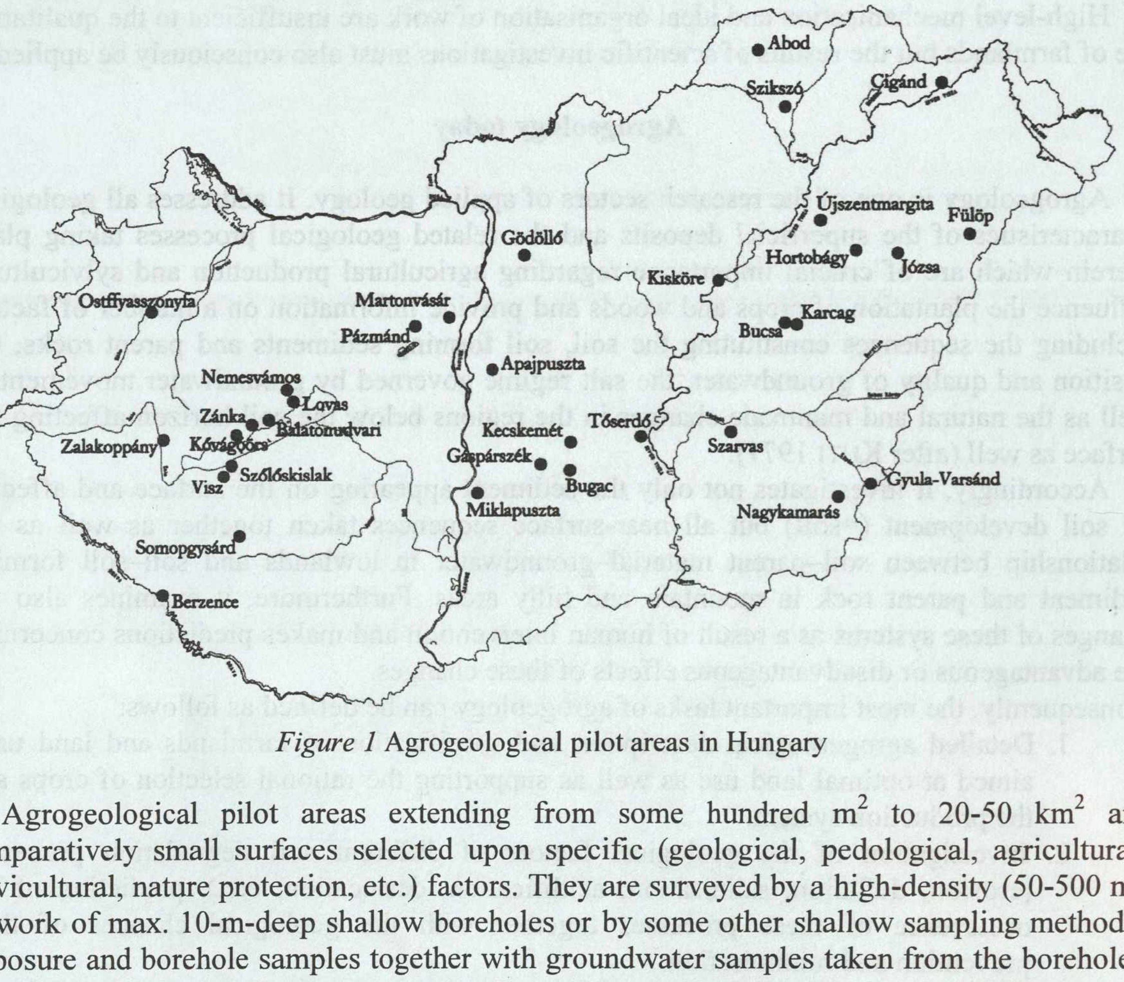


Figure 1 Agrogeological pilot areas in Hungary

Agrogeological pilot areas extending from some hundred m^2 to 20-50 km^2 are comparatively small surfaces selected upon specific (geological, pedological, agricultural, sylvicultural, nature protection, etc.) factors. They are surveyed by a high-density (50-500 m) network of max. 10-m-deep shallow boreholes or by some other shallow sampling methods. Exposure and borehole samples together with groundwater samples taken from the boreholes are subjected to detailed laboratory tests. During the early 1980s the so-called BFK-method was elaborated to the agrogeological investigation of these areas still used today. The main aspect of this method is that apart from the common geological sampling of the boreholes samples are also taken from the top- and subsoil (horizon 1), the soil forming sediment or parent material (horizon 2), the fluctuation zone of the groundwater (horizon 3) as well as from the zone permanently below the groundwater level (horizon 4) and the groundwater itself (Figure 2). These samples undergo detailed laboratory analyses. The comparative evaluation of the derived results allows making different agrogeological conclusions.

The method elaborated initially for studying geochemical relationships showed unambiguously that the knowledge of the soil itself is insufficient for the agrogeological evaluation of an area but it is necessary to know the superficial–near-surface sequence together with the groundwater moving therein down to the zone permanently below the groundwater level (green line) but at least to the depth of 10 m below the surface.

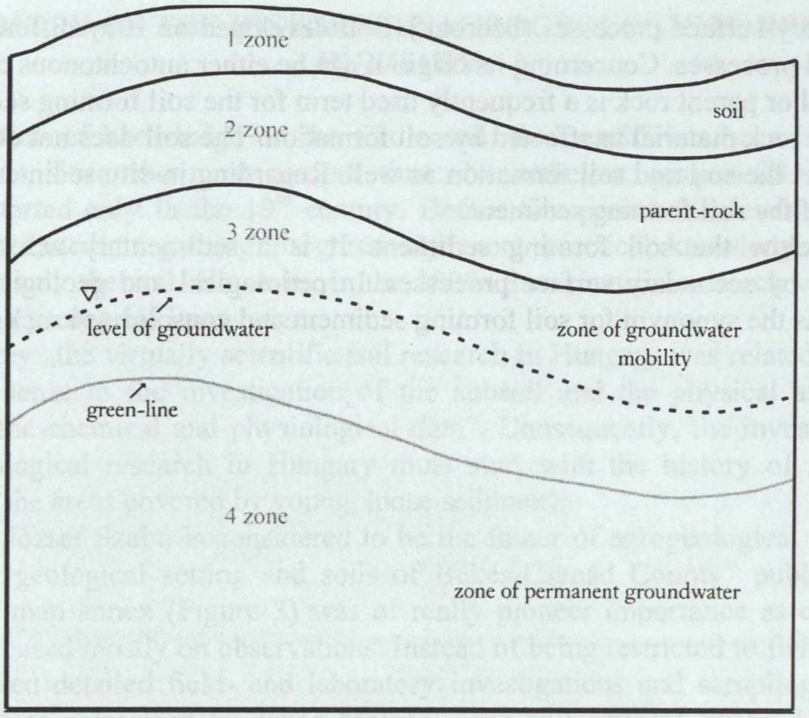


Figure 2 The soil–parent material–groundwater system (BFK horizons)

During the period elapsed from the early 1980s the survey of the pilot areas allowed us investigating among others the agrogeological relationships of salinisation, acidification, excess water risk, erosion, and trace element regime (Kuti and Tullner 1994) as well as vine chlorosis.

Frequently used basic terms in agrogeology

Loose sediment is the not diagenised or slightly diagenised aggregation of solid grains (clastic grains, colloids) or real solutions in which the grains are packed loosely next to each other and they can easily be separated by moderate mechanical effects (for instance friction by finger) or liquid. The voids between the grains or between the specific components of some biogenic sediments (pores) or the internal caverns of the shells of biogenic elements are filled with liquid or gas. Their formation of loose sediments is due to geological, physical, chemical or biological processes in which plant- and animal organisms can take a considerable part. Concerning their origin they can by volcanic, clastic, chemical, biogenic or organic. They can form in-situ, they can also be transported by some medium (water, ice and wind) or redeposited by gravitational processes.

Regolith is the commonly used term of the topmost, weathered crust of the lithosphere, the assemblage of the clastic sediments above the solid rock. Its most external part mixed with organic matter is called soil (after Balogh et al. 1991 and McQueen 2008).

Sedimentary rock is the solid material formed of loose sediments by diagenesis.

The soil is the most external solid crust of the Earth serving as the basis for plant growth (Stefanovits 1975). Under soil fertility it is understood that the soil provides the plants established thereon (in broader sense together with the organisms living therein) with water and nutrients in due time and amount (Szendrei 1998). The fertility of a specific soil is the function of the geological medium in which it forms.

Soil forming sediment is the loose superficial sediment that is the uppermost sequence of the superficial–near-surface assemblage in lowland- and hilly regions; whereas in mountain areas it is the topmost deposit of the sedimentary assemblage above the rock unaffected by secondary surface processes (bedrock). Soil developed on it by different soil forming factors and processes. Concerning its origin it can be either autochtonous or allochtonous.

Parent material or parent rock is a frequently used term for the soil forming sediment.

Bedrock is the rock material unaffected by soil formation. The soil does not derive from it but it can affect the soil and soil formation as well. Regarding in-situ sediments it is the rock of origin of the soil forming sediment.

Bedrock is below the soil forming sediment. It is a sedimentary assemblage or rock unaffected by secondary surface processes. In pedological and geological practice it is also used as the synonym for soil forming sediment and consolidated rock, respectively.

BRIEF SUMMARY OF THE HISTORY OF AGROGEOLOGICAL RESEARCH IN HUNGARY

The acquisition of knowledge on the fertile soil, the „earth" has been in the focus of attention of man since the most ancient time. Nevertheless, purposeful agrogeological investigations started only in the 19th century. Before that period the development of crop production contributed to gaining progressively more practical knowledge by man that concerned decisively the soil. However, in the 1800s the scientific research was also aimed already at getting geological knowledge.

After B. Inkey „the virtually scientific soil research in Hungary was related earlier and in more common sense to the investigation of the subsoil and the physical and geographic setting than to the chemical and physiological data". Consequently, the investigation of the history of pedological research in Hungary must start with the history of the geological investigation of the areas covered by young, loose sediments.

In Hungary József Szabó is considered to be the father of agrogeological investigations. His work „The geological setting and soils of Békés-Csanád County" published in 1861 together with a map annex (Figure 3) was of really pioneer importance as compared with previous works based mostly on observations. Instead of being restricted to field observations this work featured detailed field- and laboratory investigations and sampling as well. The laboratory analyses performed by János Molnár – the colleague of Szabó J. – stand their ground still today. The important feature of their investigation is that apart from dealing with different soils and sediments their study was extended to the observation of groundwater concerning its depth (KUTI et al. 2002b) and chemical composition in the existing wells.

Following this initial work the team of József Szabó extended its studies to three new areas. They conducted investigations of similar detail in Hegyalja, Heves and Szolnok counties as well as in the surroundings of Bugyi village.

Afterwards, agrogeological studies were put to a halt only to be relaunched some decades later again by the urging of J. Szabó.

In 1886 J. Szabó pressed on the pedological investigation of the country in the Geological Society in the frame of a national geological mapping. Referring to this lecture János Böckh, the director of the Geological Institute was able – after several attempts – to achieve the establishment of the „agronomic-geological" department of the institute. Béla Inkey, the already renowned geologist and land owner was appointed its chief while Péter Treitz, professor of the agricultural college in Magyaróvár became his associate. They both started their work with learning.

During his study tour in the summer of 1891 Inkey visited the geological institutes in Berlin, Leipzig, Heidelberg and Strasbourg where he got acquainted with the methodology and the organisation of lowland mapping and the laboratory works. It was not, however, enough for him. Being a field geologist to the core he accepts the courteous invitation of the German colleagues and goes working with them into the field to get know the practice of agrogeological mapping as well.

In his return to Hungary he summarises his experiences in a report in which he considers the geological basis to be of crucial importance in the knowledge of soils: he states that *„the knowledge of the soil is raised to a really scientific level only if it rests definitively on geology"* and describes the sequence of studies extending from the geological basis to the agricultural utilisation. In his report he defines the method and guidelines of agrogeological mapping as follows:

„First, the necessary basis is provided by topographic mapping representing the relief of the region and the distribution of its surface waters as well.

It is followed by the geological mapping aimed at the investigation of the quality, age, origin and structure of the rocks. It has to be noted that the geological mapping results normally in a map on which the subsoil or more precisely the mosaic-like pattern of different rocks forming the basis of the soil appears without the topsoil cover, whereas the structure and the relationship of the sequences and assemblages can essentially be understood by means of the geological sections annexed and the explanatory text.

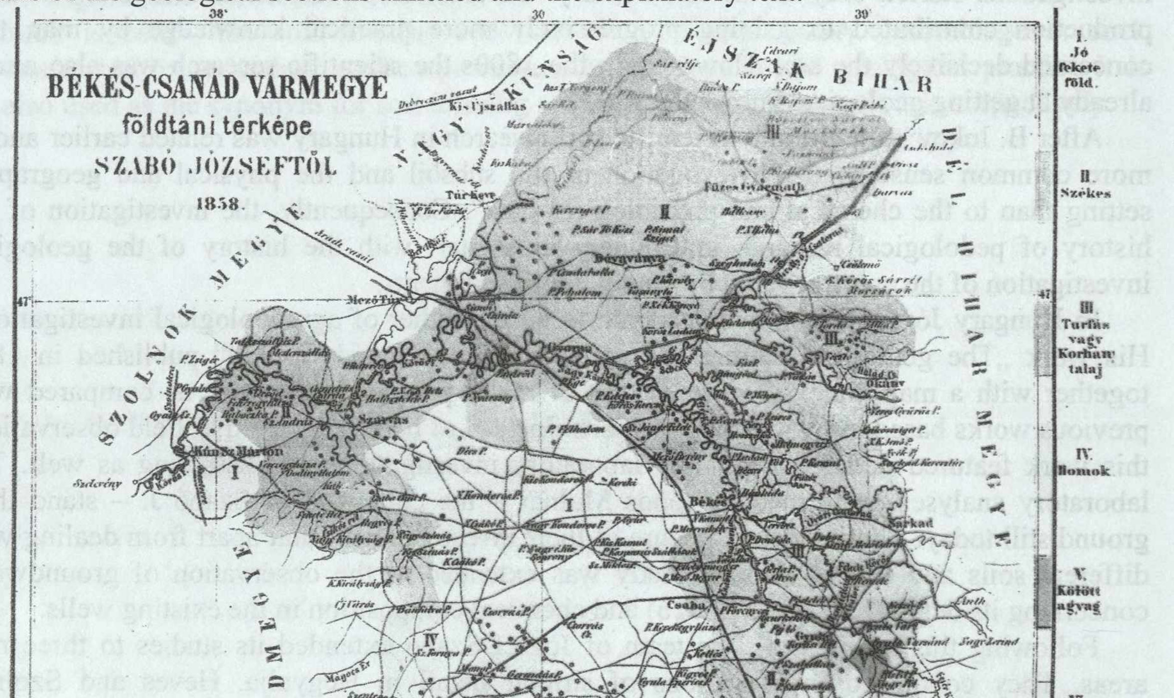


Figure 3 The geological map of Békés-Csanád County, József Szabó (1861)

The third step is the soil mapping which – as we saw on the Prussian examples – separates different types of soils and – instead of eliminating – it indicates the picture of the geological basis, for its scientific value lies in representing their relationship.

The scientific study of the soil does not stop at this point however, the further analysis of the material collected by the geologist is still ahead in compliance with the procedures applied in the Prussian institute including the mechanical and chemical tests, etc. These procedures are so closely associated with the mapping of which they derive and which they complete that their performance must be entrusted – if not exclusively but basically – to the mapping expert. He has to prepare the material for analysis and show the direction and aim of the analysis to the chemist.

Now that

1. the geological basis and consequently the origin
2. the distribution and structure of the types
3. the texture, physical characteristics and composition

of the soils of a given region have been defined — the requirements of the farming practice can be considered in order to utilise the acquired knowledge for the improvement of agricultural practice. It must be noted that this issue is not the responsibility of the geologist studying the soil any more; this is already the task of qualified farmers themselves and professionals of economic sciences. The investigation of the geologist stops at specifying the soil properties. The effect of these characteristics on plant life i.e. on the growth of the produced cultures is studied already by other scientific sectors and again others, namely the land owners must be committed to draw the practical conclusions and to apply the procedures for soil improvement."

Still in the first year after returning from Germany B. Inkey prepares his first agrogeological map of the region of Pusztaszentlőrinc in Pest County (Figure 4). In compliance with the knowledge acquired during his study tour he illustrates the superficial sequences together with the near-surface deposits and the soils on the map.

Figure 4 Geological map of the region of Pusztaszentlőrinc, the first agrogeological map of Béla Inkey, 1891

Afterwards, agrogeological maps are compiled during another four years, mainly of the area of the Great Hungarian Plain. Later the studies are expanded to other regions of the country as well (Figure 5) while the department grows progressively in number.

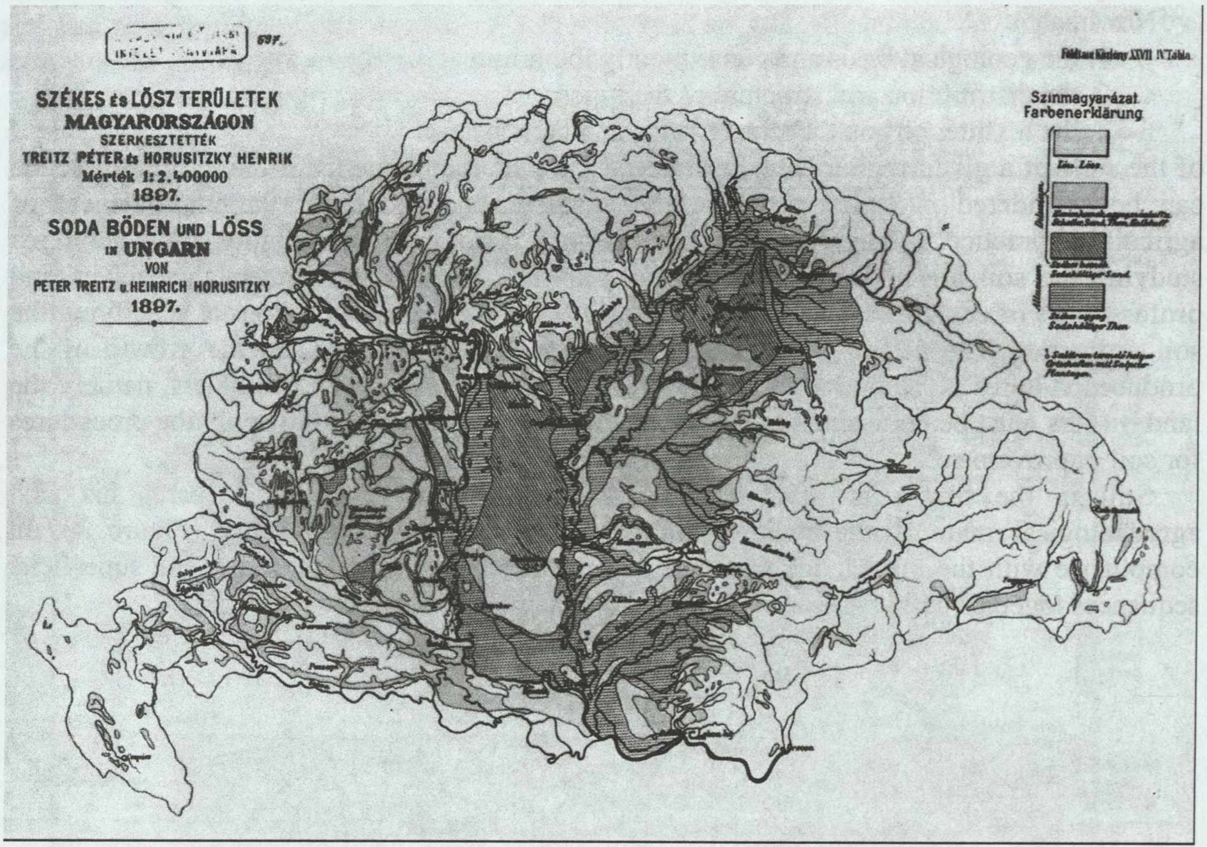


Figure 5 The first agrogeological map covering the whole area of Hungary: Alkaline and loess areas in Hungary, Péter Treitz and Henrik Horusitzky (1897)

During the work Inkey recognised, however, the mistake of his basic concept and realised that the whole country cannot be mapped starting from some small areas (land properties). The overview map of the country must be prepared first and the detailed study of smaller areas can only follow thereafter. As a result he submits a memorandum to the minister of agriculture pointing out the need for preparing the pedological overview map of the country and requests for authorisation to start with the work. His request is met, however, with incomprehension and following the recommendation of the Geological Institute's directorate it is dismissed by the minister insisting on continuing the work according to the methods of the Prussian geological institute. Inkey resigns as chief of department but agrogeological investigations go on in a direction progressively detached of geology with independent pedological priorities. The department grows with new forces.

B. Inkey thought that the turning point in the history of agrogeological investigations in Hungary occurred in the year of 1909 when the first agrogeological session took place in Budapest. It was due to a considerable extent to the relations established with Russian and Rumanian experts. Péter Treitz had the opinion by then that the Russian approach correspond much more to the Hungarian conditions than the Prussian one, since the climate of North Germany and Hungary is quite different. This concept gained further ground by the fact that the Russian approach was met with growing acceptance in other countries as well.

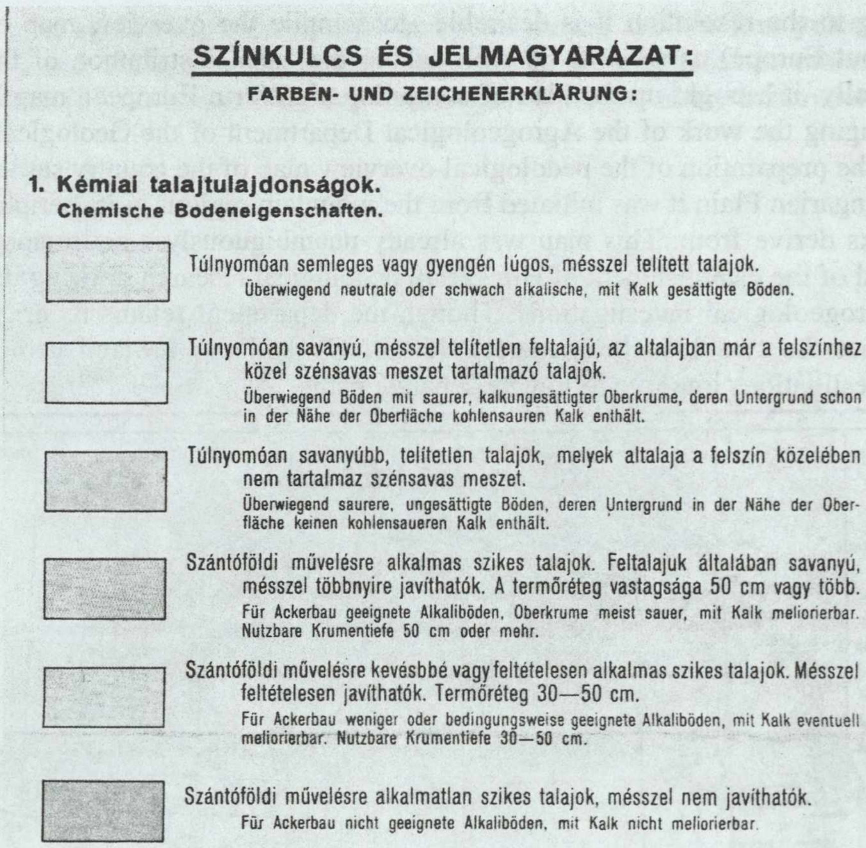
One of the most important result of the agrogeological conference was the resolution – giving subsequently right to Inkey – emphasising the importance of the pedological overview map. According to the resolution it is desirable „to compile the overview map of the soil types (throughout Europe) as soon as possible taking the zonal distribution of the soils in account". Virtually, it brought up the idea of compiling a uniform European map but it also resulted in changing the work of the Agrogeological Department of the Geological Institute. Consequently, the preparation of the pedological overview map of the country started. Instead of the Great Hungarian Plain it was initiated from the mountain regions in its periphery where the plain's rocks derive from. This map was already unambiguously a soil map. It marked virtually the end of the establishment of Hungarian pedological research drawing its origin of the bases of agrogeological investigations. Though the department retains its original name still for long but the two branches separate definitively and the lowland geological and pedological investigations improve following separate paths.

Figure 6 Climate zonal pedological map of Hungary by Péter Treitz

In the 1930s a new mapping work was initiated lead by Lajos Kreybig with very sophisticated professional preparatory works and compilation of test maps. Detailed sampling and the sophisticated laboratory analyses of the collected samples were the most important virtues of the 1:25 000 map series. The data of at least one exposure were available for the mapping staff from each km^2 of the country.

These maps were not unambiguously geological maps any more, but they have not yet been virtually pedological ones either. They illustrated pedological and land use features (e. g. cultivated areas, areas of seasonal water cover, forests, lakes, reeds, rivers, settlements) together (Figures 7, 8, 9 and 10). Several soil profiles belonged to the soil polygons of the map, one of them was representative. These profiles indicated the heterogeneity of the given area.

World War brought the mapping activities to an end. Unfortunately, it scattered the scientific staff shaken together during the work including most of the scientific material as well.



SZÍNKULCS ÉS JELMAGYARÁZAT:

FARBEN- UND ZEICHENERKLÄRUNG:

1. Kémiai talajtulajdonságok.
Chemische Bodeneigenschaften.

▭ Túlnyomóan semleges vagy gyengén lúgos, mésszel telített talajok.
Überwiegend neutrale oder schwach alkalische, mit Kalk gesättigte Böden.

▭ Túlnyomóan savanyú, mésszel telítetlen feltalajú, az altalajban már a felszínhez közel szénsavas meszet tartalmazó talajok.
Überwiegend Böden mit saurer, kalkungesättigter Oberkrume, deren Untergrund schon in der Nähe der Oberfläche kohlensauren Kalk enthält.

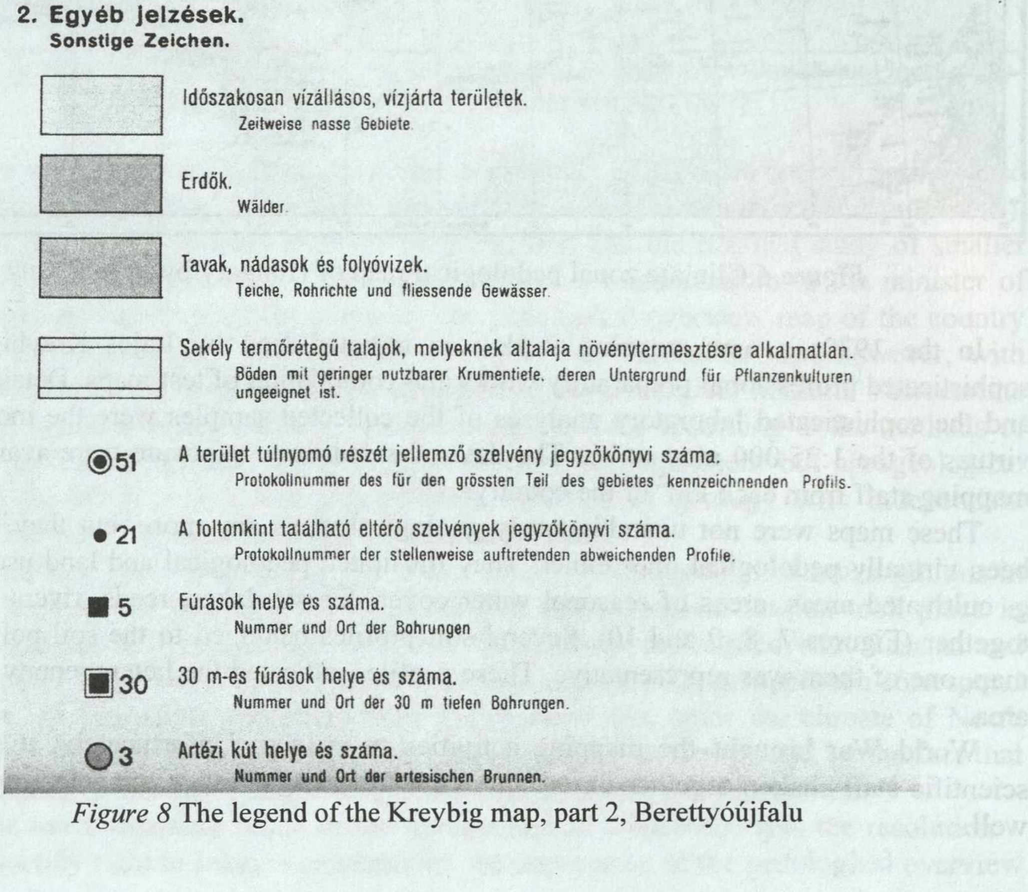
▨ Túlnyomóan savanyúbb, telítetlen talajok, melyek altalaja a felszín közelében nem tartalmaz szénsavas meszet.
Überwiegend saurere, ungesättigte Böden, deren Untergrund in der Nähe der Oberfläche keinen kohlensaueren Kalk enthält.

▨ Szántóföldi művelésre alkalmas szikes talajok. Feltalajuk általában savanyú, mésszel többnyire javíthatók. A termőréteg vastagsága 50 cm vagy több.
Für Ackerbau geeignete Alkaliböden, Oberkrume meist sauer, mit Kalk meliorierbar. Nutzbare Krumentiefe 50 cm oder mehr.

▨ Szántóföldi művelésre kevésbbé vagy feltételesen alkalmas szikes talajok. Mésszel feltételesen javíthatók. Termőréteg 30—50 cm.
Für Ackerbau weniger oder bedingungsweise geeignete Alkaliböden, mit Kalk eventuell meliorierbar. Nutzbare Krumentiefe 30—50 cm.

▨ Szántóföldi művelésre alkalmatlan szikes talajok, mésszel nem javíthatók.
Für Ackerbau nicht geeignete Alkaliböden, mit Kalk nicht meliorierbar.

Figure 7 The legend of the Kreybig map, part 1, Berettyóújfalu



2. Egyéb jelzések.
Sonstige Zeichen.

▭ Időszakosan vízállásos, vízjárta területek.
Zeitweise nasse Gebiete.

▨ Erdők.
Wälder.

▨ Tavak, nádasok és folyóvizek.
Teiche, Rohrichte und fliessende Gewässer.

▭ Sekély termőrétegű talajok, melyeknek altalaja növénytermesztésre alkalmatlan.
Böden mit geringer nutzbarer Krumentiefe, deren Untergrund für Pflanzenkulturen ungeeignet ist.

◉51 A terület túlnyomó részét jellemző szelvény jegyzőkönyvi száma.
Protokollnummer des für den grössten Teil des gebietes kennzeichnenden Profils.

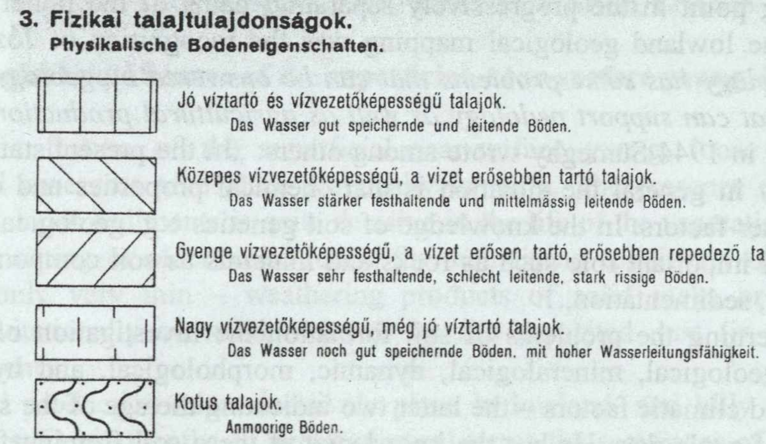
● 21 A foltonkint található eltérő szelvények jegyzőkönyvi száma.
Protokollnummer der stellenweise auftretenden abweichenden Profile.

■ 5 Fúrások helye és száma.
Nummer und Ort der Bohrungen

▣30 30 m-es fúrások helye és száma.
Nummer und Ort der 30 m tiefen Bohrungen.

●3 Artézi kút helye és száma.
Nummer und Ort der artesischen Brunnen.

Figure 8 The legend of the Kreybig map, part 2, Berettyóújfalu



3. Fizikai talajtulajdonságok.
Physikalische Bodeneigenschaften.

Jó víztartó és vízvezetőképességű talajok.
Das Wasser gut speichernde und leitende Böden.

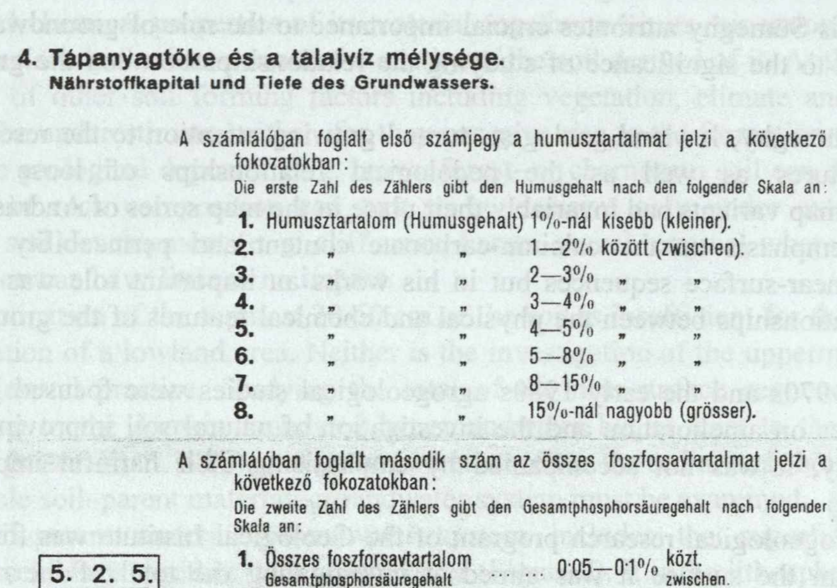
Közepes vízvezetőképességű, a vizet erősebben tartó talajok.
Das Wasser stärker festhaltende und mittelmässig leitende Böden.

Gyenge vízvezetőképességű, a vizet erősen tartó, erősebben repedező talajok.
Das Wasser sehr festhaltende, schlecht leitende, stark rissige Böden.

Nagy vízvezetőképességű, még jó víztartó talajok.
Das Wasser noch gut speichernde Böden. mit hoher Wasserleitungsfähigkeit.

Kotus talajok.
Anmoorige Böden.

Figure 9 The legend of the Kreybig map, part 3, Berettyóújfalu



4. Tápanyagtőke és a talajvíz mélysége.
Nährstoffkapital und Tiefe des Grundwassers.

A számlálóban foglalt első számjegy a humusztartalmat jelzi a következő fokozatokban:
Die erste Zahl des Zählers gibt den Humusgehalt nach den folgender Skala an:

1. Humusztartalom (Humusgehalt) 1%-nál kisebb (kleiner).
2. „ „ 1—2% között (zwischen).
3. „ „ 2—3% „ „
4. „ „ 3—4% „ „
5. „ „ 4—5% „ „
6. „ „ 5—8% „ „
7. „ „ 8—15% „ „
8. „ „ 15%-nál nagyobb (grösser).

A számlálóban foglalt második szám az összes foszforsavtartalmat jelzi a következő fokozatokban:
Die zweite Zahl des Zählers gibt den Gesamtphosphorsäuregehalt nach folgender Skala an:

$\boxed{\frac{5.\ 2.\ 5.}{30\text{-}60,\ 4.}}$

1. Összes foszforsavtartalom Gesamtphosphorsäuregehalt … … 0·05—0·1% közt. zwischen.
2. „ „ … … 0·1—0·15% „
3. „ „ … … 0·15—0·2% „
4. „ „ … … 0·2—0·3% „
5. „ „ … … 0·3%-nál nagyobb. grösser.

A számlálóban foglalt harmadik szám az összes káliumoxid-tartalmat jelzi a foszforsavra megadott fokozatokban.
Die dritte Zahl des Zählers gibt den gesamten K_2O-Gehalt nach der für den Gesamtphosphorsäuregehalt angegebenen Skala an.

A nevezőben foglalt első két szám a humuszréteg vastagságának határait jelzi cm-ben.
Die ersten zwei Zahlen des Nenners geben die untere und obere Grenze der Mächtigkeit der Humusschicht in cm an.

A nevező utolsó számjegye a talajvízszint mélységét jelzi méterekben.
Die letzte Zahl des Nenners gibt die Tiefe des Grundwasserspiegels in m an.

Az első római számjegy az illető területen előforduló talajnemet, a második a főtípust, a harmadik az altípust jelzi a „Magyarázó"-ban közölt 'SIGMOND-féle talajrendszer alapján. Pl. **XI-V-II** = talajnem: kalciumtalaj; főtípus: barna mezőségi talaj; altípus: világosbarna mezőségi talaj.
Die erste römische Zahl bedeutet die Bodenart, die zweite den Haupttyp, die dritte den Untertyp des Betreffenden Territoriums nach dem System von A. J. 'SIGMOND. Z. B. **XI-V-II** = Bodenart: Kalziumboden; Haupttyp: Steppenboden; Untertyp: Hellbrauner Steppenboden.

Figure 10 The legend of the Kreybig map, part 4, Berettyóújfalu

Another turning point in the progressively separating paths of the rather pedologising agrogeology and the lowland geological mapping was the recognition of József Sümeghy stating that *agrogeology has some problems that can be answered by geology and geology has some results that can support pedology as well as agricultural production.* In his work Tiszántúl published in 1944 Sümeghy wrote among others: „In the present state of pedology as used in Hungary in general the situation is that chemical properties and characteristics prevail over the other factors. In the knowledge of soil genetics e.g. geological-petrographic factors play also an important role such as rocks and minerals as soil components, physical weathering, erosion, sedimentation,…

Therefore concerning the problems of soil formation the investigation of soil forming factors including geological, mineralogical, dynamic, morphological, and hydrological as well as temporal and climatic factors – the latter two indicating the age of the soils – must be the responsibility of geologists. He has the knowledge of these soil forming factors, he can further improve it and deliver it to chemical experts engaged especially in production and technical sector."

Beside all this Sümeghy attributes crucial importance to the role of groundwater as well turning attention to the significance of studying the relationships between the groundwater, soil and subsoil.

Following Sümeghy, lowland geologists turned growing attention to the research of the agricultural features as well as the pedological relationships of loose sediments. Agrogeological map variants had invariably their place in the map series of András Rónai. He especially put emphasis on the calcium-carbonate content and permeability of various superficial and near-surface sequences but in his works an important role was devoted to studying the relationships between the physical and chemical features of the groundwater as well.

During the 1970s and the early 1980s agrogeological studies were focused by regional geological offices on amelioration and the investigation of natural soil improving materials but unfortunately, it was not accompanied by emphasising their harmful impact on the environment.

The new agrogeological research program of the Geological Institute was formulated in 1986. Apart from the surface it was aimed at investigating the total of the near-surface sequences and the groundwater therein as well as the soil–parent material–groundwater system with its relationships. Furthermore it was also dedicated to deal with the changes occurring in this system and with their prediction.

In the early 2000s as a result of the systematic research of mountain pilot areas it was recognised that soil developed invariably of loose sediments. From this time on it became the cornerstone aspect of the investigations especially for the reason that the material, mineralogical composition together with the physical and chemical features of these sediments have a decisive impact on the type and quality of the soil developing on them under the effect of other soil forming factors including vegetation, climate and relief position. Simultaneously, it is always necessary to answer the questions of whether the given soil forming sediment evolved in-situ or it was transported to the area and whether a transport medium or some other processes acted. It became also obvious that during the agrogeological investigations it had to be distinguished between the hilly and lowland areas covered by thick loose sediments and the mountain regions made up of solid rocks and covered essentially by thinner or thicker loose sediments.

SUPERFICIAL–NEAR-SURFACE SEQUENCES

Agrogeological significance of the superficial–near-surface young, loose sequences

The specific feature of the superficial–near-surface young, loose sediments is that agrogeological processes take place practically in them. The presence of superficial–near-surface young, loose sediments is quite decisive in the life of the vegetation of mountain and hilly areas consisting of older, solid rocks, for their living conditions are ensured by the – occasionally only very thin – weathering products of solid rocks or by the sediments deposited gravitationally on solid rocks or by the deposited dust (in summary, the soil forming sediment).

Agricultural production takes decisively place in lowland- and hilly areas consisting of loose sediments. Consequently, in agrogeological terms the sequences of these areas are the most important ones.

The basic factor of soil development is the soil forming sediment (KUTI et al. 2007). The physical and chemical properties of its material together with its mineralogical composition influence decisively the features and the quality of the soil derived of it. At the same time the importance of other soil forming factors including vegetation, climate and relief position should not be underestimated either, for they can give rise to the formation of different soils on the same geological deposits. E. g. brown forest- or chernozem soil can develop on loess. The effect of rock composition can turn to be decisive only under extreme conditions concerning soil development (e. g. cliff areas, karsts, gravel terrains) where other factors of soil formation can have little or no impact.

The examination of the topmost 20-50 cm of the soil is insufficient for the agrogeological characterisation of a lowland area. Neither is the investigation of the uppermost 1.5-2.0 m in line with general practice. Studying the total of the near-surface sequences is necessary instead down to the domain inundated by groundwater but at least to the depth of 10 m (BARTHA–FÜGEDI–KUTI 1987), and groundwater stored in the sediments should also be tested i. e. the whole soil–parent material–groundwater system must be examined.

The soil–parent material–groundwater system includes the superficial–near-surface sequence assemblage together with groundwater (Figure 2). It is the lithosphere zone that can directly be affected by human activities and that can have a direct impact on human activities. Soil formation and -development, plant growth as well as the potential for agricultural production are defined by the components of this system or they are influenced by the processes taking place therein which provide also the soils with filtering capabilities protecting the environment.

The areas with a profile made up of one specific thick sedimentary sequence have quite different agrogeological setting from those constituted by alternating thinner or thicker sequences of various types of deposits superimposed on each other.

For instance sandy regions, especially if the surface is covered by more-than-10-m-thick aeolian sands are not much valuable concerning farming even if groundwater is relatively near the surface, since sands have high permeability but their water retention capacity is low, they have thus poor water regime properties. On the contrary, if a silt horizon of favourable water regime (e. g. loess) occurs some 2-5 m below the surface it has an advantageous effect on the water regime of the sand. Similarly, a fossil soil horizon located not deeper than 3-5 m below the surface can also have a positive impact on the superficial sand since it can improve the water- and nutrient regime of the superficial deposit as if the soil were on the surface.

In clayey or silty areas in turn a water storing sand horizon located 2-4 m below the surface can have a positive impact on the water regime of the superficial sequences. Occasionally, deeper-rooted plants can gain their water supply directly of this horizon.

An impervious layer e.g. a limestone bench, calcrete layer or the fine sediment of a buried lake bottom between the superficial deposit and the groundwater has in turn a unanimously negative effect on the surface. It blocks namely the superficial deposits of the groundwater preventing the plants of taking up nutrients. The water regime of these areas is the function of the climate. Following the melting of the snow in late winter a so-called suspended- or pseudo groundwater is formed that feeds the plants during the spring but later it becomes depleted (it is exploited by the plants or it evaporates) and the water and nutrient supply of plants is blocked. Considering the one-summer-plants like corns it does not pose a problem, for they become ripened by late spring or early summer. It is however a serious problem in the case of planting fruit trees when the young saplings do not receive enough water.

In mountain and foothill regions the composition and thickness of the younger loose sedimentary sequence (soil forming sediment) covering the older, solid rocks are of agrogeologically crucial importance. The agrogeological setting is different in areas covered by some-cm- or -decimetre-thin weathered zone or by several-m-thick redeposited sediments or when the solid rock is overlain by a thick aeolian sequence, like loess. The latter area has the potential for the development of a high-quality soil with favourable water regime. On the contrary, the areas covered only by a very thin weathered zone do not have any agricultural potential.

The soil forming sediment

One of the important aspects of agrogeology is the determination of the type and quality of the soil forming sediment. The research in pilot areas revealed unambiguously that soil develops only of loose sediments. Even in areas made up of solid rocks the process of soil formation proceeds invariably of loose sediments evolved on solid rock (allochtonous) or developed thereof (autochtonous) (KUTI et al. 2007). In this case it is indispensable to define unambiguously whether the loose sediment covering the solid rock developed thereof being its weathering product or it was transported there by some geological process and soil formation started only subsequently. Consequently, loose sediments are classified upon their suitability for autochtonous soil formation as follows:

a) Different types of loesses together with sandy loess as well as coarse silt and sandy course silt of other than aeolian origin feature very favourable soil forming characteristics.

b) Different volcanic tuffs, e. g. andesitic tuff, basalt tuff and the weathering products of rhyolite tuff, furthermore concerning different fluvial and lacustrine deposits fine silt as well as clayey- and sandy fine silt, silts in general and hydroaerolites: infusion loess and clayey loess and the weathering product of the rhyolite tuff are of favourable soil forming characteristics.

c) Concerning fluvial and lacustrine sediments clayey- and silty sand together with silty- and sandy-silty clay, furthermore Pannonian clayey silt and clayey sand feature intermediate soil forming characteristics.

d) Different types of sands and clays as well as lacustrine sandy clay together with Pannonian sand and clay feature poorly intermediate soil forming characteristics.

e) Fluvial sandy, silty- and clayey gravel as well as carbonate-free clay and marly clay together with the debris and weathering products of older rocks and the sediments formed thereof feature poor soil forming characteristics.

f) Different carbonate muds, muck and peat as well as the sediment of some mires called „semlyék” of high organic matter content are of very poor soil forming characteristics.

Types of the disposition of sediments in the areas covered by loose sediments

In order to characterise the agrogeological setting of loose sedimentary areas in lowland- and hilly regions it is commonly insufficient to know some specific superficial deposits, for it provides information only on the surface or on some of its details but it is necessary to acquire knowledge on the disposition of the near-surface sequences representing the series of beds and sections of different granulometric characteristics. It is important to know the succession of different horizons in the uppermost 10 m of the profile and especially above the groundwater level. E. g.: how thick is the superficial impermeable layer, what deposit does it underlie or are there any thick impermeable deposits underlying the superficial permeable horizons or is the near-surface sedimentary assemblage uniform or is it densely bedded?

In Hungarian practice it is recommended to study the types of the disposition of sediments down to the depth of 10 m below the surface. This part of the profile represents generally well the soil–parent material conditions of the related areas.

The first step in determining different types of the disposition of sediments is the classification of loose sediments according to their grain size. Practical purposes justified to distinguish the following four groups:

1 = gravel, i. e. sediment of grain size > 2 mm
2 = sand, i. e. sediment of grain size between 0.06 and 2 mm
3 = coarse silt, i. e. sediment of grain size between 0.02 and 0.06 mm
4 = clay and fine silt[1], i. e. sediment of grain size < 0.02 mm.

The order of the disposition of these four groups from the surface downward the profile determines the code of the type of the disposition of sediments. The definition of the codes is based on aspect which of the 4 types appears on the surface (first digit). (0 does not have to be considered it was required only to ensure computer-assisted processing). Subsequently, it has to be considered whether the superficial deposit is thick (0) or it alternates with other beds (anything of 1-4). This concept enables us to know invariably the thickness of the specific superficial deposit, whether it fills the 10-m-thick profile or not and in the latter case the type and the bedding characteristics of the underlying sediment or sedimentary assemblage.

This method facilitated to distinguish some 172 types of the disposition of sediments. They are characteristic of the given land and they can clearly be illustrated on the map. During the classification only the grain size of the specific sediments must be considered, their genetics must not.

The most characteristic types of the disposition of sediments

Very thick gravel (011)[2]

This type of the disposition of sediments features gravel achieving closely the thickness of 10 m. It is a sedimentary assemblage of very high permeability that is only slightly influenced by the material filling the voids between the grains.

Very thick sand (021)

This type incorporates very thick aeolian and fluvial sands achieving or even exceeding the thickness of 8-10 m. It features commonly high permeability affected by its grain size and sorting. Fine sand is less permeable than the coarse one while well-sorted sand features higher permeability then the ill-sorted one especially when the part of the fine

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[1] In the following, this group is called simply clay but it refers in the text invariably to the assemblage made up of clay (<0.005 mm)+fine silt (0.005-0.02 mm) i. e. the fraction < 0.02 mm.

[2] The code in brackets is the map code of the type of the disposition of sediments.

fraction is significant in the latter. Simultaneously, it is important to note the good filtering characteristics of the fine- and small-grained sand.

Thick sand underlain by thick clay (221)

In this type 4-6-m-thick superficial sand is underlain by clay of similar thickness. The clay horizon of poor permeability below the highly permeable surface determines the permeability of the whole assemblage if groundwater is positioned therein or underneath. If in turn the groundwater is above the clay horizon the clay prevents its vertical movement.

Thick sand underlain by thick silt (222)

Some 4-6-m-thick superficial sand is underlain by coarse silt of similar thickness. This type of the disposition of sediments is commonly characteristic of the areas featuring the alternation of aeolian sand and loess. This sedimentary assemblage is susceptible to environmental impacts having high permeability where the permeable surface is underlain by a deposit of high water retention capacity.

Thick sand underlain by thick gravel (223)

Some 4-6-m-thick superficial sand is underlain by gravel of similar thickness. It represents the fluvial sediments of high-energy rivers having transported a large volume of bed load mainly during the Pleistocene and subordinately during the Holocene. It features unambiguously high permeability.

Thin sand underlain by thick gravel (233)

Some 2-4-m-thick superficial sand is underlain by a gravel bed of 6-8 m thickness or more. Similarly to the type „thick sand underlain by thick gravel" (223) it is the fluvial sediment of high-energy rivers having transported a large volume of bed load mainly during the Pleistocene and subordinately during the Holocene. It features also unambiguously high permeability. It is even more susceptible to environmental impacts than the type „thick sand underlain by thick gravel" (223), for the gravel of high permeability appears below a thinner sand horizon.

Thin sand underlain by thick clay (231)

Some 2-4-m-thick superficial sand is underlain by clay of 6-8 m thickness. It is impermeable, its permeability characteristics are similar to the type „thick sand underlain by thick clay" (221), and only the highly permeable superficial horizon is thinner in this case.

Thin sand underlain by thick silt (232)

Some 2-4-m-thick superficial sand is underlain by coarse silt of 6-8 m thickness. Similarly to the type „thick sand underlain by thick silt" (222) this sedimentary assemblage also occurs in aeolian terrains. It is highly susceptible to environmental impacts featuring high permeability where the permeable surface is underlain by a deposit of high water retention capacity.

Sand–clay–sand (241)

Some 2-4-m-thick sand is underlain by clay of the same thickness followed by sand of similar thickness again. It is a sedimentary assemblage commonly characteristic of fluvial areas referring to slower then again accelerated transport and deposition. It can also occur in aeolian terrains where aeolian sand is consecutively blown on the fine sediments of lakes between the sand dunes. Its permeability is defined by the clay horizon as a function of the groundwater located below or above it.

Sand–silt–sand (251)

Some 2-4-m-thick sand is underlain by coarse silt of the same thickness followed by sand of similar thickness again. It is the sedimentary assemblage of aeolian terrains described by the alternation of sand- and loess horizons of similar thickness. The permeability of the assemblage is only slightly affected by the layer of high water retention capacity between the two permeable beds.

Sand–gravel–sand (261)

Some 2-4-m-thick sand is underlain by gravel of the same thickness followed by sand of similar thickness again. It is the sedimentary assemblage of fluvial areas characterised by accelerating and slowing periods of a high-energy river carrying the bedload. It is of high permeability.

Sand–gravel–clay (262)

Some 2-4-m-thick sand is underlain by gravel of the same thickness followed by clay of similar thickness. It is also the sedimentary assemblage of fluvial terrains where coarse deposits are laid down by the accelerating and again slightly slowing river on the floodplain clay beds. The clayey horizon of poor permeability in the lower part of the assemblage impedes the vertical movement of the groundwater.

Sand–clay–sand–clay (271)

The profile is made up of densely alternating 2-3-m-thick sand- and clay layers. It is the sediment of the rivers slowing completely down and accelerating again. It refers to frequent changes of floodplain and channel environments. Its permeability is defined unequivocally by the clay horizons of poor permeability especially when groundwater is located below the first clay layer.

Very thick silt (031)

This type is characterised by coarse silt of 8-10 m thickness or more. It represents commonly thick loess terrains but occasionally it can feature fluvial silt as well. Due to its structure it is of high permeability above the groundwater level if typical loesses are concerned. If its structure is destroyed or it is not typical loess or it is not loess it has intermediate permeability but in turn it features good water retention capacity.

Thick silt underlain by thick clay (321)

Some 4-6-m-thick superficial coarse silt is underlain by clay of similar thickness. Its permeability is fundamentally determined by the clay bed of low permeability.

Thick silt underlain by thick sand (322)

Some 4-6-m-thick superficial coarse silt is underlain by sand of similar thickness. It is commonly the sedimentary assemblage of aeolian terrains where loess is deposited on aeolian sand of similar thickness. Rarely, it can occur in fluvial areas as well. It is of intermediate permeability.

Thin silt underlain by thick clay (331)

Some 2-4-m-thick superficial coarse silt is underlain by clay of 6-8 m thickness. It is the sedimentary assemblage of aeolian surfaces where loess was presumably deposited on older, thick, clayey deposits of aqueous origin or frequently of Pannonian age. It features areas of less than intermediate permeability which is fundamentally determined by the clay horizon as a function of the groundwater depth.

Thin silt underlain by thick sand (332)

Some 2-4 m superficial coarse silt rests on 6-8-m-thick sand horizon. Similarly to the type „thick silt underlain by thick sand" (322) it is also the sediment of aeolian terrains where loess was deposited by the wind on the surface of thick sand. It is of comparatively high permeability.

Silt–sand–silt (351)

Some 2-4-m-thick superficial coarse silt is underlain by sand of the same thickness followed by coarse silt of similar thickness again. It is the sedimentary assemblage of aeolian landscapes representing the alternation of loess- and sand horizons of similar thickness. The permeability of the assemblage is only slightly influenced by the superficial horizon of high water retention capacity.

Silt–sand–clay–sand (385)

Some 2-3-m-thick superficial coarse silt is underlain by sand of similar thickness followed by clay and then sand again. It is presumably the sedimentary assemblage of foothill terrains. Its permeability is fundamentally determined by the clay horizon as a function of whether the groundwater table is located below or above it.

Very thick clay (041)

This type of the disposition of sediments is constituted by clay achieving or exceeding the thickness of 8-10 m. It is an aquiclude sedimentary assemblage of definitively poor permeability.

Thick clay underlain by thick sand (421)

Some 4-6-m-thick clay is underlain by sand of similar thickness. It is commonly the sediment of fluvial terrains where thick, fine, floodplain sediments were laid down on the previously deposited sand. Its permeability is chiefly determined by the superficial impermeable clay horizon protecting the deeper-seated sand bed of high permeability.

Thick clay underlain by thick gravel (423)

Some 4-6-m-thick clay is underlain by gravel of similar thickness. It is generally the sediment of fluvial landscapes where thick, fine, floodplain deposits were laid down on the gravel spread out earlier. Its permeability is basically determined by the superficial impermeable clay horizon protecting the deeper-seated gravel bed of high permeability.

Thin clay underlain by thick sand (431)

Some 2-4-m-thick clay is underlain by 6-8-m-thick sand. It is usually the sediment of fluvial regions where a thin layer of fine, floodplain deposits were laid down on the previously deposited sand. Its permeability is determined by the superficial impermeable clay horizon which is thinner though than that of the type „thick clay underlain by thick sand" (421) it still protects the deeper-seated sand bed of high permeability.

Thin clay underlain by thick gravel (433)

Some 2-4-m-thick clay is underlain by 6-8-m-thick gravel. It is usually the sediment of fluvial regions where a thin layer of fine, floodplain deposits were laid down on the previously deposited gravel. Its permeability is determined by the superficial impermeable clay horizon which is thinner though than that of the type „thick clay underlain by thick gravel" (423) it still protects the deeper-seated gravel bed of high permeability.

Clay–sand–clay (441)

Some 2-4-m-thick superficial clay is underlain by sand of similar thickness followed by clay again. Its permeability is fundamentally determined by the thickness of the superficial clay horizon of poor permeability.

Clay–sand–gravel (443)

Some 2-4-m-thick superficial clay is underlain by sand of the same thickness followed by gravel of similar thickness. It is a typical fluvial sedimentary assemblage. Its permeability is chiefly determined by the thickness of the superficial clay horizon of poor permeability.

Clay–silt–clay (451)

Some 2-4-m-thick superficial clay is underlain by silt of the same thickness followed by clay of similar thickness again. Its permeability is chiefly determined by the thickness of the superficial clay horizon of low permeability.

Clay–silt–sand (452)

Some 2-4-m-thick superficial clay is underlain by coarse silt of the same thickness followed by sand of similar thickness. It is a typical fluvial sedimentary assemblage. Its permeability is unambiguously defined by the superficial, practically aquiclude clay horizon.

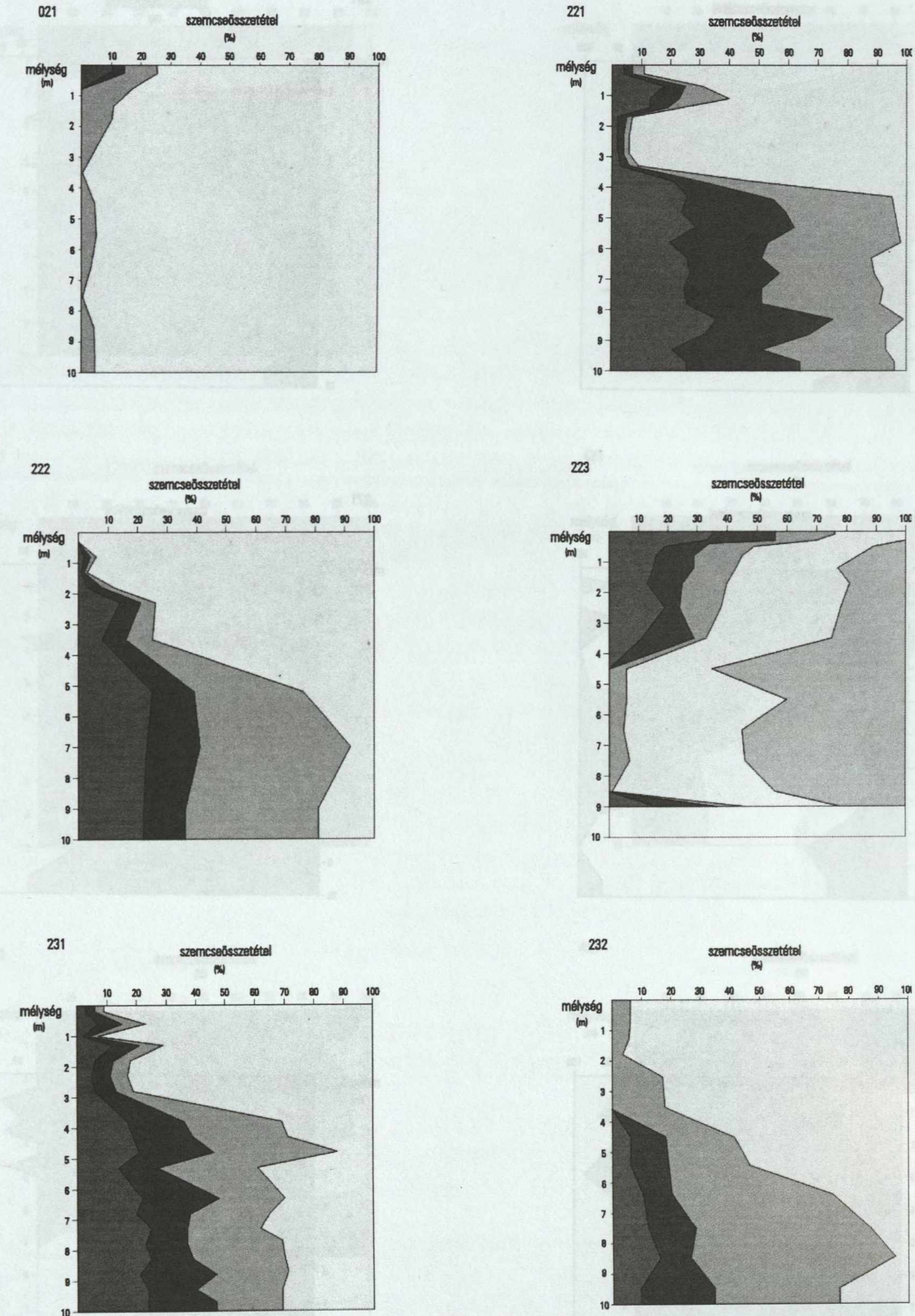

Figure 11 Typical types of the disposition of sediments with sand on the surface

▨	■	▨	☐	▨
agyag	**finom kőzetliszt**	**durva kőzetliszt**	**homok**	**kavics**
clay	fine silt	coarse silt	sand	gravel

Legend to the Figures 11, 12, 13, 14, 15

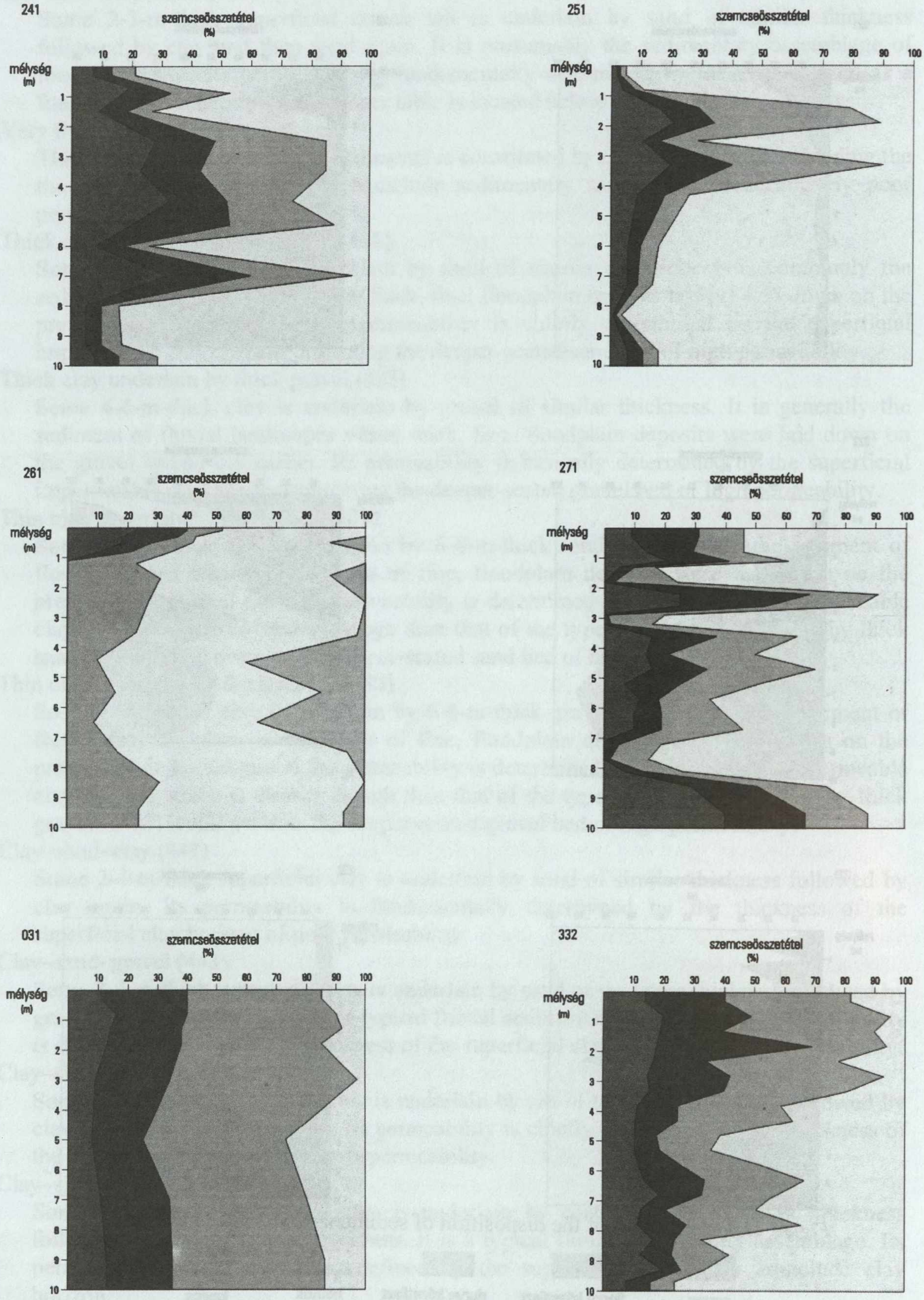

Figure 12 Typical types of the disposition of sediments with sand and silt on the surface
See legend in Figure 11

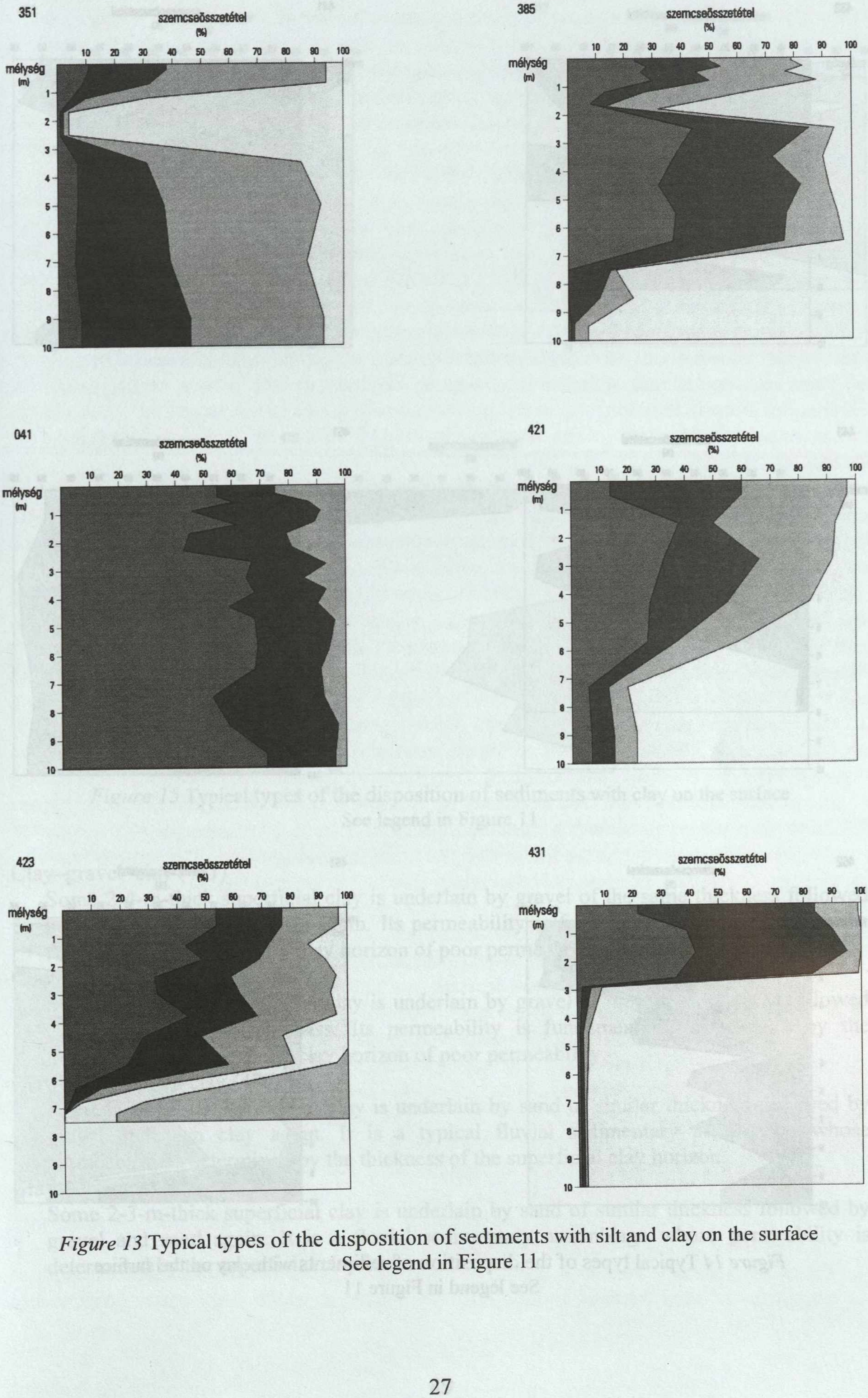

Figure 13 Typical types of the disposition of sediments with silt and clay on the surface
See legend in Figure 11

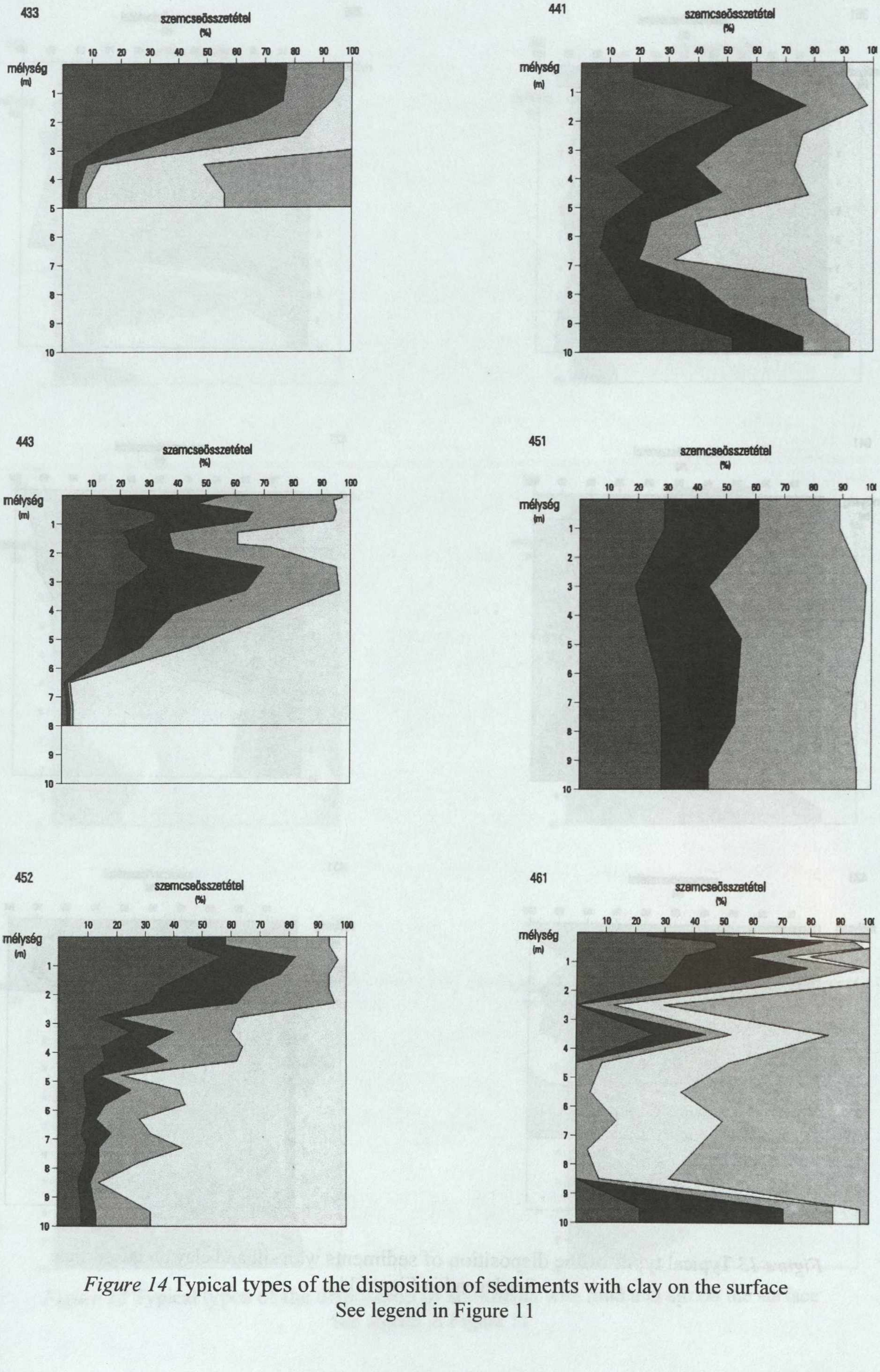

Figure 14 Typical types of the disposition of sediments with clay on the surface
See legend in Figure 11

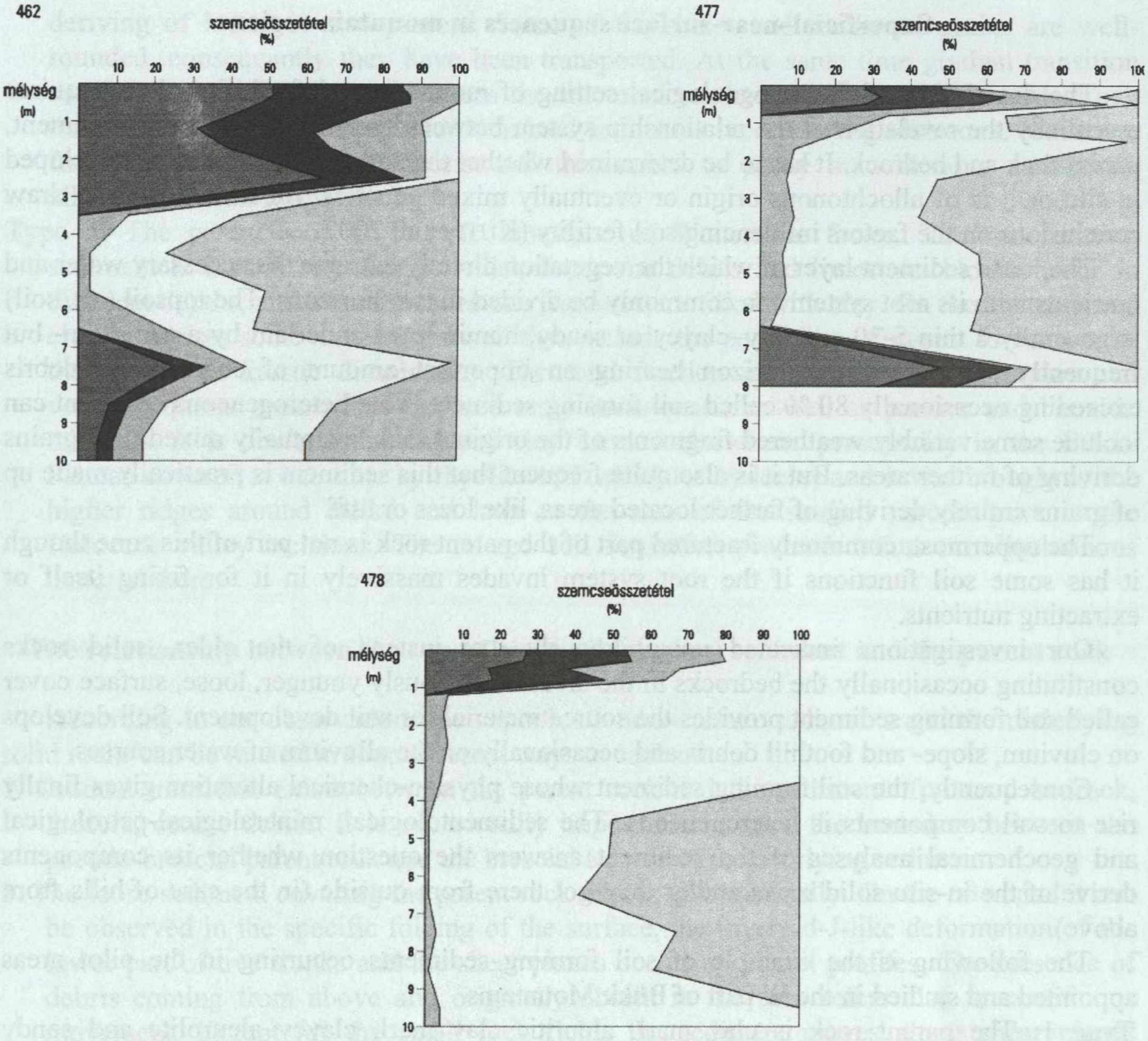

Figure 15 Typical types of the disposition of sediments with clay on the surface
See legend in Figure 11

Clay–gravel–clay (461)

Some 2-4-m-thick superficial clay is underlain by gravel of the same thickness followed by clay of similar thickness again. Its permeability is fundamentally determined by the thickness of the superficial clay horizon of poor permeability.

Clay–gravel–sand (462)

Some 2-4-m-thick superficial clay is underlain by gravel of the same thickness followed by sand of similar thickness. Its permeability is fundamentally determined by the thickness of the superficial clay horizon of poor permeability.

Clay–sand–gravel–clay (477)

Some 2-3-m-thick superficial clay is underlain by sand of similar thickness followed by gravel and then clay again. It is a typical fluvial sedimentary assemblage whose permeability is determined by the thickness of the superficial clay horizon.

Clay–sand–gravel–sand (478)

Some 2-3-m-thick superficial clay is underlain by sand of similar thickness followed by gravel and sand again. It is a fluvial sedimentary assemblage whose permeability is determined by the superficial clay bed.

Superficial–near-surface sequences in mountain regions

The description of the agrogeological setting of mountain and foothill regions requires essentially the revelation of the relationship system between the soil, soil forming sediment, parent rock and bedrock. It has to be determined whether the soil forming sediment developed in-situ or it is of allochtonous origin or eventually mixed genetics, for it facilitates to draw conclusions on the factors influencing soil fertility (KUTI et al. 2007).

The loose sediment layer of which the vegetation directly extracts the necessary water and nutrients with its root system can commonly be divided in two horizons. The topsoil (s.s. soil) is generally a thin 5-30-cm silty–clayey or sandy, humic level underlain by a some-dm- but frequently several-m-thick horizon bearing an important amount of coarse rock debris exceeding occasionally 80 % called soil forming sediment. This heterogeneous sediment can include some variably weathered fragments of the original rock, eventually mixed with grains deriving of farther areas. But it is also quite frequent that this sediment is practically made up of grains entirely deriving of farther located areas, like loess or tuff.

The uppermost, commonly fractured part of the parent rock is not part of this zone though it has some soil functions if the root system invades massively in it for fixing itself or extracting nutrients.

Our investigations indicated unambiguously that instead of the older, solid rocks constituting occasionally the bedrocks in the area, its obviously younger, loose, surface cover called soil forming sediment provides the source material for soil development. Soil develops on eluvium, slope- and foothill debris and occasionally on the alluvium of water courses.

Consequently, the soil forming sediment whose physico-chemical alteration gives finally rise to soil components is heterogeneous. The sedimentological, mineralogical-petrological and geochemical analyses of the sediment answers the question whether its components derive of the in-situ solid rocks and/or they got there from outside (in the case of hills from above).

The following is the example of soil forming sediments occurring in the pilot areas appointed and studied in the W part of Bükk Mountains.

Type 1: The parent rock is clay marl, aleuritic clay marl, clayey aleurolite and sandy aleurolite. The soil forming sediment is its debris in sandy or silty matrix whose mineralogical composition is identical with the parent rock though some rounded (transported) shale debris as well as volcanic and metamorphic quartz and pumice also appear in the sand fraction in the topmost levels. Altogether, the soil formation can be qualified as autochtonous.

Type 2: The parent rock is shale (aleuritic shale, clayey aleurolite and sandy aleurolite) with basic eruptive rocks (lava flows, dykes, volcanic conduits and subvolcanic bodies). The soil forming sediment is its debris in sandy or silty matrix. It is important to note that several types of eruptive rock debris can be identified in most part of the studied area (e. g. variably disintegrated basalt, diabase and gabbro being part of the same magmatic process), but it is quite unlikely that they can occur next to each other in a 50x150 m^2 area accompanied by siliceous sandstone and Triassic limestone. Accordingly, the soil forming sediment is of allochtonous character.

Type 3: The parent rock is disintegrated basic eruptive rock. The soil forming sediment is its variably further weathered debris in sandy or silty matrix. Consequently, soil formation had autochtonous character.

Type 4: The parent rock is siliceous (polymictic or grauwacke-type) sandstone or shale with intercalations of algal–bioclastic limestone. The soil forming sediment is sandstone-, shale-, occasionally limestone debris, in some cases basic eruptive rock debris (the latter mainly in the sand fraction) in sandy or silty matrix, in which scaly quartz (presumably deriving of loess) is also present. Some of the shale- and sandstone grains are well-rounded, consequently they have been transported. At the same time gradual transition can be observed in the profile from the fractured sandstone still considered as bedrock through the overlying breccia to the mixed sediments incorporating also some sandstone fragments and other rock debris. All this refers to partly autochtonous and partly allochtonous soil formation.

Type 5: The parent rock is Triassic limestone of Wetterstein facies. The soil forming sediment is karstic red clay in which limestone debris and limestone blocks occur in different depths, and even the limestone fractures are filled with clay. On the contrary, red clay comprises some minerals as well that exclude the possibility of in-situ formation (as the residue of karstic dissolution). The sand fraction includes thus metamorphic and volcanic quartz grains, lens-like and scaly loess-quartz as well as pumice and bauxitic minerals. It is obvious that the red clay formed elsewhere, presumably in the Bükk-Plateau covered at one time by rhyolite tuff (and later by loess) and it was brought to the higher ridges around Bélkő and later to the area of the studied parcels prior to the Holocene valley incisions. The related soil formation proceeded thus on allochtonous material there.

The relationship between the superficial (soil forming) sediment and the parent rock

According to our observations the superficial–near-surface sediments and the underlying solid rocks can be related in four different ways to each other.

1. Gradual transition exists between the parent rock and the sediment: fractured bedrock, breccia, coarse debris. It is occasionally impossible to draw the boundary between the pseudo-breccial parent rock and the breccial texture of the overlying sediment.
2. The loose sediment covering the parent rock moves gravitationally. On the one hand it can be observed in the specific folding of the surface, the inversed-J-like deformation of the lower part of tree trunks and the shear planes occurring in soil profiles. The presence of debris coming from above and originally absent in the area refers also to continuous movement. Except for the small rock fields the sediment moves along shear planes massively, in blocks and it accumulates at the bottom of the slope as proluvial sediment.
3. The cavities, depressions and, occasionally the dolines of the karstic parent rock are filled with clayey sediments washed in. The sediment invades the fractures in the limestone, fills the cavities of the karstic breccia and mixes with the limestone breccia falling therein. Red (and black) clay is constantly transported by recent erosion from the ridges and higher levels of valley incisions towards the valley floor – the local base level – where it forms a narrow, terrace-like filling. Consequently, instead of massive movement the sediment is transported downslope like slush during rains and snow melting.
4. The barren, eroded surface of the parent rock becomes covered by an alien sequence (e. g. loess on Triassic limestone), and the soil forms on its topmost part being the allochtonous soil forming sediment. In this case the relationship between the two sequences is determined by the actual state of the surface of the parent rock. The sediment deposited on the parent rock fills its depressions but the two sequences remain clearly separated along a sharp boundary without transition.

GROUNDWATER

„Groundwater is called the uppermost water horizon near the ground surface which is considerably affected by meteorological conditions." (JUHÁSZ 1976).

Apart from being one of the most important factors of soil evolution and changes in the soil groundwater has direct impact on farming as well. The study of its depth, quality and movement in relationship with the sequences in which it is stored gives answer among others to the eventual occurrence and anticipated extent of salinisation, determines the possibility and the method of irrigation and facilitates the prediction of the risk of excess water inundation and soil erosion. Groundwater has to be considered in building operations as well especially at the selection of the most appropriate foundation and insulation technologies. Simultaneously, it is the most important transmission agent, the main carrier and transmitter of pollution brought in the geological medium. Therefore it is of utmost importance to know its depth below the surface, its horizontal and vertical movements, chemistry and the altitude of its table above sea level alike.

Groundwater occurs in lowland- and hilly areas made up of loose sediments. It is virtually absent in mountain regions, at least it does not form an expansive, continuous table like in the basins filled with sediments (RÓNAI 1956). In mountain regions it occurs at most in the sedimentary filling of intramontane basins of various size or in the floodplain deposits of variably wide river valleys. Bedrocks do not contain groundwater, whereas water coming and stored in fractured or karstic rocks are called fissure water or karstwater.

Groundwater occurs in the first subsurface horizon capable of storing water. Its material must not necessarily have high transmission capability but it is frequently inappropriate for water transport like clay or silt. This feature is of crucial importance concerning farming, for plants are capable of extracting the necessary moisture even of the sequences of low transmissibility.

In lowland- and hilly areas groundwater occurs commonly below the sequences subjected to soil formation.

The groundwater-storing aquifer extends frequently up to the ground surface. This scenario is called free groundwater table. On the contrary, it occurs also frequently (e. g. in one considerable part of the Great Hungarian Plain) that aquiclude layers can be found above the uppermost aquifer that can hold the groundwater under pressure. Just another scenario is when a so-called „pseudo-groundwater" develops for some short, definite amount of time (e. g. following snow melting) above a subsurface aquiclude lens (e. g. buried lacustrine bed) which is not connected with the subsurface water system. This water is comparatively rapidly depleted by the plants and evaporation in early summer and under favourable circumstances it is eliminated only by mid summer until renewed recharge next year.

The level of the groundwater is called groundwater table. It follows the relief of the surface comparatively well. Rising and falling, the groundwater level is in constant fluctuation. During the year it drops to its minimum level commonly by late summer and early autumn and it rises to maximum level during the winter months. According to our observations in the pilot areas this movement is in close association with evaporation.

Groundwater has another, 12-16-month-period fluctuation as well when the depth of its level is especially high or low as compared to the surface. This fluctuation is due to climatic factors, it follows distinctively the changes in the climate regime of Hungary.

Water–sediment relationship in the lowland- and hilly areas made up of loose sediments

1. Precipitation getting on the surface is trapped

Precipitation getting on the surface, melting snow or falling rain cannot or can only slowly infiltrate in the impermeable layers covering the surface and it is trapped on the surface. Some fragment of the water stranded on the surface infiltrates in the soil but its larger part evaporates with the passage of time. In this scenario precipitation does not get into the groundwater but the water stopped on the surface or impregnating it prevents it from evaporating resulting in rising groundwater table in the given area.

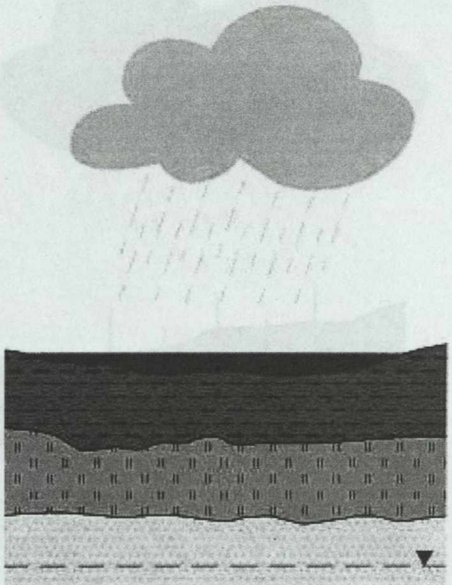

Figure 16 Precipitation is trapped on the surface

2. Precipitation getting on the surface moves downslope

Melting snow or rain falling on the surface cannot infiltrate in the superficial sediments but it moves downslope forming a lake of seasonal- or eventually permanent water cover or it flows away as a seasonal- or eventually permanent water course emptying in some lake or water course. As a function of the intensity of precipitation the related overland flow may provoke surface erosion.

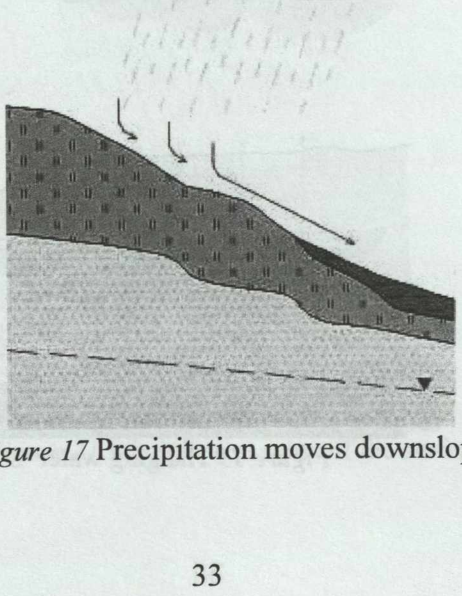

Figure 17 Precipitation moves downslope

3. Precipitation getting on the surface infiltrates in the sediment and becomes stored in it
   Precipitation infiltrates in the superficial deposits of high water storing capacity and commonly greater thickness and becomes stored in it. The water stored there is consumed by the plants and it is evaporated by them or it evaporates due to the heat precluding thus the depletion of the groundwater whose table will rise.

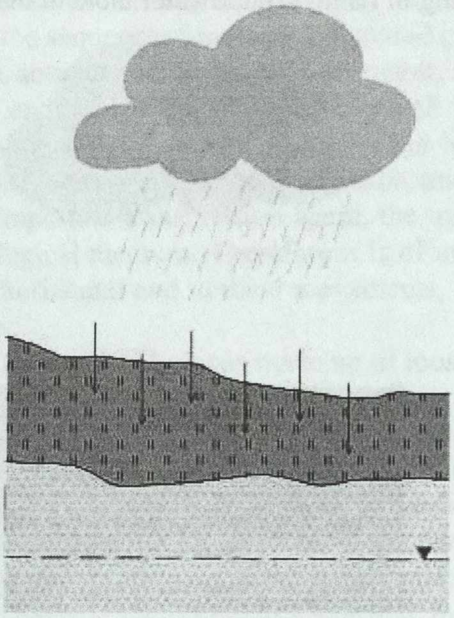

Figure 18 Precipitation infiltrates in the sediment and becomes stored in it

4. Precipitation getting on the surface infiltrates in the sediment and is trapped over an aquiclude
   Precipitation infiltrates in the soil through the superficial sediments of high transmissibility but it becomes trapped over a subsurface aquiclude layer (e.g. buried lacustrine sediment, calcrete level or paleosol layer) constituting hanging water or pseudo-groundwater. By early summer this water is depleted by the vegetation or evaporation. It does not have any considerable effect on deeper groundwater.

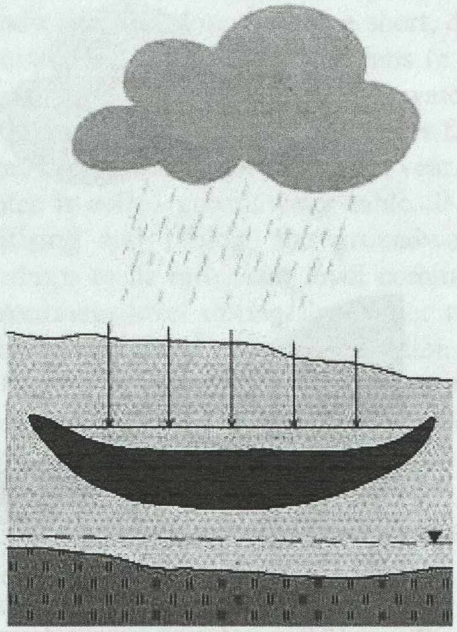

Figure 19 Hanging water

5. Precipitation getting on the surface infiltrates in the sediment and passes in the groundwater

Precipitation getting on the surface (melting snow or falling rain) infiltrates through the permeable sediments above the groundwater table and achieves the groundwater. It contributes thus to its growing volume and to the rise of its level.

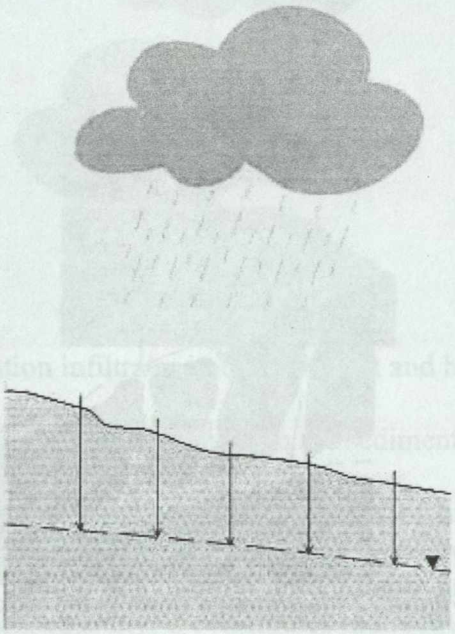

Figure 20 Precipitation infiltrates in the sediment and passes in the groundwater

Water–sediment relationship in mountain regions

1. Solid rocks on the surface

1.1. Precipitation getting on the surface runs off on the compact rock

Precipitation cannot infiltrate in the compact, solid rock, it runs off the surface towards the foothills and valleys and constituting a seasonal or permanent water course it joins the surface drainage system.

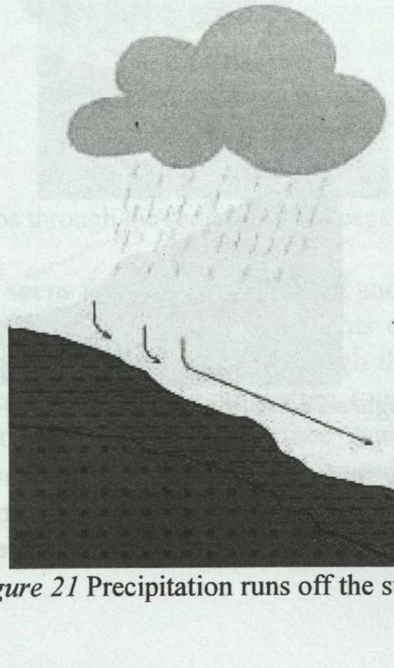

Figure 21 Precipitation runs off the surface

1.2. Precipitation getting on the surface flows in the rock fractures

Through the fractures of the rock a considerable part of the precipitation passes in deeper horizons and joins the subsurface water system. Migrating there towards deeper domains it passes very slowly in the deeper part of the subsurface water system of lowland areas. Consequently, it contributes indirectly to the rise of groundwater in the upwelling zone of lowlands.

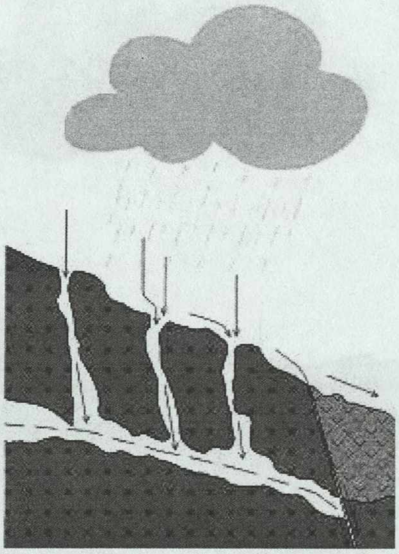

Figure 22 Precipitation flows in the rock fractures

2. Solid rocks covered by sediments

2.1. Precipitation getting on the surface runs off the impermeable sediments

The solid rock is covered by impermeable loose sediment (e. g. clay) and precipitation falling on it runs off the surface towards the foothill and valleys and constituting a seasonal or permanent water course it joins the surface drainage system.

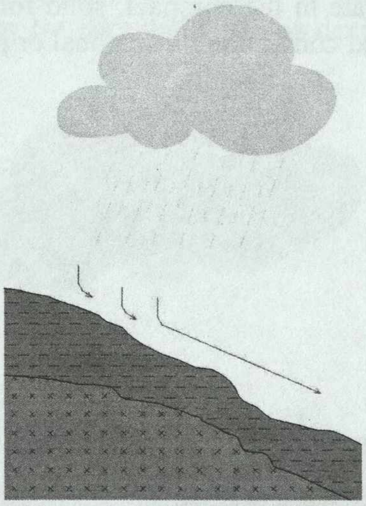

Figure 23 Precipitation runs off the surface

2.2. Precipitation getting on the surface infiltrates in the sediment and becomes stored in it

A considerable part of the precipitation getting on the surface infiltrates in the commonly thick sediment covering the solid rocks and becomes stored in them. A smaller part of the precipitation moves downslope and constituting a seasonal or permanent water course it joins the surface drainage system.

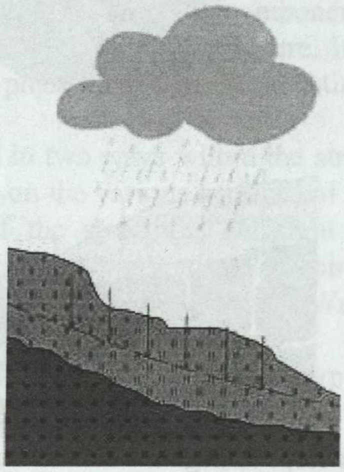

Figure 24 Precipitation infiltrates in the sediment and becomes stored in it

2.3. Precipitation getting on the surface seeps through the sediment and it seeps downward on the rock surface

Precipitation seeps through the variably thick sediments of high permeability overlying the solid rock but it cannot infiltrate in it and seeps downward on its surface. Migrating towards deeper domains it passes very slowly in the deeper part of the subsurface water system of lowland areas. Consequently, it contributes indirectly to the rise of groundwater in the upwelling zone of lowlands.

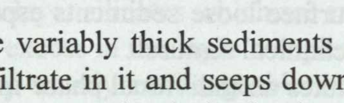

Figure 25 Precipitation seeps through the sediment and seeps downward on the rock surface

2.4. Precipitation on the surface seeps through the sediment and passes in the rock cavities

Precipitation seeps through the variably thick sediments of high permeability overlying the solid rock and it passes into deeper horizons through the fractures of the karstic rock. It joins the subsurface water system where migrating towards deeper domains it passes very slowly in the deeper part of the subsurface water system of lowland areas. Consequently, it contributes indirectly to the rise of groundwater in the upwelling zone of lowlands.

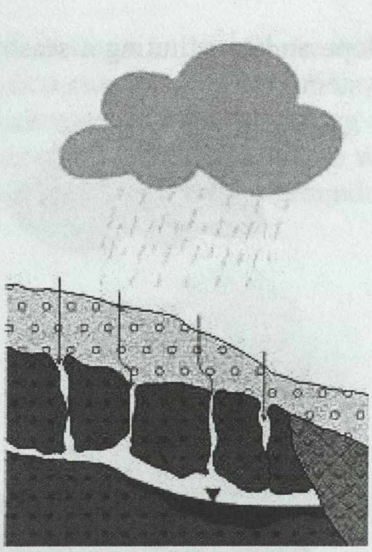

Figure 26. Precipitation seeps through the sediment and flows in the rock fractures

Water budget of the superficial–near-surface sediments

The water content of near-surface loose sediments especially soils has a decisive impact on their agricultural and soil mechanical features.

One part of the water constitutes an individual phase in the pores of the sediments. Water volumes corresponding to various water capacities fill the pore spaces of different diameter as follows:

a) Pore space of strongly bound water (P_e). It is filled with a water film bound to the surface of the sediment grains by very strong adsorptive, electrostatic forces acting in their internal space. The equivalent diameter of the pore space is the fraction of micron and its amount is nearly equal to the hygroscopic value of the „dry" sediment. In our samples it correlates with the value of the fine, colloidal- or clay fraction.

b) Pore space of loosely bound water (P_1). It is the pore space where water is bound to the sediments also by electrostatic forces but weaker than that for the adsorptive films. The equivalent pore diameter constitutes several microns and quantitatively it is the same order of magnitude as the hygroscopic value. Though weaker than in the previous case it can also be correlated with the fine fraction's amount.

c) The space of capillary pores (P_{kap}) consists of intermediate diameter (3-300 µm), capillary-sized pores in which water movement is determined by the surface tension and capillarity.

d) The space of capillary-gravitational pores ($P_{k\text{-}g}$) is the sum of capillary pores of larger diameter than the previous one in which gravitational forces affect water movement in the same order of magnitude than the capillary ones.

e) The space of gravitational pores (P_g) is the group of pores that are made up of larger, sub-capillary gaps and cavities. Their diameter is the same order of magnitude as that of the sand grains, their volume can approach or even exceed the value of the theoretical DARCY pore space.

The metabolism or material movement necessary for the subsistence of the higher plants' root system takes place in the pore space of capillary, capillary-gravitational- and gravitational water.

The value of the gravitational pore space and its relation to the pore space of capillary and bound water allow drawing conclusions to the structure of the near-surface sediments, especially to their capability for soil formation and its intensity.

Water films bound by adsorptive forces also appear on the surface of the grains constituting the sediment. Their bounding force is the function of the grains' surface properties. There are quite a number of mineral components in the sediment containing molecular water as it were built in the mineral's structure. In these cases the water and the mineral form one particular solid phase in which the constituting minerals of the sediment play an important role.

Water molecules can be bound in two ways within the structure of the minerals affecting water budget: by adsorptive forces on the various surfaces of the structure or by coordination forces around specific cations of the structure. Different water types occurring in the particular phases can also be their combination. Concerning chemical bounds secondary valence forces and transitional bounding forces (van der Waals attraction forces, hydrogen bound, coordinative bound) are acting in these cases.

Polar surface is needed for the establishment of adsorptive bounds. Dipole molecules (SiO_4 and AlO_4 tetrahedrons) are bound by them. Polar water molecules getting into the force field of polar ions on the surface of the solid body are bound oriented by van der Waals forces. The evolving monomolecular layer produces a polar surface itself on which some other water molecules can be bound oriented. Surface bounding may take place on the minerals' exterior surface and on the surface of the internal spaces as well.

Inter-layer water may appear in layer silicates which are rather frequent sediment forming minerals if negative charges are in excess in the layer complex constituting the minerals. The negative charge is compensated by mostly exchangeable cations located in the inter-layer space or by water. Virtually free water may exist in the inter-layer space as well as different sorption waters or waters bound partly directly on the lattice plane or partly as second, third or nth molecule layer on the active sites of the surface. Zeolithic water, the water of amorphous structures and the main part of the water bound by organic components occur also in the internal space of sediment constituents. Crystalline water of structurally defined position which does not, however, affect the structure itself must also be noted at this point in which the water molecules are bound by coordination forces.

In compliance with the water types listed above the groups of minerals occurring in the sediments are as follows:

a) Clay minerals: they contain fairly high volume of water bound with low energy; they include illite, chlorite, montmorillonite, vermiculite, occasionally kaolinite. Due to the small size of their grains the clay minerals of 2:1-type layer structure are capable of bounding substantial amount of water even on their surface. At the same time they contain molecular water layers bound by comparatively low energy in the space between the lattice planes made up of SiO_4 tetrahedrons.

b) Minerals containing mineral waters: gypsum, vivianite.

c) Zeolithes: mineral group occurring rather scarcely in nature but they have a considerable role as soil improving material like clinoptilolite and mordenite.

d) Iron-oxide gels or ferrihydrite featuring commonly high water content.

Apart from the mineral phases water content adsorbed on the surface of the organic components may also play a role.

Smectites and iron oxide-gels are the phases of the listed groups that are sensible to the environmental conditions whose modification may result in the change of their water content. Consequently, they may be considered mostly if assuming the sediment's water budget.

Groundwater chemistry

As a function of its position, environment together with the type, quality as well as chemical and mineralogical-petrological composition of the enclosing sediment the chemical composition of groundwater varies in space and time in a wide extent. It occurs quite frequently that the chemical composition of water samples taken close to each other deviates substantially. The mixing of different waters as well as various antropogenic and other contamination sources may also affect groundwater chemistry in a specific area.

The generic qualitative characteristics of the groundwater are as follows: alkalinity, hardness, pH and total dissolved solids content. The main cations defining groundwater chemistry are sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), ammonium (NH_4^+), manganese (Mn^{2+}) and iron (Fe^{3+}). The main anions are in turn chloride (Cl^-), hydrogen carbonate (HCO_3^-), sulphate (SO_4^{2-}), nitrate (NO_3^-), nitrite (NO_2^-) and phosphate (PO_4^{3-}).

Furthermore, various microelements play also a considerable role affecting water quality.

Quite similarly alkaline earth metals as well as the salts of calcium and magnesium have also a considerable impact on the chemical composition of the water, defining its hardness (JUHÁSZ 1976). The alkalinity of the water is brought about essentially by hydrogen carbonates.

Table 1 Geochemical types of water as a function of the amount of main cations and anions

	chloride (Cl)	chloride-sulphate ($Cl-SO_4$)	chloride-hydrogen carbonate ($Cl-H_2CO_3$)	sulphate (SO_4)	sulphate-chloride (SO_4-Cl)	sulphate-hydrogen carbonate ($SO_4-H_2CO_3$)	hydrogen carbonate (H_2CO_3)	hydrogen carbonate-chloride (H_2CO_3-Cl)	hydrogen carbonate-sulphate ($H_2CO_3-SO_4$)	mixed ($Cl-H_2CO_3-SO_4$)
sodium (Na)	11	12	13	14	15	16	17	18	19	10
sodium-magnesium (Na-Mg)	21	22	23	24	25	26	27	28	29	20
sodium-calcium (Na-Ca)	31	32	33	34	35	36	37	38	39	30
magnesium (Mg)	41	42	43	44	45	46	47	48	49	40
magnesium-sodium (Mg-Na)	51	52	53	54	55	56	57	58	59	50
magnesium-calcium (Mg-Ca)	61	62	63	64	65	66	67	68	69	60
calcium (Ca)	71	72	73	74	75	76	77	78	79	70
calcium-sodium (Ca-Na)	81	82	83	84	85	86	87	88	89	80
calcium-magnesium (Ca-Mg)	91	92	93	94	95	96	97	98	99	90
mixed (Ca-Mg-Na)	101	102	103	104	105	106	107	108	109	100

The chemical types of the groundwater are defined according to the percentage ratio of the three main cations (sodium, calcium and magnesium) and the three main anions (hydrogen carbonate, chloride and sulphate) (KUTI 1979). During the interpretation it is suggested that if one of the ions is present in the water in more than 50 equivalent percentage (EP) it is then the predominant one (e. g. sodium water, sulphate water). The water is of dual type if none of the ions exceed 50 EP but two of them are present in the amount between 25-50 EP (e.g. magnesium-calcium water). Denominating dual-type waters the name of the one in bigger amount is written ahead. Mixed waters are those in which the value of three elements is between 25 and 50 EP (e. g. calcium-magnesium-sodium- or hydrogen carbonate-chloride-sulphate water). In this case the name of the components will be featured in alphabetical order. It is not infrequent either that the six main ions are in nearly the same amount in some waters.

Different chemical types of the groundwater are characteristic of areas of variable geological setting. Like the type of the disposition of sediments near the surface they also allow distinguishing between different geological landscapes.

A quite spectacular example is the profile extending from Danube Valley to the valley of Hármas-Körös in the central part of the Great Hungarian Plain. Apart from the geological deposits, different groundwater chemistry data, total dissolved solids content as well as the volume of the main cations and anions in mg/l have been represented on the related figure (Figure 27). The profile compiled upon some 76 10-m-deep mapping boreholes crosses three lands of typically different genetics and geological setting including the Danube Valley, the ridge of the Danube-Tisza interfluve and the Tiszazug.

Figure 27 Position and orientation of the geological profiles in the central part of the Great Hungarian Plain

Superficial–near-surface sediments of the Danube Valley are constituted by Late Pleistocene and Early Holocene deposits of the Danube varying extensively from gravel to clay. Expansive beds of the coarsest sediment, the gravel is quite near the surface, only 2–3 m deep below it (Figure 28). It is overlain by variably thick upward-fining fluvial sand appearing frequently on the surface. In most of the area the sand is covered by 0.5–1.5-m-thick floodplain clay or silt which is fairly alkaline. The groundwater table is between 1 and 3 m below the surface. The total dissolved solids content of the groundwater fluctuates commonly between 1 000 and 3 000 mg/l except for some samples taken from the vicinity of the Danube and the Kígyós-Canal which have been affected by dilution of the surface water and remaining thus below 1 000 mg/l. In the essential part of the area the groundwater is sodium-hydrogen carbonate. Sodium content varies between 100 and 800 mg/l, whereas that of the calcium and magnesium remains below 100 mg/l (Figure 29). In most samples the amount of magnesium exceeds that of the calcium. Concerning the anions hydrogen carbonate prevails (500–1 000 mg/l) followed by the chloride (40–500 mg/l) (Figure 30). The high total dissolved solids content and the predominant sodium-hydrogen carbonate feature are due to the backwater effect of the Danube on the water seeping from the ridge along the middle of the Danube Valley becoming trapped and standing still there and turning thus enriched in solids.

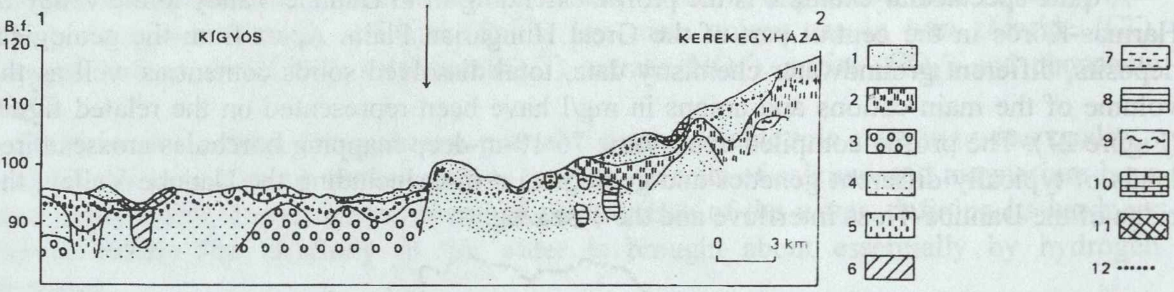

Figure 28 Geological profile on the boundary of the Danube Valley and the ridge in the Danube-Tisza interfluve

1 aeolian sand; 2 loess; 3 gravel; 4 fluvial sand; 5 fluvial silt; 6 flood-laid clay; 7 lacustrine silt; 8 lacustrine clay; 9 peat; 10 calcareous mud; 11 alkaline deposit; 12 groundwater level

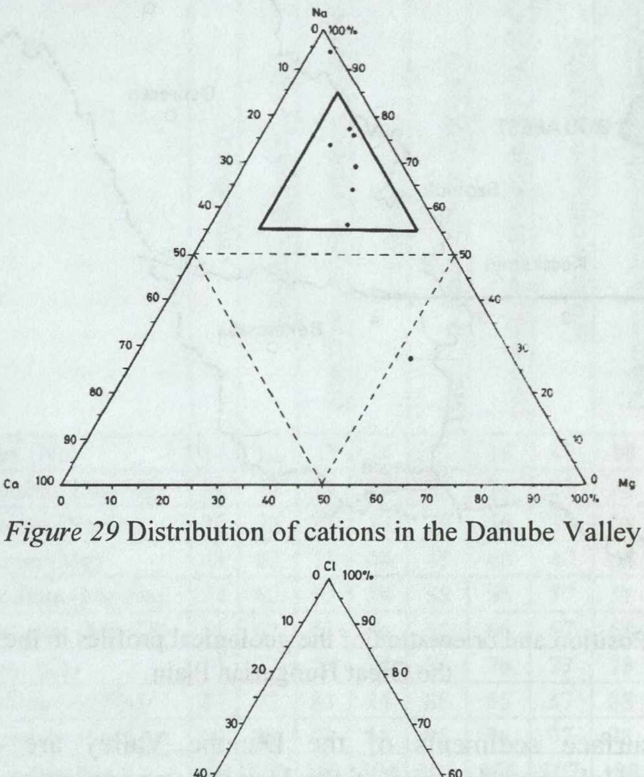

Figure 29 Distribution of cations in the Danube Valley

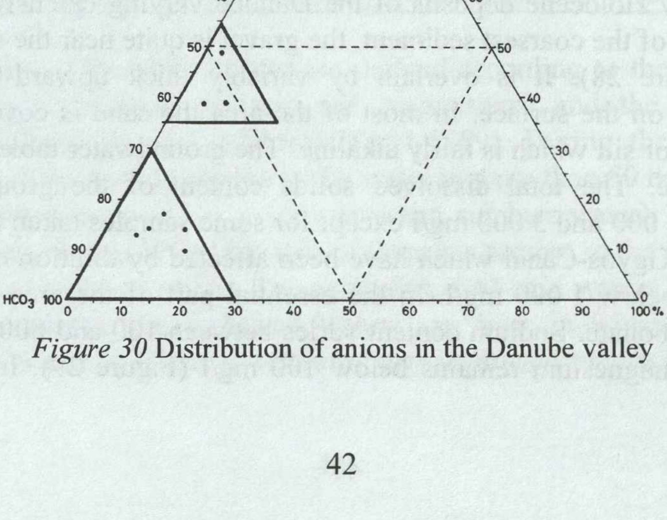

Figure 30 Distribution of anions in the Danube valley

The predominant sequences of the ridge between the Danube-Tisza interfluve are Pleistocene aeolian sediments including aeolian sand and loess (Figures 28, 31 and 34) extending generally in 2-3-m-thick horizons. At the same time it may also be characteristic that some of them become considerably thicker surpassing even 10 m. In the flats between the sandhills the sediments (silt, clay or calcareous mud) of some smaller and larger lakes formed of groundwater or precipitation can be observed transformed commonly alkaline. Further downward the profile lacustrine clay, silt and peat occur extensively proving that the onetime terrain was similar to that of today. The groundwater table is generally 2–6 m below the surface. In sand terrains it is closer to the surface than in loess areas.

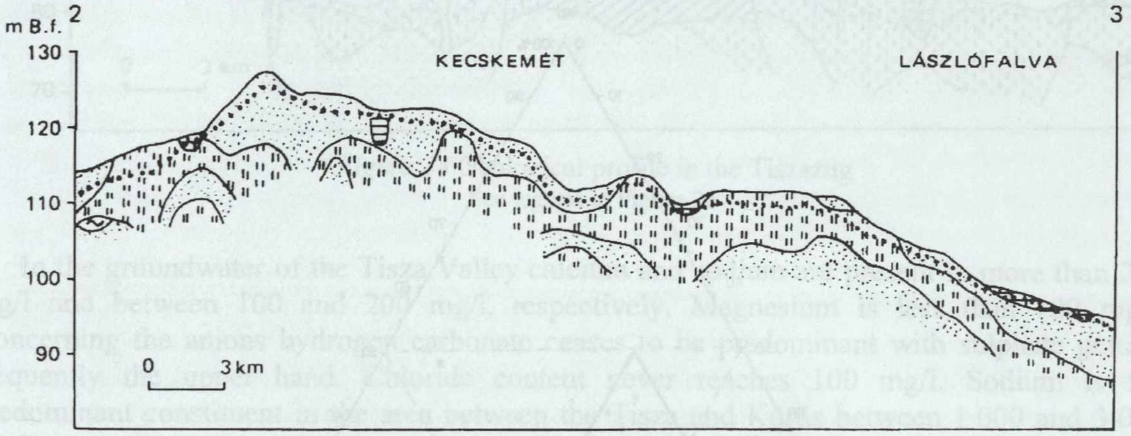

Figure 31 Geological profile in the ridge of the Danube-Tisza interfluve
See legend in Figure 28

The total dissolved solids content of the groundwater is between 500–1 000 mg/l but in the more-than-8–10 m-thick loess terrain it can be more. It is similarly quite high where the likelihood of groundwater contamination from the surface is high, like in the built-up area of Kecskemét or next to the densely set farmsteads. The groundwater is predominantly calcium-hydrogen carbonate and subordinately magnesium-hydrogen carbonate. Mixed waters are also quite common in which several ions are present in nearly the same amount. The calcium ion being around 100 mg/l rarely exceeds that but never achieves 300 mg/l. Magnesium varies between 10 and 20 mg/l. The amount of the sodium ion rises considerably in the groundwater below the flats between the sandhills and in residential areas, frequently exceeding 200 mg/l but it attains even 800 mg/l in one spot (Figure 32). The rising amount of sodium in the flats is due the conditions similar to that in the Danube Valley, whereas in residential areas it is induced by antropogenic pollution.

Concerning the anions hydrogen carbonate occurs in the highest amount in the ridge of the Danube-Tisza interfluve as well (500–800 mg/l). But in contrast to the Danube Valley the sulphate is qualified second becoming occasionally even predominant. Chloride content increases solely in the groundwater of residential areas (Figure 33).

In the Tiszazug superficial and near-surface sediments consist of the Late Pleistocene and Holocene deposits of the Tisza and Körös rivers (sand, silt, clay) so that younger sequences are deposited as incised in the older, previously laid down series of similar granulometric composition (Figure 34). The coarsest sediment is sand which is finer than the Danubian one and it is commonly silty. Apart from the bank of Körös made up of clay silt is laid down on the alkaline surface E of the meander belt of the river. The fourfold division is characteristic of the water chemistry as well, the meander belt of the two rivers is separated of the area of formerly deposited sediments illustrated on the profiles. Groundwater level is around 2–3 m below the surface, its total dissolved solids content varies between 600 and 9 000 mg/l so that in the Tisza Valley and in the Tisza–Körös interfluve it is 600–3 000 mg/l and 1 500–9 000 mg/l, respectively. In the Körös Valley it fluctuates between 500 and 1 100 mg/l but it exceeds 4 000 mg/l in one spot. E of the Körös Valley the dissolved solids content exhibits a slightly growing tendency. The chemical pattern of the groundwater is predominantly calcium-sulphate in the Tisza Valley, whereas it is of sodium-type with variable anion content in the area between the Tisza and Körös. In the Körös Valley and W of the Hármas Körös it is of sodium- eventually magnesium-hydrogen carbonate character becoming calcium-hydrogen carbonate E of the Hármas Körös. E of the Körös Valley the groundwater is of sodium-hydrogen carbonate pattern.

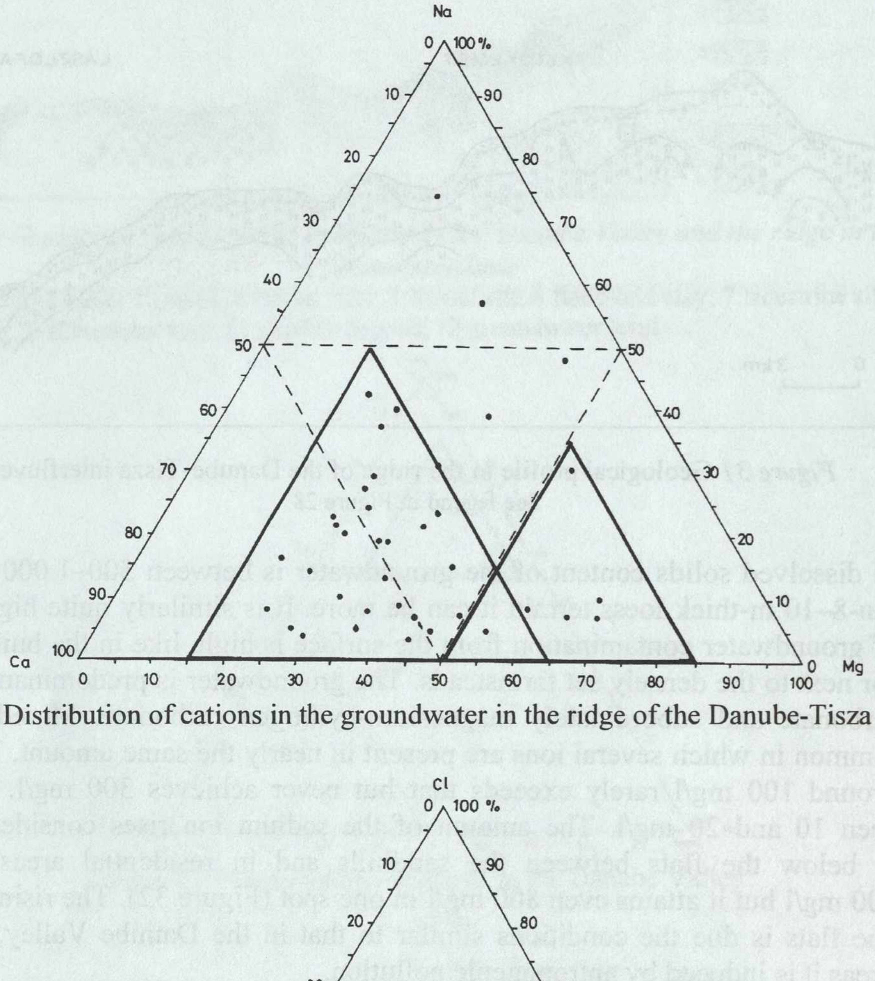

Figure 32 Distribution of cations in the groundwater in the ridge of the Danube-Tisza interfluve

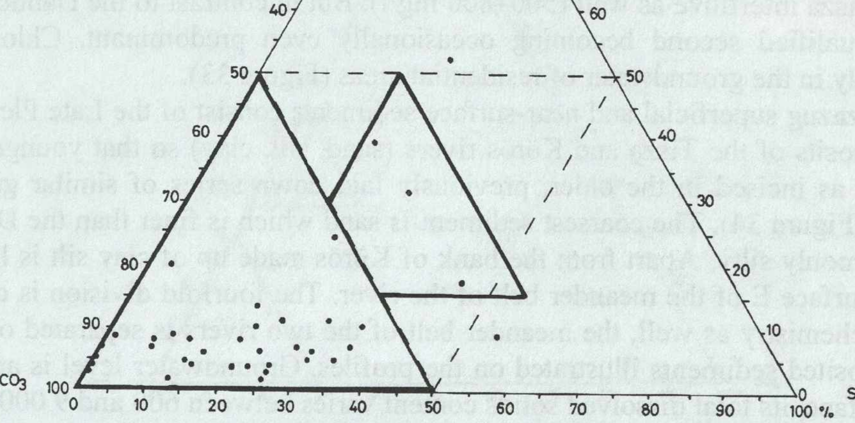

Figure 33 Distribution of anions in the groundwater in the ridge between the Danube-Tisza interfluve

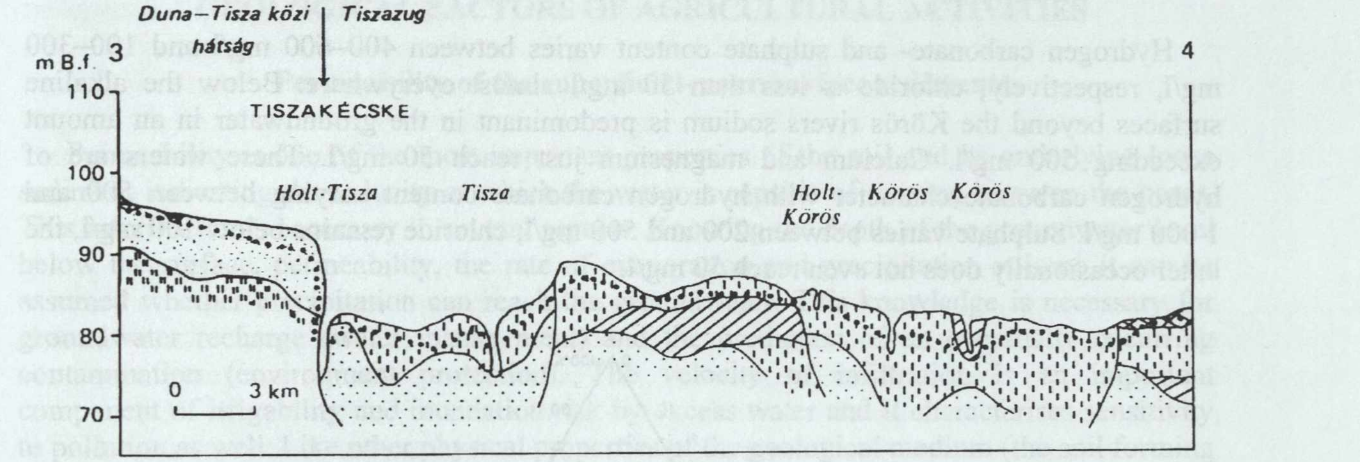

Figure 34 Geological profile in the Tiszazug
See legend in Figure 28

In the groundwater of the Tisza Valley calcium and sodium are present in more than 200 mg/l and between 100 and 200 mg/l, respectively. Magnesium is less than 100 mg/l. Concerning the anions hydrogen carbonate ceases to be predominant with sulphate getting frequently the upper hand. Chloride content never reaches 100 mg/l. Sodium is the predominant constituent in the area between the Tisza and Körös between 1 000 and 3 000 mg/l. Magnesium invariably surpasses calcium but it exceeds 1 000 mg/l only exceptionally rarely. Calcium remains below 50 mg/l. Both hydrogen carbonate and sulphate exceed 1 000 mg/l of which sulphate can occasionally be more in the water. The amount of chloride increases to the E becoming predominant with values surpassing 2 000 mg/l in the E margin of the area. The strong sodium-type character of the groundwater is due to the conditions similar to that in the Danube Valley. In the W part of the meander belt of the Körös sodium (50–500 mg/l) and calcium (150–300 mg/l) are the prevailing cations. Magnesium is rather scarce except for a small area where its amount in the water is equivalent to that of the sodium (400 mg/l).

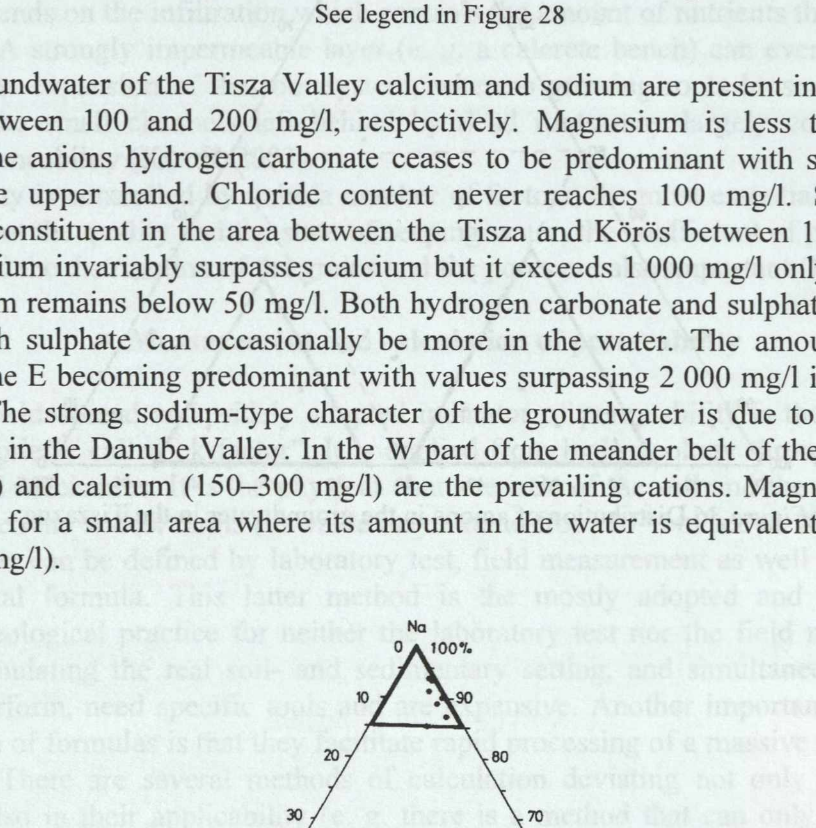

Figure 35 Distribution of cations in the groundwater in the Tiszazug

Hydrogen carbonate- and sulphate content varies between 400–600 mg/l and 100–300 mg/l, respectively, chloride is less than 50 mg/l almost everywhere. Below the alkaline surfaces beyond the Körös rivers sodium is predominant in the groundwater in an amount exceeding 500 mg/l. Calcium and magnesium just reach 50 mg/l. These waters are of hydrogen carbonate character with hydrogen carbonate content varying between 500 and 1 000 mg/l. Sulphate varies between 200 and 500 mg/l, chloride remains below 100 mg/l, the latter occasionally does not even reach 50 mg/l.

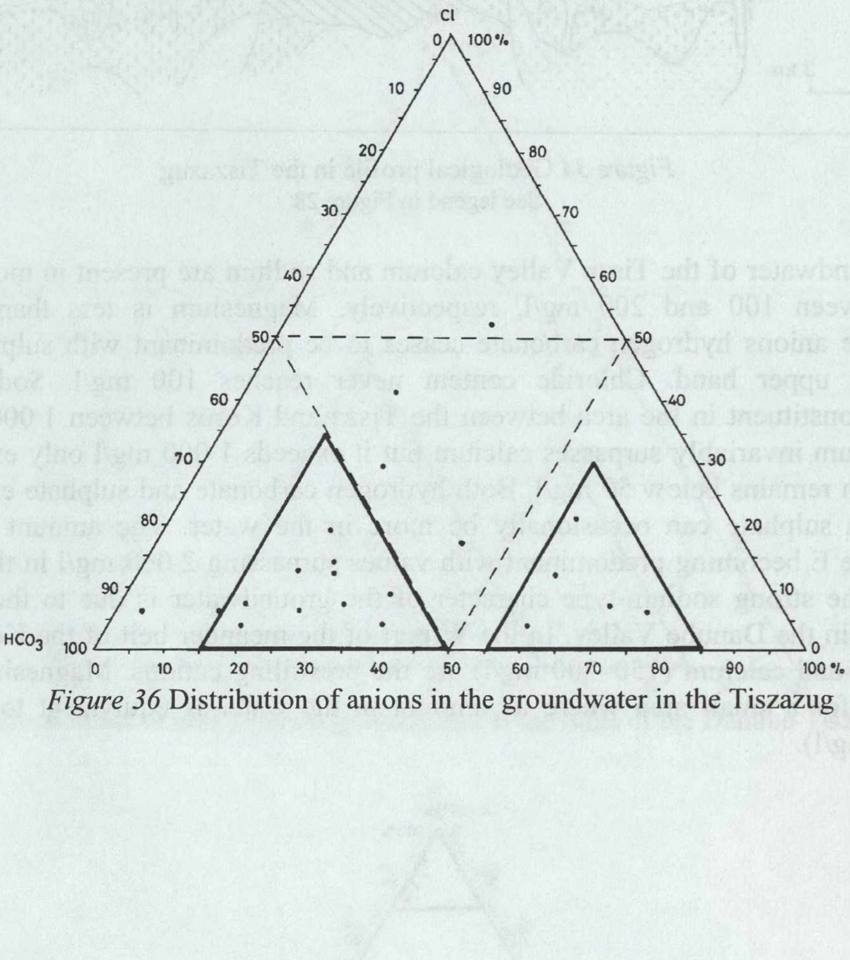

Figure 36 Distribution of anions in the groundwater in the Tiszazug

GEOLOGICAL FACTORS OF AGRICULTURAL ACTIVITIES

Permeability of the superficial–near-surface sediments

Permeability is one of the most important properties of the soil and its underlying loose sediment indicating the velocity at which the water is capable of moving between the pores. This information is necessary in several aspects. Knowing the depth of the groundwater level below the surface, permeability, the rate of evaporation and precipitation volume it can be assumed whether precipitation can reach the groundwater. This knowledge is necessary for groundwater recharge (water management) and the prediction of an eventually occurring contamination (environment protection). The velocity of infiltration is an important component of irrigability and inundation risk by excess water and it characterises sensitivity to pollution as well. Like other physical properties of the geological medium (the soil forming its part as well), permeability has a certain influence on the vegetation, for the humidity state of the soil depends on the infiltration which controls the amount of nutrients that can be taken up by plants. A strongly impermeable layer (e. g. a calcrete bench) can even be a physical obstacle for the expansion of the root system, whereas growing roots loosen the soil. This process like the small channels left behind by dead roots may largely contribute to the increase of permeability (KERÉK 2003).

Permeability is controlled by quite a number of factors, the most essential being the size of the grains but the quality and the state of seeping water, the coefficient of porosity as well as the form and the distribution of the grains and the pores are also important (KÉZDI 1960).

Measurement and calculation of permeability

The most widespread and widely adopted indicator of permeability is the coefficient of permeability, briefly called „k factor". It is applied from hydrogeology through engineering practice to soil mechanics. It is the physical characteristic of the soil and the loose sediment varying between the widest limits (its value may extend from 10^{-2} cm/sec to 10^{-12} cm/sec). Its numerical value can be defined by laboratory test, field measurement as well as by theoretic or experimental formula. This latter method is the mostly adopted and widespread in engineering-geological practice for neither the laboratory test nor the field measurement is capable of simulating the real soil- and sedimentary setting, and simultaneously, they are difficult to perform, need specific tools and are expensive. Another important argument for the application of formulas is that they facilitate rapid processing of a massive amount of data and samples. There are several methods of calculation deviating not only in the applied formula but also in their applicability (e. g. there is a method that can only be applied on sand).

Due to the complexity of the calculations attempts have been made in the Department of Agrogeology and Environmental Geology of the Geological Institute of Hungary to elaborate new methods which may replace the application of the k factor. During the 1960s András Rónai applied first the definition of the „clay ratio" worked out by him as the numerical characteristic of permeability (RÓNAI 1969). Thereafter in the early 1990s László Kuti attempted to use the sand–clay ratio for the same purpose in two pilot areas (KUTI–FARKAS–MÜLLER 1990).

The calculation of the coefficient of permeability (k factor) was performed by the procedure developed by E. A . Zamarin (MAKSZIMOV ed. 1967), for this method considers the whole granulometric domain. According to the procedure of Zamarin the integral granulometric curve should be divided in small intervals and specific values are calculated through multiplying them by the value of the exponential function defined by Zamarin corresponding to grain-size intervals. The result is the reciprocal of the predominant grain diameter calculated by summarising and averaging the received values (JUHÁSZ 1976).

The clay ratio corresponds to the joint weight percentage ratio of the clay (0-0.005 mm) and fine silt (0.005-0.02 mm). The sand–clay ratio is in turn the quotient of the weight percentage of the grains pertaining to the sand- (0.06-2.0 mm) and clay (less than 0.005 mm) fractions.

The calculations performed on the samples of the Bugac pilot area, in the Little Hungarian Plain and the NE part of the Great Hungarian Plain indicated that the k factor featured strong negative and strong positive correlation with the clay- and sand–clay ratio, respectively. The clay- and sand–clay ratios show an even more negative correlation with each other than with the k factor. The final result of the studies is that the k factor is in strong correlation with both the clay ratio (negative) and the sand–clay ratio (positive) considering the whole data set and the two groups as well. The same applies to the relationship between the clay- and sand–clay ratios. Consequently, the three methods can be replaced with each other but only at the existence of certain conditions. Provided that the sand–clay ratio is below 100 the clay ratio correlates better with the k factor than the sand–clay one, therefore it is reasonable to use the first one. On the contrary, if the sand–clay ratio is above 100 there is hardly any difference in the relationship of the two ratios with the k factor, any of them can thus be used (though by logic it is better to apply one method on the whole sample mass).

As a result and due to its reliability and more simple calculation method it was decided to apply the clay ratio for the determination of the sediments' permeability.

Table 2 Permeability expressed in the percentage of the clay fraction (0.000-0.02 mm Ø) according to A. Rónai

Weight percentage of the fraction below 0.02 mm grain diameter	Character of permeability	
0-10	Permeable	Perfectly permeable
10-20		Slightly retaining
20-40	Water storing	Good intake and good retaining capacities
40-60		Strongly retaining
60-80	Impermeable	Cracking
80-100		Strongly cracking

Sensitivity to pollution

Pollution is caused by man. He may bring about point-like contamination of the environment (area extending from some m^2 to some km^2) or induce expansive ones (through the medium of essentially dust depositing of the air or gases passing in the soil with rain water).

Pollutions in extensive areas appear directly on the surface and the soluble contaminants infiltrate slowly in deeper horizons by precipitation attaining down to the groundwater. On the contrary, point-like contaminations frequently happen to pass directly in deeper horizons instead of persisting on the surface, like during the damage of pipelines. In this case the pollutants passing in subsurface water contaminate the deeper horizons more extensively through the medium of the moving groundwater (VATAI 2000).

As a consequence, most contaminations affect not only the surface but the entire soil–parent material–groundwater system. It is therefore necessary to study the state of pollution of the geological medium and the groundwater stored and moving in it (playing often the role of transmitter).

In the domestic and international literature the notions „sensitivity” and „vulnerability” are different terms (ALFÖLDI 1994). Sensitivity considers the superficial–near-surface sequences on the given spot as well as the composition and the type of the aquiferous horizon, whereas vulnerability evaluates their spatial position and environment as well. For instance a sand layer with its groundwater horizon is sensitive but it is vulnerable only if protecting impermeable layers are missing on the surface or somewhere above it. Human intervention by establishing a well may abolish that protection as well.

The sensitivity of an area is essentially controlled by the permeability of the sequences above the groundwater level as well as the depth of the groundwater below the surface (the thickness of this complex). The less permeable the sequence above the groundwater level and the deeper the groundwater below the surface, the less sensitive is the given area. (Table 3).

In order to define the loadability of a specific area or set of sequences it is necessary to consider the granulometric composition and sorting of the sediment, the clay mineral content of the sequences, their liability to swelling or contraction, their adsorptive and cation bounding capabilities together with their organic matter content. For instance due to its high transmissibility sand and the groundwater stored in or beneath it are themselves sensitive to different sorts of contamination. However, this statement is not always true, for lysimetric experiments have proven that sands may feature rather important sewage cleaning capability even when the thickness of the transmissive layer is not more than 1 m (VERMES–KLIMÓ–FEKETE 1990, 1991), in other words they act as filters.

Table 3 Sensitivity of the areas to pollution

groundwater depth(m)	Permeability of the sequence above the groundwater level			
	permeable	slightly impermeable	intermediately impermeable	impermeable
<1	1	2	2	3
1-2	1	2	3	4
2-4	1	3	4	5
>4	3	4	5	5

1: very strongly sensitive >>>>>> 2 >>>>>> 3 >>>>>> 4 >>>>>> 5: insensitive
(Numbers from 1 to 5 are the codes of the legend of the sensitivity map)

The local background concentration level should also be considered for the definition of loadability that can vary quite extensively in different types of areas.

Geological factors of excess water and excess water risk

Excess water inundation is a specific geological event in lowland areas when seasonally but rather persistently water covers the surface in extensive areas (PÁLFAI 2001). Given that Hungary is a typically lowland country more than 45% of its surface is affected by risk of excess water inundation. Accordingly, it is a commonly occurring phenomenon in typically lowland countries or in those having extensive lowlands (e. g. Russia, Romania, China, Bangladesh), but its definition — as we will see later — considerably deviates. Excess water causes the most important damage first of all in farmlands but it can provoke serious problems within residential areas as well if the flattest sites were built in disregarding the laws of nature.

The task of agrogeology is the prediction of excess water risk based on geological factors that can be performed with reasonable accuracy by getting knowledge on its provoking processes and the geological setting as well as by the focused evaluation of the latter. Instead of the excess water occurring in the area the related prediction maps illustrate its possible appearances. Generally they answer the question whether the risk of excess water occurrence exists in the area or not. The decisive geological factors of excess water risk include the permeability of the superficial—near-surface sediments together with the groundwater depth below the surface.

For instance excess water hazard may be higher or lower depending on whether the surface is covered by impermeable or permeable sequences. Impermeable layers hinder namely to a more or less extent or eventually preclude completely the infiltration of precipitation accumulated on the surface in deeper horizons which will thus persist there for some time.

The possibility of excess water inundation is also influenced by the depth of the groundwater table below the surface. Excess water is brought about — or at least facilitated — namely by near-surface groundwater.

The formation of excess water is facilitated largely by near-surface groundwater table, whereas it is affected only slightly or not at all by deeper groundwater depending on its depth.

Areas are affected by excess water with highest probability if the uppermost impermeable sequence is on the surface and it is considerably thick since the superficial thick, impermeable sediment precludes or significantly hinders the infiltration of precipitation accumulated on the surface in deeper horizons, whereas a less-than-1-m-thick layer especially if it is easily cracking clay lets the water more readily through downward.

The deeper the uppermost impermeable layer in the near-surface 10 m profile and the thicker the less important is the risk of the occurrence of excess water.

Excess water hazard is least in the areas where impermeable layers are missing in the near-surface 10 m profile. Permeable layers do not namely affect the infiltration of precipitation accumulated on the surface towards deeper horizons.

Table 4 Probability of the occurrence of excess water as a function of the position and thickness of the uppermost impermeable horizon

Thickness of the uppermost impermeable horizon	Depth of the uppermost impermeable horizon below the surface				
	Impermeable horizon on the surface	<2 m	2-4 m	4-10 m	>10 m
<1 m	0.2	1.8	3.6	4.8	5
1-2 m	0.1	1.5	2.7	4.2	5
2-4 m	0.1	0.9	1.8	3.4	5
>4 m	0.1	0.3	1.1	3.0	5

Most probable Least probable

0.1 >>>5

Excess water risk in an area can most accurately be specified by the comparison of the superficial–near-surface sediments' permeability and the depth of the groundwater table below the surface.

Groundwater depths nearer than 1 m, between 1 and 2 m and below 2 m are considered for risk assessment. Comparing it with the permeability of the sequence above the groundwater in the area excess water risk can be specified as follows (Table 5):

1. The risk is of highest probability (80 %) if the groundwater depth is less than 1 m below the surface and
   - at least more-than-2-m-thick clay horizon can be found on the surface (C1). The clay of low permeability slows the infiltration of precipitation towards deeper horizons or the thin superficial layer becomes easily filled with water thanks to the cracks of the desiccated clay;
   - some 2-m-thick or thicker clay occurs below at least 2-m-thick silt on the surface (C2). In the silt of high capillary water lifting capability water rises close to the surface and

accelerates the saturation of the superficial deposit with water or the near-surface clay layer upwells the infiltrating waters;

- silt or clay occurs below at least 2-m-thick superficial gravel or sand (B1, B2). The finer-grained layers of low permeability near the surface may upwell the water seeping downward;
- some 4-6-m-thick or thicker silt is on the surface (B3) or at least 2-m-thick silt is underlain by sand or gravel (B3). In the silt of high capillary water lifting capability water rises close to the surface and accelerates the saturation of the superficial deposit with water or the near-surface clay layer upwells the infiltrating waters.

Table 5 Classification of the types of the disposition of sediments as a function of their sensibility to excess water risk (see the actual chapter)

Risk group		Type of the disposition of sediments
A	**A1**	011, 121, 122, 123, 132, 151, 152, 153, 181, 182, 183, 184, 185, 186,187, 188, 189
	A2	021, 221, 222, 223, 233, 261, 262, 263, 291, 292, 293, 294, 295, 296, 297, 298, 299
B	**B1**	131, 133, 141, 142, 143, 161, 162, 163 171, 172, 173, 174, 175, 176, 177, 178, 179, 191, 192, 193, 194, 195, 196, 197, 198, 199
	B2	231, 232, 241, 242, 243, 251, 252, 253, 271, 272, 273, 274, 275, 276, 277, 278, 279, 281, 282, 283, 284, 285, 286, 287, 288, 289
	B3	031, 321, 322, 323, 333 351, 352, 353,361, 362, 363, 381, 382, 383, 384, 385, 386, 387, 388, 389, 391, 392, 393, 394, 395, 396, 397, 398, 399
C	**C1**	041, 421, 422, 423, 431, 432, 433,441, 442, 443, 451, 452, 453, 461, 462, 463, 471, 472, 473, 474, 475, 476, 477, 478, 479, 481, 482, 483, 484, 485, 486, 487, 488, 489, 491, 492, 493, 494, 495, 496, 497, 498, 499
	C2	331, 341, 342, 371, 372, 373, 374, 375, 376, 377, 378, 379

2. The chance of excess water occurrence is high (60 %) when the groundwater depth is less than 1 m below the surface and the surface is covered by more-than-4-6-m-thick gravel- or sand horizon (A1, A2) or an at least 2-m-thick superficial gravel is underlain by sand (A1) or an at least 2-m-thick sand is underlain by gravel (A2). The near-surface groundwater upwells the infiltrating water but the latter has the opportunity to infiltrate in the sediments of high transmissibility further downward.

   Excess water risk is also high (60%) if groundwater level is between 1 and 2 m below the surface and an at the least 2-m-thick gravel or sand layer on the surface is underlain by silt or clay (B1, B2). In this case the finer sediments of lower permeability upwell the infiltration water or at least they hinder its seepage towards deeper horizons.

The chance of excess water occurrence is still high (60 %) if groundwater is deeper than 1 m below the surface, and

- an at least more-than-2-m-thick clay layer is on the surface (C1). The clay of low permeability slows the infiltration of precipitation towards deeper horizons but it is impossible or at least quite difficult for it to reach the deeper positioned groundwater.
- an at least 2-m-thick superficial silt is underlain by more-than-2-m-thick clay (C2). It is the clay layer of lower permeability which precludes or hinders the passage of infiltrating waters towards deeper horizons and it is upwelling and through the action of capillary water lifting it can return close to the surface and may meet with infiltrating waters.

3. The chance of excess water occurrence is intermediate (30 %) if groundwater is deeper than 2 m below the surface, and
    - an at least 2-m-thick superficial gravel- or sandbed is underlain by silt or clay (B1, B2). In this case groundwater is already deeper of the surface but the finer beds of low permeability may hinder or preclude the passage of infiltrating waters towards deeper horizons upwelling them.
    - some more-than-4-6-m-thick silt is on the surface (B3), or an at least 2-m-thick superficial silt bed rests on gravel or sand (B3). Groundwater rises readily in the silt of high capillary water lifting capability but due to the greater depth it has to cover a larger distance and it is thus difficult for it to meet infiltrating water.
4. The chance of excess water occurrence is low (10 %) if the depth of the groundwater table is between 1 and 2 m below the surface and a gravel or sand bed 4-6 m thick can be found on the surface (A1, A2) or an at least 2-m-thick superficial gravel- or sand layer is underlain also by sand or gravel (A1, A2). Infiltrating waters pass through the highly pervious beds without difficulty towards deeper horizons, only the groundwater table relatively close to the surface hinders them slightly.

Table 6 Chance of excess water occurrence

Chance of excess water occurrence %	Risk group according to the type of the disposition of sediments	Depth of the groundwater table below the surface in m	Risk code
0	A1, A2	>2	5
10	A1, A2	1-2	4
30	B1, B2, B3,	>2	3
60	C1, C2	>2	2
	C1, C2	1-2	
	B1, B2	1-2	
	A1, A2	<1	
80	B1, B2, B3, C1, C2	<1	1

5. There is not any excess water risk (0 %) if the groundwater table is deeper than 2 m below the surface and a gravel or sand bed more than 4-6 m thick covers the surface (A1, A2), or an at least 2-m-thick superficial gravel- or sand layer is underlain also by sand or gravel (B1, B2). Infiltrating waters pass through the highly pervious beds unhindered towards deeper horizons.

Basic geological aspects of erosion

The fertility of the topsoil is controlled by several factors. The most important of them is erosion. Soil degradation is a complex process taking place under natural conditions but it is also frequently initiated by antropogenic effects bringing about and accelerating adverse changes. It is important for far-sighted planning to be capable of predicting the risk and rate at which erosion occurs in order to prevent its provoking natural effects and to stop the human activities causing damage.

In our case erosion occurs essentially through the action of water. There are quite a number of factors controlling the degradation of the soil and the soil forming sediment including

- *relief* (slope steepness, form, length and exposure of the slope),
- *climate* (first of all precipitation conditions including its volume, intensity and temporal distribution),
- *the superficial sequence* (sensitivity to weathering, granulometric composition, dip of the beds as well as some other physical and chemical properties),
- *soil* (its genetic type, compactness, permeability, humus content, the state of its structure as well as some other physical and chemical properties),
- *vegetation* (rate of coverage, its type, extent of the root system, length of the vegetation period, etc.) and
- *anthropogenic impact* (nature of agricultural production, its intensity, the applied technologies, rate of irrigation, method of soil improvement and rate of grazing).

Particular attention should be taken to the parent material of this list, for it can determine the quality of the soil forming sediment and the soil evolving on it. Owing to the differences in their sedimentological pattern specific superficial deposits are affected by erosion in different ways. The low permeability of clayey soil forming sediments accelerates soil erosion inducing gully erosion. Loess is exposed to increased erosion due to its loose structure. But if degradation exposes buried soil on the surface it is capable of considerably attenuating the speed of the process though the underlying loess keeps degrading. It is especially important to pay due attention to loess, since it possesses the most advantageous physical and water management characteristics concerning agriculture. Sands are at less risk for they swallow a lot of water considerably decreasing the amount of surface water running off them. At the same time the soils of different tuffs are less resistant to erosion.

The soil forming sediment affects erosion not only through the medium of the soil evolved on it but directly through the relief forms as well. Different sediments are characterised by specific slope designs (e. g. convex slopes develop on loesses) due to their physical and chemical properties which in turn affects further erosion.

The erosion risk of an area depends on the erosion rate and its extent as well. In the case of different soil forming sediments the same erosion rate (how much % of the area is eroded) corresponds to different risk categories. With regard to silt the process proceeds smoothly from slight through intermediate to strong erosion. Clayey–marly sequences seem first to be more resistant though with erosion progress increasingly more important erosional patterns appear but serious risk occurs only if the erosion rate exceeds 80 %. Various types of loesses feature different pictures but if the areal erosion rate is low the sequence hardly degrades either. On the contrary, if degradation is in progress there is a sudden rise in the risk as well attaining the category of high risk at the erosion rate of 50 %. Gravelly and sandy areas feature extreme pictures. If erosion was initiated the process becomes very quick. Consequently, at the erosion rate of slightly more than 25 % the risk becomes already high. The above presented differences have a considerable impact on the methods and costs of soil protection as well.

Water erosion proceeds in different forms and at different rates. For instance splash erosion exerts its action through the detachment of soil clods and –crumbs, whereas it makes the soil more compact during rain showers. The degree of the negative effect depends on the rain's intensity, the diameter of the raindrops and the velocity of their impact.

Another type of water erosion is by overland flow called sheet erosion. This process can be observed if the amount of precipitation or melting snow exceeds infiltration. In this case water removes the finer soil components (clay fraction) and dissolves one part of the mineral constituents as well as the organic matter upsetting thus the soil structure and bringing about unfavourable conditions for the vegetation. The volume of the removed soil is different. The denudation of the topsoil rich in humus, nutrients and microorganisms may expose the more compact, less pervious accumulation level further decreasing thus infiltration and promoting erosion.

The third form of water erosion is accumulation by erosion. The denuded material may cause trouble not only by its deficiency but by its accumulation in lower terrains as well. Spreading out over the vegetation it may choke the plants but the deposition of an important volume of fine load can result in the formation of wetlands as well. Another cause for precaution is that the organic matter and all materials brought in the soil during farming like fertilizers and/or other chemicals are washed down together with the sediments especially with the soil. If they happen to reach still waters (e. g. Lake Balaton) they enhance their organic matter content increasing eutrophication.

To combat erosion it is necessary to attempt complex protection. While elaborating prevention methods attention should be paid to the local setting and integral protective measures must be taken for the whole catchment area. The unperturbed natural vegetation cover ensures appropriate protection. Consequently, if possible, it is highly recommended to strive for saving the state of such areas. The situation is different in cultivated areas, since adverse processes can be accelerated by human intervention there with the likelihood of the occurrence of new ones making constant observation indispensable. The possible forms of protection are proper land use management (setting up suitable parcels), improvement of the soil structure, appropriate nutrient- and water management, contour-line (e. g. terrace) cultivation, planned grazing, deep ploughing as well as other farming and sylvicultural protective measures. The combination of the different protection methods elaborated for the specific local conditions and their professional performance can bring the required results.

Approximately one-third of Hungary's agricultural land is covered by loose sediments subjected to soil erosion or to its risk. Therefore it is necessary to know the areas of the country which require special attention being the most sensitive to erosion.

Degradation of the soil is controlled essentially by three – previously already mentioned – factors: relief, precipitation and the granulometric composition of the superficial–near-surface sediments (i.e. the soil forming sediment). Relief properties can be characterised by slope steepness, whereas the Bacsó precipitation index was used for describing the precipitation conditions. The properties of the superficial–near-surface sediments are furnished by geological maps. The Farkas formula was applied to calculate the value of erosion risk based on these data as follows: $E_v=(L_k \times Cs_{ei})+T_{sz}$; where E_v, L_k, Cs_{ei}, and T_{sz} represent the degree of erosion risk, the value of slope steepness, the precipitation index and the type or granulometric composition of the superficial–near-surface sediments, respectively. On the basis of the values received by the formula the investigated areas can be assigned to 4 categories according to the rate of risk (not threatened, slightly, intermediately and strongly threatened) (Table 7).

The maps of erosion risk provide prediction on the anticipated processes to which geology furnishes a reliable basis. The soil forming sediment determines the main properties of the soil evolving on it while the parent material controls the slope conditions. The geological setting may both facilitate and hinder the process of erosion.

Table 7 Factors provoking and controlling erosion

Number of the category	Slope steepness % (L_k)	Precipitation Bacsó index (Cs_{Ei})	Superficial sequence, soil forming sediment (T_{sz})
1	0 - 5	< 20	solid rock, boulder, gravel
2	5 - 15	20 – 30	coarse sand
3	15 - 25	30 – 40	clay, muck, peat
4	25 <	40 – 50	clayey silt
5		50 – 60	silt, fine sand, silty sand
6		>60	sandy silt

The related maps indicate the areas where strict measures for soil protection have to be taken but they also facilitate to select the crops which are optimal for the related environment. The position and the extent of the areas requiring most precaution can also be determined providing a reliable basis for prevention and the necessary rehabilitation.

Geological factors controlling deflation

Wind erosion i. e. deflation exerts its influence in loose sediments.

The most important geological factor controlling wind erosion is the granulometric composition of the sediments for the sequences coarser than fine silt and finer than medium-grained sand i. e. in the domain between 0.02 and 0.5 mm are mostly affected by deflation. Within this limit it is true in initial state that the less the diameter of the grains and the looser the binding between them and to the soil surface the higher is the probability that they become picked up by the wind. On the contrary, the grains of fine silts and clayey sediments below the 0.02 mm limit of diameter adhere already to each other and the wind cannot cling in them and pick them up. The grains above the limit cannot be transported by the wind due to their own weight, it can only roll them in short distance. It is not infrequent in the aeolian sand terrains of Hungary — mainly in the ridge of the Danube-Tisza interfluve — that coarse sand becomes enriched on the surface of sand dunes like „serirs". Similar sediments formed also in the earlier periods of Pleistocene proven by the otherwise poor number of exposures in the Little Hungarian Plain in which it was succeeded to describe some-mm- (maximum 10-mm-) thick sandstone layers with calcareous cement quite frequently.

In the sediments with little fines (<0.02 mm diameter) and colloids (clay, humus) the cohesion between the grains decreases which in turn enhances the possibility of aeolian transport. Consequently, if the amount of the fine fraction and colloids is less than 15 % in the sandy deposits the wind can blow them out of the related sediments and picks them up with the sand grains and it can carry them even farther than the sand.

The rate of deflation is affected also by the density of the grains and their unit weight depending on the mineralogical composition of the specific sequences.

If the density of the organic matter of the soil (humus) is low a considerable amount of organic matter can be blown out of the granular, coarser sediments. If in turn the surface is covered by coherent deposits they are practically not affected by the wind even if the volume of the sand fraction is quite high.

If fine grains are adhered to crumbs by the organic matter in the sediment and it dries out these crumbs behave like sand grains i. e. they can easily be picked up and blown out by the wind.

Groundwater depth is also an important geological factor. Humidity facilitates the grains to adhere stronger to each other and the wind cannot thus cling in them. Even humid sand can resist to wind erosion until it dries out. It is also true in turn that through the action of the wind it can more easily dry out than the finer-grained sediments.

The capillary water lifting of the sand is lowest in the sediments endangered by deflation which also enhances the possibility of drying. Consequently, the related areas eventually with deep groundwater table dry easily out and if vegetation cover is missing they can easily fall a victim to wind erosion.

Our observations showed that the groundwater depth of less than 2 m is advantageous concerning the resistance of the sediments to deflation but in the case of sands — as it was discussed above — the groundwater level needs to be fairly shallower in order to avoid wind erosion. Consequently, based on geological factors those areas are regarded to be affected by deflation risk where the surface is covered by sand and the groundwater is deeper than 2 m below the surface.

Acidity state of the soils

In agrogeology the term acid medium corresponds to carbonate-free environment independently of the pH (e. g. acid sands in Nyírség).

The factors responsible for the acidification of the soil can be assigned to two main categories. The first one is represented by natural factors including the presence of acid soil forming sediment, the leaching of precipitation, root respiration, root acids, humic acids and other organic acids. Acid soil forming sediments give rise to the formation of carbonate-free soil which is the result of natural processes. They are not to be assigned to acidified soils and if agriculturally utilised it is recommended to change the cultivation method or to grow crops resistant to acidity. On the contrary, if the acid parent material gave rise to acid-free or slightly acid soil it has high sensitivity to acidification due to its low buffer capacity. The second category is represented by acidification factors brought about by man including the deposition of acid materials falling of the air, acid rain, the use of inappropriate chemical and organic fertilizers, calcium extracted by the crops as well as acidising materials passing in the soil by waste water, waste water mud and wastes. With regard to the acidification effect there is not any major difference between the stable- and chemical fertilizers, since the nitrogen occurs in the same form in them (NH_3, NH_4, NH_2).

The final result of all processes specified above is the drop of the pH of the soil brought about by the enrichment in H-ions in the soil solution. However, due to its buffer capacity the soil is capable of delaying the changes adsorbing the H-ions or by exchanging them to other cations. This process enhances in turn the degree of potential acidity, for the bounded H-ions can return in the soil solution if their amount drops there (e. g. through the action of liming). Consequently, apart from measuring the pH of the soil solution it is also necessary to record the amount of the H-ions on the surface of the colloids. The attenuating capacity depends on the quality and amount of the soil colloids including first of all the humic matters and clay minerals, on the presence of readily weathering silicate minerals as well as on the carbonate content and the type of carbonates (if the soil is carbonated).

During the agrogeological survey higher emphasis was put on the study of carbonates, for acidification triggers first the dissolution of carbonates and other buffer materials go into action only after the carbonates' amount decreased considerably. The definition of the amount and the type of carbonates (quickly or slowly soluble carbonates) gives comparatively rapid result even in the case of a large mass of samples facilitating thus the determination of the sensibility of larger areas to acidification. Carbonates in soil may derive from the parent material, but they may also have been carried there by transport. The few calcareous crusts also belong to this category.

Clay minerals exert their buffer effect through their cation exchange capacity. The rate of this effect is controlled by the cation exchange capacity varying by clay minerals. Montmorillonite features the most important one, its presence in the soil is thus the most favourable concerning the attenuating effect. Without the need to be complete it is followed by halloysite, illite, chlorite and kaolinite.

The readily weathering silicate minerals (e. g. feldspar, pyroxene, amphibole, olivine, and biotite) are the least important concerning acidification, for their dissolution takes a long time and as a consequence they feature a rather limited proton-binding capacity.

The specification of the areal extent of acid soils is not the task of geology. Nevertheless, the illustration of acid media facilitates to separate the soils developed on originally acid parent material of those acidified under antropogenic impact. We think that the distinction between these two categories (acid and acidified) is of utmost importance concerning soil protection since the treatment of unperturbed soils requires quite different approach than those changed by human activities.

With regard to the evolution of autochtonous soil forming sediments superficial sediments are classified in two groups. The first one is the group of the so-called „hard" rocks. They are subdivided according to the classic geological classification. Concerning sedimentary rocks the ones of high carbonate content are regarded as protected of acidification including limestones, dolomite, calcareous marls as well as all sandstones, breccias and conglomerates having carbonate matrix. All carbonate-free sedimentary rocks are considered acid. Regarding magmatic sequences all volcanic, effusive rocks are carbonate-free they are thus qualified acid. The majority of deep magmatic rocks are also carbonate-free except for the domains crossed by a dense network of dykes of hydrothermal origin filled with carbonate (calcite-bearing) dyke rocks. The assignment of metamorphic rocks depends on the carbonate content of the original, pre-metamorphic rock not yet subjected to metamorphosis. Consequently, metamorphites formed of sedimentary rocks of originally high carbonate content are insensitive to acidification.

Geologically speaking those areas are regarded sensitive to acidification that did not form in an acid environment and whose carbonate content is capable of counteracting the acidification effects only for a short period of time. The sequences with very low carbonate content (less than 5 %) are not really at risk since following the total elimination of the carbonates the sequence cannot further be acidified. The deposits of high carbonate content (more than 30 %) are not threatened either for the large volume of carbonates is capable of attenuating the acidification effects for long. The areas with intermediate carbonate content (between 5 and 30 %) and under agricultural cultivation are in turn the sensitive ones since under natural conditions the processes are much slower and a state of equilibrium persists. The type of carbonates also plays a role since a slowly soluble carbonate (dolomite) features smaller buffer capacity at the same percentage ratio than a rapidly soluble one (calcite), due to the difference in the speed of the processes.

Special attention needs to be paid to areas where changes are taking place today (acidifying category). If the geological medium does not justify soil acidification it was brought about by human action then. In the case of dropping carbonate content as a result of agricultural cultivation regular soil improvement is required to stop or eventually reverse the process in order to sustain fertility.

As a function of the original soil properties soil acidification can have different consequences including in general the decrease in carbonate content and buffer capacity, the growing intensity of weathering, the decrease in the potential of taking up several important nutrients, the mobilisation of toxic heavy elements, the diminishing efficiency of the use of fertilizers and biological degradation.

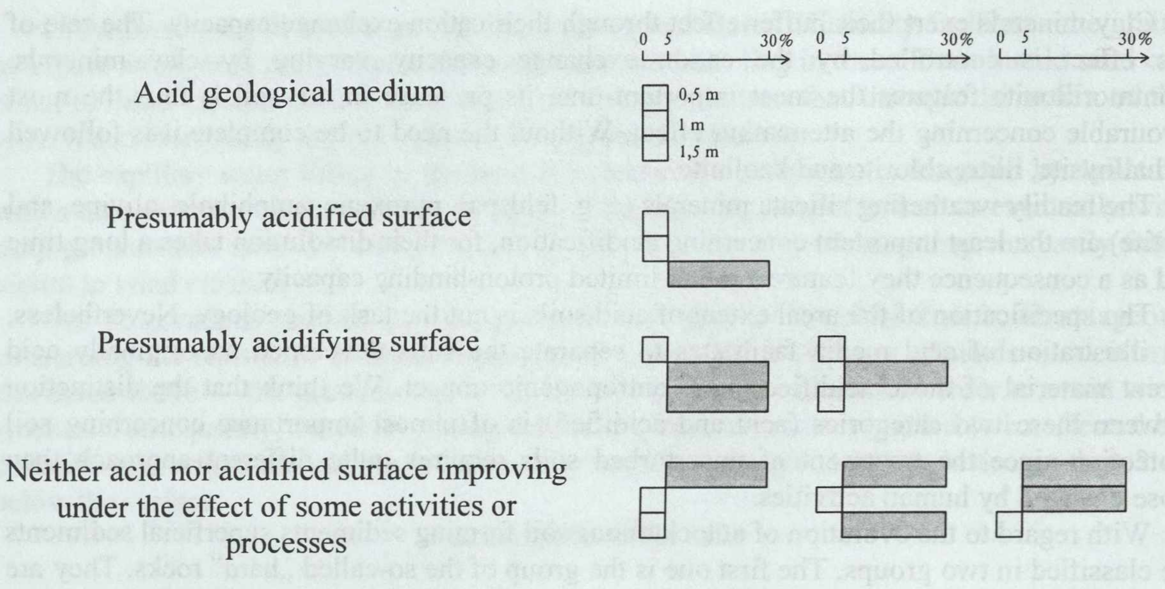

Figure 37 Possible occurrence of acidification according to the calcium carbonate content of the superficial–near-surface sediments

Geological factors of salinisation

The formation of alkaline areas is controlled by their geological setting as well as the geological processes affecting them. The factors controlling and influencing the process of salinisation can be listed as follows: depth of the groundwater table below the surface, altitude of the groundwater table above sea level, chemical type of the groundwater and its total dissolved solids content as well as the type of the disposition of sediments and the granulometric composition of the sequences located in the fluctuation zone of the groundwater and above it.

Extensive unbroken alkaline areas occur in Hungary in river valleys and deep-lying regions covered by fluvial sediments. Some smaller alkaline spots can also be found in more elevated lowland regions divided by hills and flats e. g. in the ridge of the Danube-Tisza interfluve or in the N margin of the Great Hungarian Plain. Seasonal or permanent alkaline lakes and flats formed there in the small valleys between the hills and sand dunes. Their surface is invariably covered by fine sediments including silt or clay resting commonly on sand of high transmissibility.

Field observations indicated that the process of salinisation is strictly controlled by a specific groundwater level. In the areas where the alkaline surface is underlain by sand i. e. the sequences possess low capillary water lifting capacity principally the dissolving effect of the groundwater rising close to the surface prevails. The groundwater level is between 1 and 2 m below the surface there. It was also observed in these areas that with considerably dropping groundwater level the process of unsalinisation started.

In the areas where the alkaline surface is underlain by silt or occasionally clay the salts can comparatively frequently be brought up close to the surface from the deeper positioned groundwater through stronger capillary water lifting.

The fluctuation of the altitude of the groundwater table above sea level determines the groundwater flow, and it defines the directions of the groundwater seepage from higher towards lower located areas (KUTI et al. 2002a) (Figure 38).

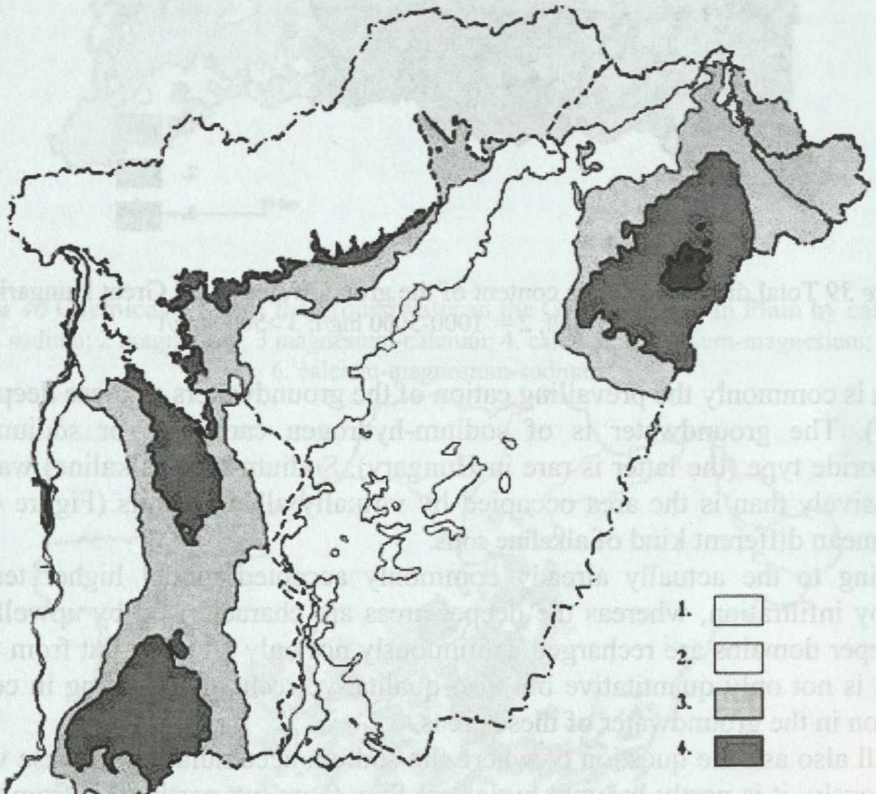

Figure 38 Altitude of the groundwater table above sea level in the Great Hungarian Plain
1 <80 m; 2 = 80-100 m; 3 = 100-120 m; 4 = 120-150 m; 5 = 150-240 m

Considering the pattern of the groundwater's total dissolved solids content it is also obvious that waters of higher solids content extend invariably below the above specified deeper domains (Figure 39). The total dissolved solids content of the groundwater frequently reaches or even surpasses 5 000-10 000 mg/l there, attaining even to 30 000 mg/l in extreme cases in the end of long warm and dry periods.

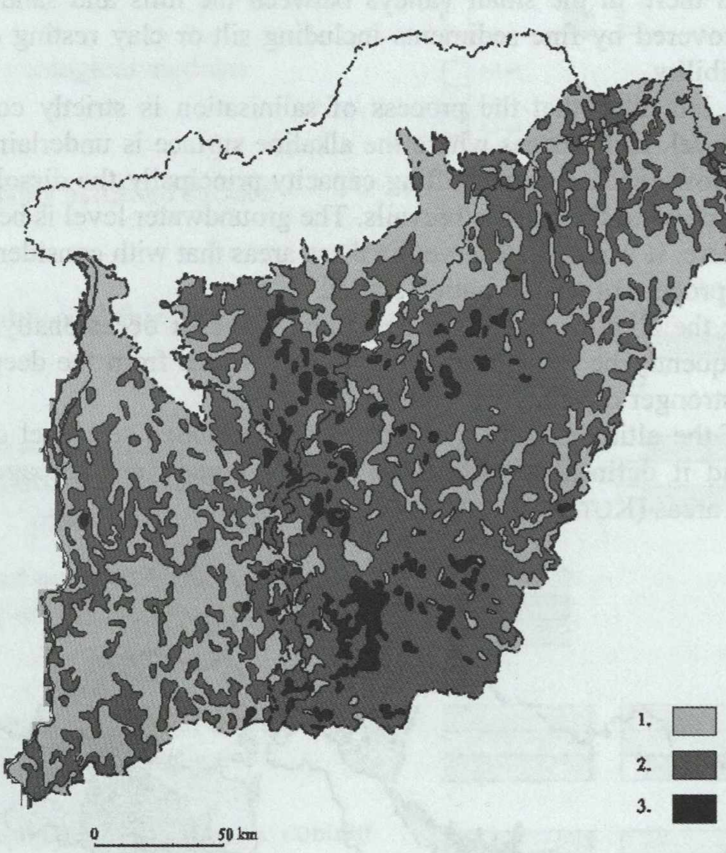

Figure 39 Total dissolved solids content of the groundwater in the Great Hungarian Plain
1 <1000 mg/l; 2 = 1000-5000 mg/l; 3 >5000 mg/l

Sodium is commonly the prevailing cation of the groundwaters of these deeper lying areas (Figure 40). The groundwater is of sodium-hydrogen carbonate or sodium-sulphate or sodium-chloride type (the latter is rare in Hungary). Sodium-type (alkaline) waters occur far more extensively than is the area occupied by virtually alkaline soils (Figure 41). Different grey tones mean different kind of alkaline soils.

According to the actually already commonly accepted model higher terrains can be described by infiltration, whereas the deeper areas are characterised by upwelling. It means that the deeper domains are recharged continuously not only laterally but from underneath as well which is not only quantitative but also qualitative recharge resulting in continuous salt accumulation in the groundwater of these areas.

We shall also ask the question of where the sodium accumulating in these waters derives from. Obviously, it is partly brought by lateral flow there but partly also from underneath of deeper horizons, for these areas are unambiguously positioned in the zone of upwelling. It is quite obvious of the data of deep wells that the sodium ion content of deep subsurface waters is quite considerable. Consequently, due to the upwelling continuous sodium replenishment is ensured in these areas. For that matter sodium is suggested to be dissolved of Pannonian or Early Pleistocene deposits across which subsurface water percolates for more or less time.

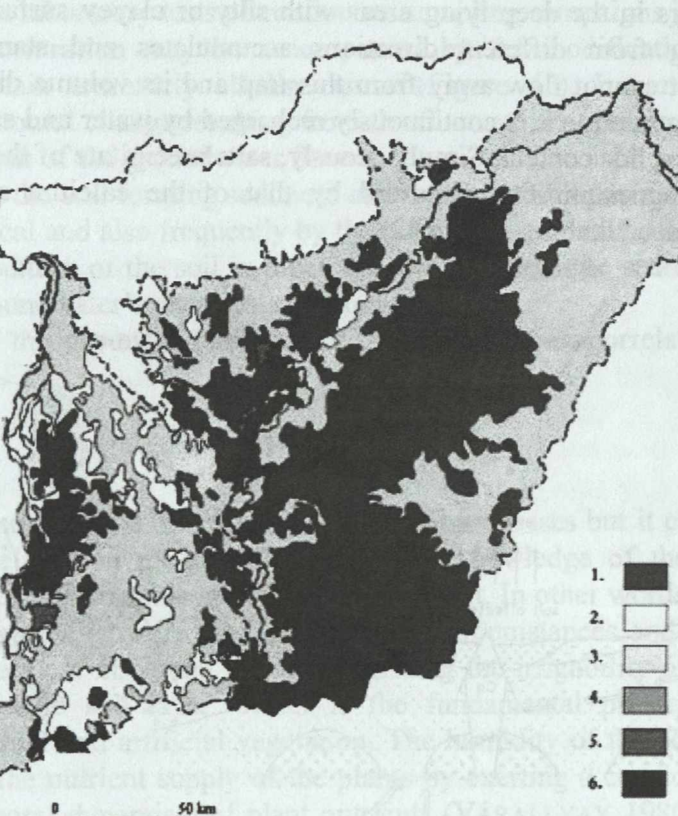

Figure 40 Chemical types of the groundwater in the Great Hungarian Plain by cations
1 sodium; 2 magnesium; 3 magnesium-calcium; 4. calcium; 5. calcium-magnesium;
6. calcium-magnesium-sodium

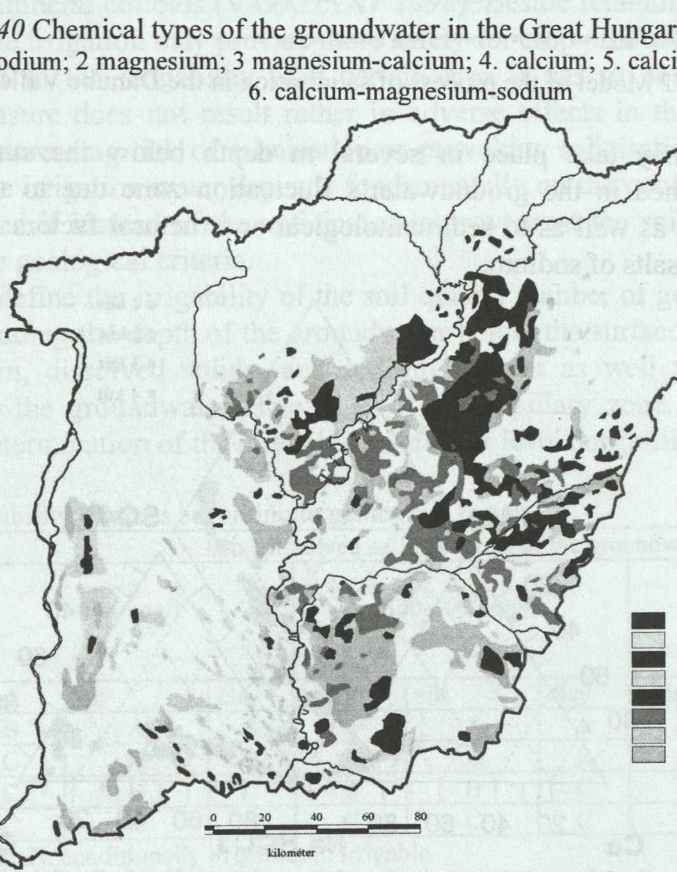

Figure 41 Alkaline soils in the Great Hungarian Plain (after Szabolcs, Várallyay and Mélyvölgyi, 1974)

Salinisation occurs in the deep lying areas with silty or clayey surface cover where the groundwater flowing from different directions accumulates and stands still becoming practically trapped. It cannot flow away from this trap and its volume diminishes solely by evaporation. At the same time it is continuously recharged by water and salts densifying thus with rising dissolved solids content. Simultaneously, salts precipitate of the evaporating water with the salts of magnesium first followed by that of the calcium and finally sodium transforming the surface alkaline (Figure 42).

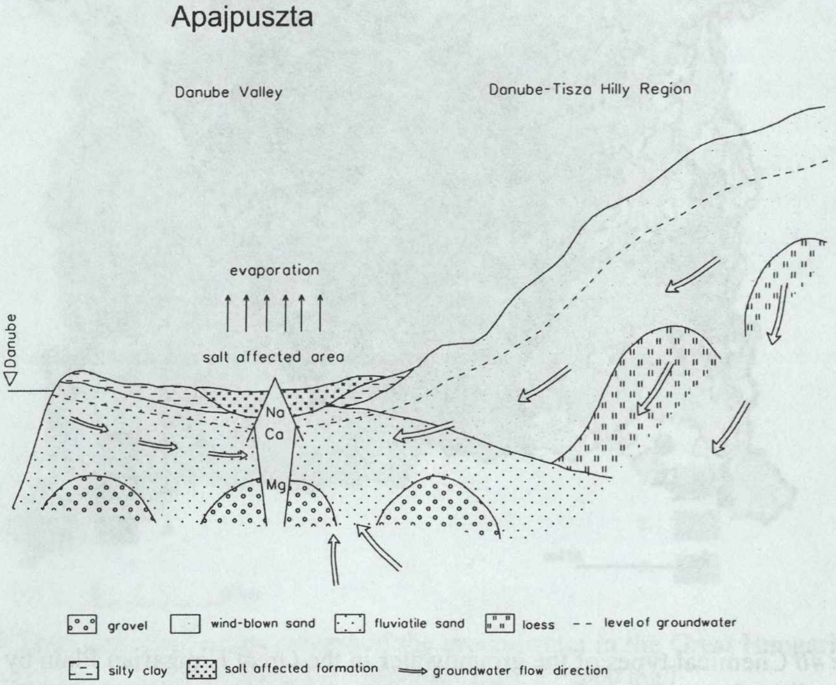

Figure 42 Model of the process of salinisation in the Danube Valley

The same process may take place in several m depth below the surface, where a geochemical trap is formed in the groundwater's fluctuation zone due to the type of the disposition of sediments, as well as to sedimentological or structural factors resulting in the precipitation of different salts of sodium.

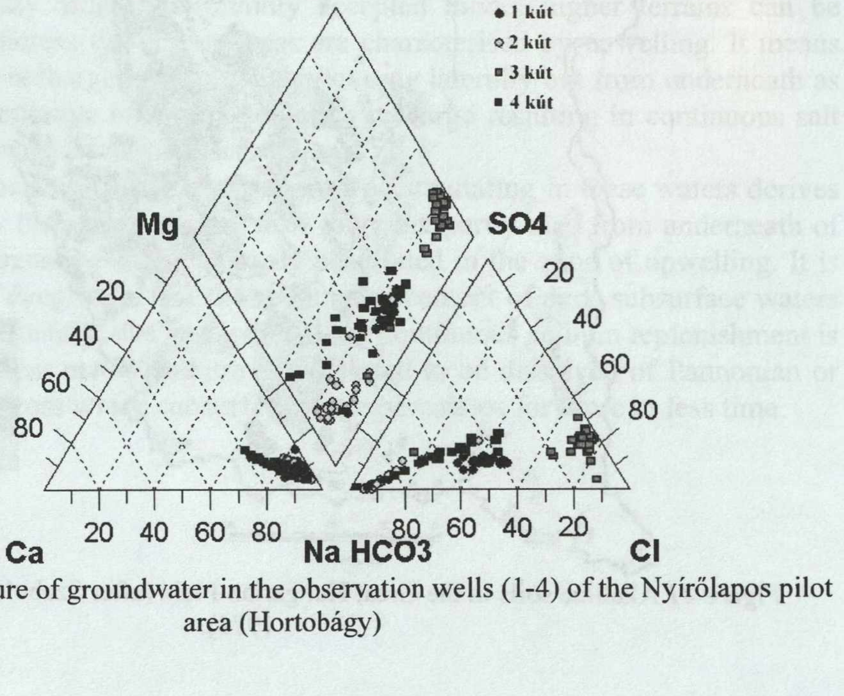

Figure 43 Change in the nature of groundwater in the observation wells (1-4) of the Nyírőlapos pilot area (Hortobágy)

The results of the laboratory tests of continuous sampling campaigns justified also that the change in salt concentration may be accompanied by the modification in the nature of groundwater in certain extremely alkaline areas (Figure 43). It can be due with high probability to a horizontal change resulting from the fluctuation of the groundwater i. e. to the change in the direction of the groundwater flow.

It is obvious that the soil forming sediment and the soil development in a specific area are affected by the vertical and also frequently by the horizontal groundwater flow i. e. the reason of the mosaic-like pattern of the soil in a certain area must also be searched for in the local deviations in the groundwater's chemical composition.

The position of the groundwater level and its composition correlates with its altitude above sea level.

Irrigability

Salinisation cannot only be the result of geological processes but it can be brought about by inappropriate melioration measures as well. The knowledge of the irrigability of the related areas provide indispensable information to avoid it. In other words it shows whether it is reasonable to irrigate a specific area, under which circumstances and with which type of irrigation water. The most important aspect in defining the irrigability of an area is thus the protection of the fertile soil layer. Water is the fundamental prerequisite of plant life concerning both natural and artificial vegetation. The humidity of the soil controls not only the water- but also the nutrient supply of the plants by exerting a considerable influence on the spatial and temporal dynamism of plant nutrients (VÁRALLYAY 1980). The fundamental reason of the increased sensitivity of sand soils to drought is the absence or deficiency in organic and/or mineral colloids (VÁRALLYAY 1998). Beside retaining natural precipitation as much as possible irrigation may provide more safety for crop production (PÁLFAI 1999).

With regard to the irrigability of a certain area it has to be considered whether the benevolent measure does not result rather in adverse effects in the fertile soil concerning especially the increasing risk of salinisation or provoking salinisation. The effect as well as efficiency of the irrigation water depends fundamentally on the geological environment. It is not just the same if instead of the anticipated improvement the soil degrades as a result of disregarding the geological criteria.

In order to define the irrigability of the soil quite a number of geological factors must be considered including the depth of the groundwater below the surface, its flow characteristics, chemical pattern, dissolved solids- and sodium content as well as the properties of the horizons above the groundwater table, i. e. of the capillary zone. Their complex analysis results in the determination of the critical groundwater level concerning irrigation.

Table 8 Irrigability of areas according to geological factors

Ground-water depth (m)	Total dissolved solids content of the groundwater								
	<500 mg/l			500-1000 mg/l			>1000 mg/l		
	sand	silt	clay	sand	silt	clay	sand	silt	clay
<1	B	A	A	A	A	A	A	A	A
1-2	C	A	B	B	A	B	A	A	A
2-4	C	B	C	C	B	C	B	B	B
>4	C	C	C	C	C	C	C	C	C

A: not irrigable, B: conditionally irrigable, C: irrigable

To start with groundwater depth it is assigned to the classes 0.0-1.0 m, 1.0-2.0 m, 2.0-4.0 m and > 4.0 m whereas its total dissolved solids content must be considered with the limits of 500 mg/l and 1000 mg/l. This classification is to be further refined based on the granulometric composition of the sequences due to the relationship between grain size, the height of the groundwater rising in the soil and the capillary water lifting capability of the deposit. In the related analysis sediments are assigned to three categories concerning their grain size as follows: sand (dominant grain size > 0.06 mm), silt (dominant grain size between 0.02 and 0.06 mm) and clay (dominant grain size < 0.02 mm; the clay and fine silt fractions were joined here) (Table 8).

The capillary lifting is the highest and least persistent in silts, whereas it is fairly lower but slower and persistent in clays. In sands following a slight, rapid rise the capillary water persists practically on the same level.

According to all these aspects it can be stated that sand soils can be irrigated though with certain conditions if groundwater is closer than 1 m to the surface and its total dissolved solids content does not exceed 500 mg/l. At groundwater depth between 1 and 2 m and total dissolved solids content below 500 mg/l or groundwater depth between 2 and 4 m and total dissolved solids content between 500 and 1 000 mg/l irrigation may proceed without particular reservations. For silts irrigation is prohibited even if groundwater depth is between 1 and 2 m and the total dissolved solids content remains below 1000 mg/l and it may proceed only with certain conditions at groundwater level between 2 and 4 m and total dissolved solids content less than 500 mg/l. Concerning clays irrigation may proceed without particular reservations even at groundwater depth between 2 and 4 m and total dissolved solids content between 500 and 1000 mg/l (Table 8).

Rapidly flowing groundwater exerts a beneficial effect on the irrigability of sandy areas for it is a further improving factor. If groundwater moves rapidly irrigation may proceed at groundwater depth between 1 and 2 m and total dissolved solids content exceeding 1000 mg/l with certain precautions, and at groundwater depth between 2 and 4 m and total dissolved solids content exceeding 1000 mg/l without particular reservations.

During the qualification process the sodium content of the groundwater should also be considered. If it is present in high amount it can become a seriously adverse factor. Exceeding 40 % it presents a certain risk of salinisation.

According to a 1998 data (PÁLFAI 1999) the irrigated area of the Great Hungarian Plain under agricultural cultivation amounts solely to 8 %. It can be explained by the water charge, the comparatively high investment need and operation costs of irrigation, the eventual harmful side effects including salinisation and the formation of marshes (VÁRALLYAY 1980) as well as the unavailability of irrigation water of required quality (e. g. too salty groundwater).

Chlorosis

The thickness of the fine sediment developed on hard rock or its type may be factors provoking chlorosis.

The yellowing of the vine leafs raised the attention of the experts already in the 19th century. Initially, it was suspected that it is caused by a pest like phylloxera but it was not justified by experiments, for healthy vines inoculated with the sap of yellowing leafs did not turn yellow, moreover the process of yellowing was observed in a certain area on several plants including e. g. on the blackberry offshoots, peach trees, willows and even on some weeds as well. Hence the possibility of the role of the soil was also brought up as a likely cause to be investigated provoking the adverse change. It can be associated essentially with the *continuous* supply of the plant by or its deficiency in mineral materials, nutrient- and trace elements since iron, magnesium and potassium – to mention only the most important elements – are built in the components lending the green colour to the leafs including the vitally important component of the photosynthesis, the polysaccharides of the chlorophyll.

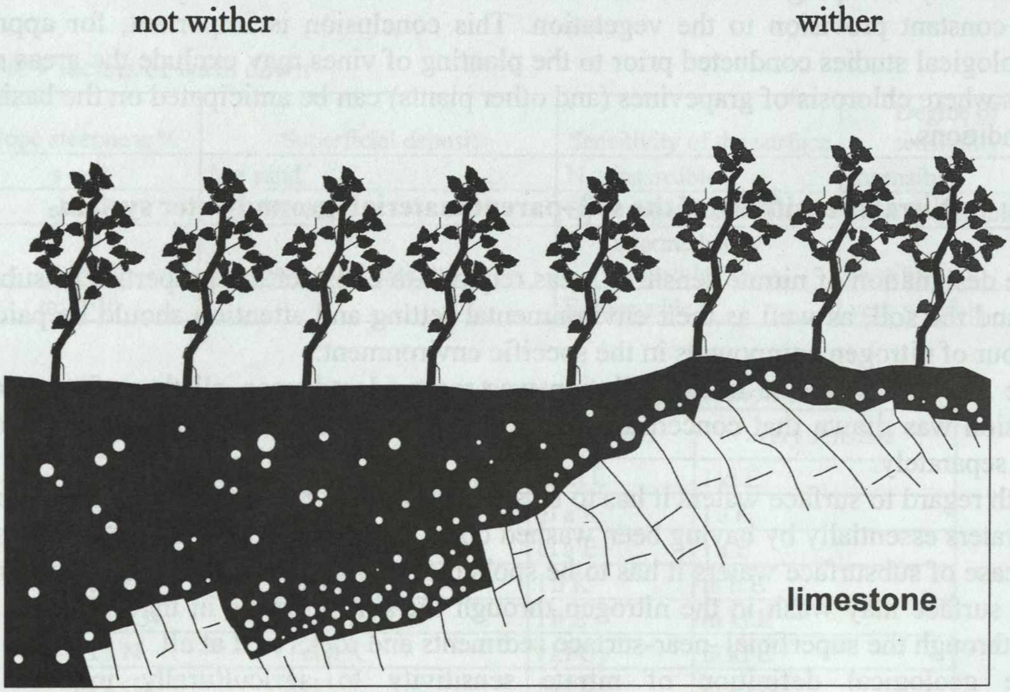

Figure 44 Chlorosis in limestone areas

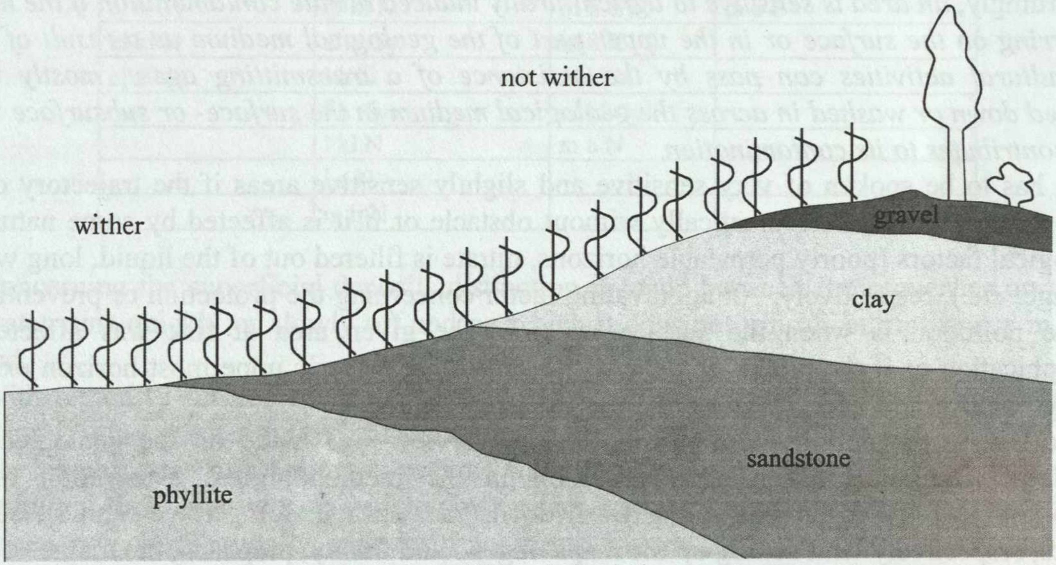

Figure 45 Chlorosis in shale areas

Our research on the lime-film-bearing skeletal soils of the Balaton Highland contributed with some results to solve this problem. It was proven in the three investigated pilot areas of different geological setting (Lovas, Balatonudvari, and Zánka) that the risk of chlorosis persists where the hard rock is near the surface. Chlorosis does not occur if the limestone is overlain by thicker sediments with soil developing thereon. On the contrary, in the sites where the parent material crops out to the ground surface (the soil forming sediment is missing or it is very thin) or the vine was planted on debris poor in fine components („skeletal soil") the leafs of the grapevines are yellow, the bunches of grapes become contracted even before ripening and the woody parts necrose (Figure 44). Chlorosis also occur in areas where soil developed on the eluvial weathering product of impervious shales (Figure 45). Considering the budget of nutrient- and trace elements and the hydrogeological setting it can be stated that chlorosis is most likely to occur where the soil layer is incapable of temporarily or persistently „keeping the otherwise available nutrient- and trace elements moving" to ensure constant provision to the vegetation. This conclusion is important, for appropriate agrogeological studies conducted prior to the planting of vines may exclude the areas or parts of areas where chlorosis of grapevines (and other plants) can be anticipated on the basis of the soil conditions.

Nitrate sensitivity of the soil–parent material–groundwater system

The designation of nitrate sensitive areas requires to consider the properties of subsurface water and the soil, as well as their environmental setting and attention should be paid to the behaviour of nitrogen compounds in the specific environment.

The mechanism of the likely pollution was reconsidered upon all these factors and the conclusion was drawn that concerning sensitivity surface- and subsurface waters should be treated separately.

With regard to surface waters it has to be spoken of *wash down*, for nitrogen can appear in these waters essentially by having been washed down by precipitation running off the surface. In the case of subsurface waters it has to be spoken of *wash in* since the precipitation running off the surface may wash in the nitrogen through the soil horizons in the groundwater if it passes through the superficial–near-surface sediments and rocks to it at all.

The geological definition of nitrate sensitivity to agriculturally induced nitrate contamination was formulated upon our previous investigation results of similar nature. Accordingly, *an area is sensitive to agriculturally induced nitrate contamination if the nitrate occurring on the surface or in the upper part of the geological medium as a result of some agricultural activities can pass by the assistance of a transmitting agent, mostly water washed down or washed in across the geological medium in the surface- or subsurface water and contributes to its contamination.*

It has to be spoken of very sensitive and slightly sensitive areas if the trajectory of the wash down or wash in is practically without obstacle or if it is affected by some natural or geological factors (poorly permeable horizons, nitrate is filtered out of the liquid, long way of seepage, etc.), respectively. An aggravating factor concerning the protection or prevention of nitrate pollution is when the surface water in the given area at risk was affected by eutrophication or if the nitrate content of the subsurface water's uppermost horizon exceeds 50 mg/l below most of the surface in a freshly taken sample.

Following the definition of sensitivity an overview was made on the geological and pedological factors of sensitivity resulting in the methodological elaboration of the compilation of the maps illustrating wash down and wash in for surface- and subsurface waters, respectively with setting up the maps' legend and finally, preparing the maps.

Wash down

Concerning wash down it has to be studied whether the nitrate pollution getting or present on the surface can reach the surface water (still- or running water) and how quickly and in what amount it can.

Wash down can be expressed by the combination of the following factors:

1. slope conditions in the area (slope steepness),
2. the geological sequence on the surface (lithology)
3. the state of the surface cover in the area (surface cover)

4. the distance of the area from surface waters

Concerning slope conditions flat, gently sloping, sloping and steep areas are distinguished. The steeper the slope the easier the pollution reaches the water i. e. the easier it is washed down.

Table 9 factors of wash down

Slope steepness %	Superficial deposit	Sensitivity of the surface	Degree of sensibility
s <2	h = sand	N = insensible	insensible
el 2-5	kl = silt, loess	Gy = slightly sensible	slightly sensible
l 5-10	a = clay, solid rock, tuff	K = intermediately sensible	sensible
m >10		É = sensible	very sensible

Table 10 Categories of wash down based on the combination of the factors

insensible	slightly sensible	sensible	very sensible
s h N	s h É	el kl É	l kl É
s h Gy	s kl K	el a K	l a K
s h K	s kl É	el a É	l a É
s kl N	s a K	l h K	m h É
s kl Gy	s a É	l h É	m kl K
s a N	el h K	l kl Gy	m kl É
s a Gy	el h É	l kl K	m a Gy
el h N	el kl Gy	l a Gy	m a K
el h Gy	el kl K	m h Gy	m a É
el kl N	el a Gy	m h K	
el a N	l h N	m kl N	
	l h Gy	m kl Gy	
	l kl N	m a N	
	l a N		
	m h N		

Concerning the superficial deposits distinction is made between the sequences on which the water runs quickly or slowly off and on which it does not run off but infiltrates in them instead.

With regard to surface cover it is considered whether the surface of the specific area is open and if it is not what the type of the surface cover is.

The combination of all these elements (Table 10) facilitates the compilation of the map representing the sensitivity to wash down. The specific elements are illustrated in an integrated way. Consequently, the sensitivity of the areas is presented from the insensibles to the very sensitive ones (Figure 46).

Concerning the distance from surface waters areas closer than 100 m, between 100 and 500 m and farther than 500 m are distinguished. The closer the given area to the water the higher the likelihood that contamination reaches it. Due to scale limits this factor is not considered on overview maps but it is vitally important in practical farming, a local factor that is needed to be taken invariably into account.

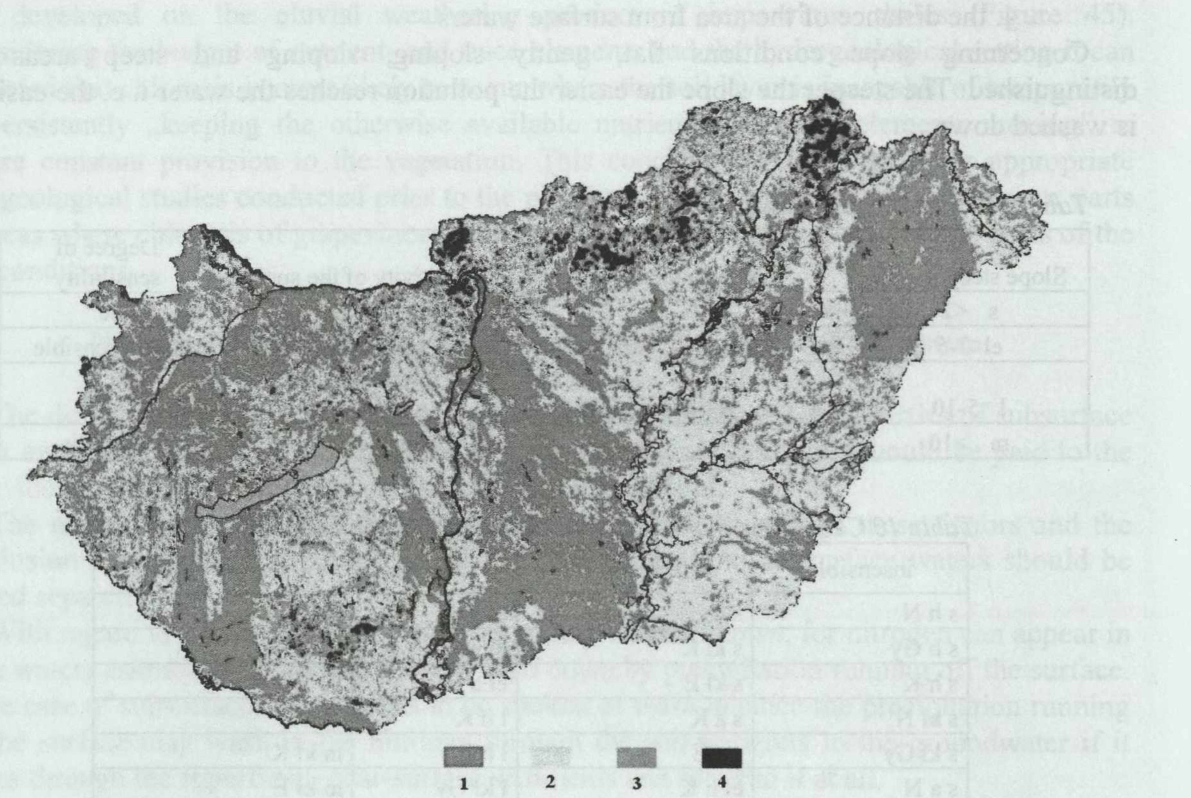

Figure 46 Map of the sensibility to wash down
1 insensible; 2 slightly sensible; 3 sensible; 4 very sensible

Wash in

The key question of the sensitivity to wash in is whether nitrate can pass from the soil surface in the subsurface waters (mainly groundwater). Therefore in order to assume sensibility to wash in it has to be studied if the nitrate contamination getting or already present on the surface can reach the subsurface water (groundwater) at risk and how quickly and in what amount it can.

Wash in can be expressed by the combination of the following factors:

1. permeability of the sequence above the groundwater level
2. groundwater depth below the surface
3. organic matter supply of the soil
4. water budget of the soil

Concerning permeability permeable, slightly permeable, intermediately permeable and impermeable sequences are distinguished. Knowing the types of the disposition of the sequences above the groundwater table their permeability, thickness and bedding characteristics can be assumed. It is important since the same impermeable qualification must be assigned to the areas where impermeable layers cover the surface and to those where they occur below the surface but above the groundwater level.

With regard to the position of groundwater depth values < 1 m, between 1 and 2 m, between 2 and 4 m and > 4 m below the surface are considered. Groundwater closer than 2 m to the surface affects directly the surface. The depth < 1 m characterises virtually wetlands. In this case even the superficial sequences are frequently saturated with water. The groundwater table in the interval of 2-4 m can still have an indirect influence on the surface i. e. surface contaminations can still reach the water in this depth. The risk of their reaching the groundwater in more than 4 m depth is quite low and this water does not affect the surface at all.

The organic matter supply of the soil is considered by the classification of its amount (t/ha) in the soil (Table 11).

With regard to water budget it was considered whether it is absorbed and at which rate by the specific soil. Based on the numerical determination of water management parameters the Hungarian soils were assigned to the following 9 water management categories by Gy. Várallyay and his associates in 1980:

1. Soils of very high water absorbing capacity and permeability with poor water storing- and very poor water retaining capacity;
2. Soils of high water absorbing capacity and permeability with intermediate water storing- and poor water retaining capacity;
3. Soils of good water absorbing capacity and permeability, as well as good water storing- and water retaining capacity;
4. Soils of intermediate water absorbing capacity and permeability with high water storing and good water retaining capacity;
5. Soils of intermediate water absorbing capacity and poor permeability with high water storing and strong water retaining capacity;
6. Soils of poor water absorbing capacity and very poor permeability with strong water retaining capacity and unfavourable water management,
7. Soils of very poor water absorbing capacity and extremely poor permeability with very strong water retaining capacity and very unfavourable, extreme water management;
8. Soils of good water absorbing capacity and permeability with very high water storing- and water retaining capacity;
9. Soils of extreme water management due to the thinness of their fertile layer.

Except for the slightly or strongly alkaline, peaty (6, 7, 8) categories and the one described as featuring extreme water management due to the thinness of its fertile layer (9) the water management of the soils is associated essentially beside the structural state and compactness with the physical soil type.

Table 11 Organic matter supply of the soil

Based on the soil's organic matter supply the area is to nitrate wash in	Organic matter supply [t/ha]
Insensitive	>300
Slightly sensitive	200 - 300
Intermediately sensitive	100 - 200
Highly sensitive	50 - 100
Very highly sensitive	<50

The legend of the sensibility to wash in was elaborated upon the combination of the four base maps (Table 12) facilitating to compile the final map. The collation of the factors resulted in 313 combinations. Some 51, 91, 83 and 88 of them pertain to the insensitive, slightly sensitive, sensitive and highly sensitive categories, respectively.

The map features the area of Hungary illustrating the different categories of sensitivity to wash in.(Figure 47). The four-component combined legend applied on the map represents finally the rate of sensitivity on the map such as insensitive, slightly sensitive, sensitive and highly sensitive.

Table 12 Factors of wash in

Permeability of the sequences above the groundwater table	Groundwater depth below the surface (m)	Organic matter supply of the soil (t/ha)	Water management of the soil	Classification of the rate of sensitivity
z = strongly impermeable	4 = >4	300 = >300	N = poor absorbing-, strong retaining capacity	insensitive
k = intermediately impermeable	3 = 2-4	200 = 200-300	Gy = intermediate absorbing-, good retaining capacity	slightly sensitive
gy = poorly impermeable	2 = 1-2	100 = 100 200	K = good absorbing-, good retaining capacity	sensitive
a = permeable	1 = <1	50 = 50-100 25 = <50	É = very high absorbing-, very poor retaining capacity	highly sensitive

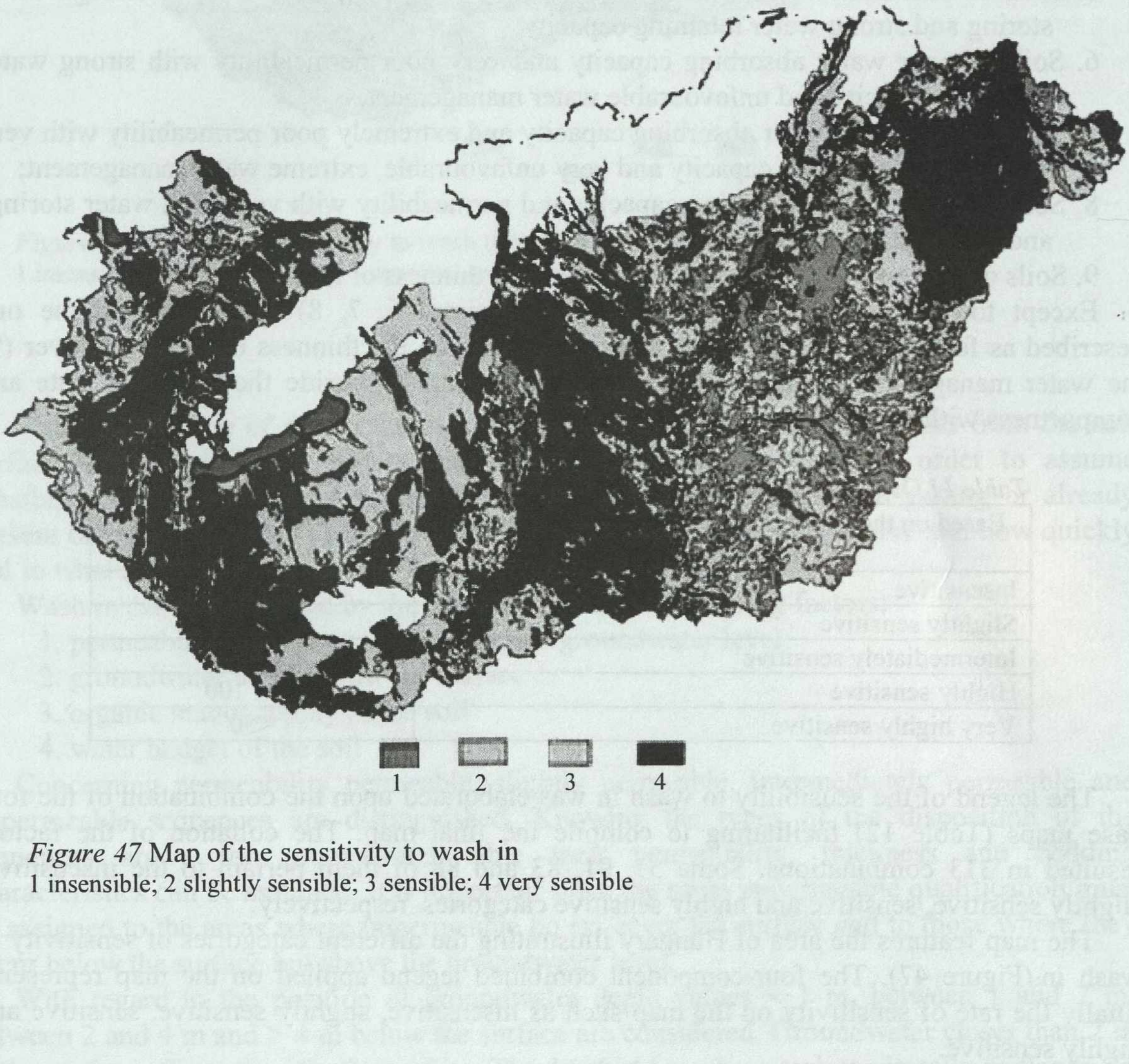

Figure 47 Map of the sensitivity to wash in
1 insensible; 2 slightly sensible; 3 sensible; 4 very sensible

GEOCHEMISTRY

Processes controlling the element budget in the soil

The environmental impact of different materials, the chances of their passing in the geological medium and their behaviour there as well as their movement in the near-surface sequences are fundamentally controlled by the physico chemical parameters of the geological medium, especially the pH, Eh and the concentrations.

Generic rules can be applied to near-surface processes only with restrictions, they are largely influenced by the climate. The most crucial local factors are as follows:

1. type of the soil forming sediment,
2. climate,
3. nature of vegetation,
4. origin of the groundwater (composition) and its flow direction.

The most significant parameters of the soil forming sediment concerning the element budget are water transmissibility together with water retaining-, nutrient supplying- and nutrient bounding capacities.

ad 1. The nutrient supply capacity of the soil forming sediment is fundamentally determined by the nature of the parent rock and the time of the chemical-biological weathering. The soluble elements are bit by bit mobilised by weathering together with the breakdown of thermodynamically unstable minerals exposed on the surface. The final products of the biochemical weathering (till which the process only rarely passes) are quartz and the so-called placer-like concentrating minerals. All the rest breaks down and it is removed by the water as suspended in colloids or dissolved.

The nutrient bounding capacity of the soil and the soil forming sediment is mainly the function of the granulometric composition and organic matter content. The more the clay- and organic matter content in the soil the more cations it is capable of fixing.

At the same time, with regard to the binding of a specific group of elements the leading role is played b some other, occasionally massively occurring mineral phases. Accordingly, the black metals of varying valence (iron, manganese, cobalt, and partly chromium) and some semi-metals (arsenic, antimony and bismuth) are bound by iron oxi-hydroxides (limonite spots, iron peas), whereas alkaline earth metals (calcium, magnesium, strontium and partly barium) are bound essentially by lime precipitations and carbonate accumulation levels.

ad 2. Hungary is situated around the central part of the moderate climatic zone. Its continental climate is alternately affected by continental, oceanic and Mediterranean features also influenced by its basin-type nature. Its climate is therefore changeable and rather erratic.

The average of sunshine hours is 1700–2100/year, the most is in the Danube-Tisza interfluve and the least in the W part of the country. The annual average temperature is around +10°C, the average January and July temperatures are -1.7°C and +20.5°C, respectively. The warm-moderate climatic zone is separated of the cold-moderate one by the -2°C January isotherm called the Middle-Danubian floral divide (KEVEY 2006).

Wind enters the Carpathian Basin basically of three directions, through the Vienna gate, the Verecke Path and from the S; the second and the third ones are less important. Wind entering from the NW fans out which is reflected distinctively on the relief of the terrains W of the line of the Tisza river (Figure 48, after TIMÁR et al. 2003): the valleys in the Danube-Tisza interfluve and in South Transdanubia follow the direction of the wind tracks evolved in the ice age. Consequently, north-western winds are the most frequent and strongest occurring in the Carpathian Basin. Loose sediments in comparatively elevated terrains are eroded first of all by deflation (wind erosion). Consequently, it affects basically the Danube-Tisza interfluve, Nyírség and the W part of the Somogy Hills.

The annual precipitation is 600-800°mm and 500-600°mm in the W and E parts of the country, respectively with the country average of 580°mm. The main late spring – early summer (60–110 mm/month) and the secondary autumn (50–80 mm/month) precipitation maximums are characteristic. According to recent climate models as a result of global warming the amount of precipitation falling in Hungary will decrease for some time (till further warming by some 1.5°C) then it will start to rise.

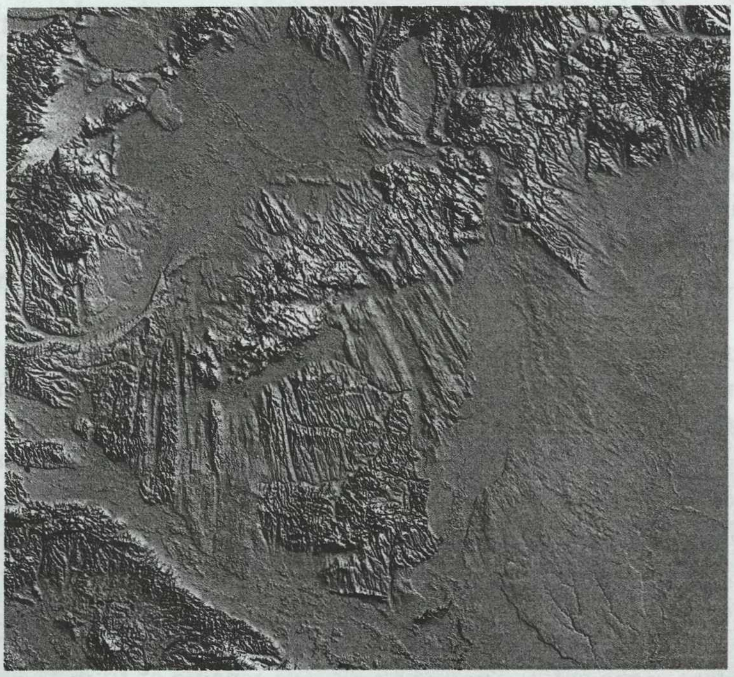

Figure 48 Sand dunes reflecting the direction of prevailing winds

In Hungary the pH of the precipitation water increases from W (3.8) to E (till 5.5). Its average value is 4.6. pH values under 3.7 are exceptionally rare. Since silicon starts to be dissolved only under pH=3.5 quartz (and the other silica-based minerals) are chemically stable near the surface. Weathering does not reach the phase of bauxite formation, even the *terra rossa*-type red earths occurring on some karst plateaus are essentially Pliocene relicts.

Precipitation with pH <5 is usually called acid rain. Since groundwater is neutral or alkaline (alkaline soils) the acid rain getting in Hungary exerts an environmentally positive rather than negative effect.

ad 3. The climate zonal vegetation zones of Hungary (corresponding to the climate) are as follows (after BORHIDI, 2003):

1. Zone of the woody barrens (the Great Hungarian Plain): the N woody barren, Tiszántúl (the area beyond the Tisza river) Nyírség, and partly the foothills and embayments of the North Hungarian Range; as well as the southern woody barren (Sub-Mediterranean woody barren): the Danube-Tisza interfluve and the South Hungarian Plain; basically on sand.
2. Zone of the Sub-Mediterranean white oak woods: south facing slopes of the Hungarian Middle Range, the Mecsek Range and Villány Hills between 200 and 550 m.
3. Zone of the sub-continental oak woods: in the hills and the middle ranges (between 200 and 550 m).

4. Zone of the hornbeam-oak woods: the major part of West Transdanubia (from Sopron Hills to the Kemeneshát), some terrains of South Transdanubia and the Hungarian Middle Range between 400 and 600 m.
5. Zone of the submontane beech woods: the major part of West Transdanubia (from Sopron Hills to the Kemeneshát), Zala Hills, Zselic and the region of the North Hungarian Range between the altitude of 600-800 m.
6. Zone of the montane beech woods: Kőszeg Range, Vend Land and the regions of the North Hungarian Range above 800 m.

In West Transdanubia the subcontinental oak woods are partly replaced by mixed fir oak woods. Eventually, climate zonal firs do not grow in Hungary, the few patches of ancient fir woods (e. g. in Fenyőfő) are the relicts of the ice age. The other fir forests were planted when it came occasionally increasingly in fashion in sylviculture (e. g. the ones around Sopron in the late 19th century, whereas those of the Aggtelek National Park in the 1960s).

The type of the forest fundamentally determines the nature of the soil developing underneath: below fir woods the soil becomes acid, it becomes leached out (grey forest soil), whereas under leafy forest it does not since the calcium content of the leafs is by an order of magnitude higher than that of the pine needles and it absorbs partly the acids released during the breakdown of the long carbon chain compounds.

Just on the contrary, in alkaline areas the nature of vegetation is defined by the soils (VÁRALLYAY 1997) (see in the corresponding chapter). Apart from geological–geographical factors the process of salinisation is also affected by climate (BORHIDI 2003): alkaline areas evolve where the water budget of the soils is negative during the long summer drought. Groundwater seeps upward in the soil's pores and following its evaporation the readily soluble salts crystallise in the upper layers of the soil or on the surface. Alkaline salts make the soil alkaline (pH = 8–12) and increase its osmotic sucking- or water retaining force. Consequently, alkaline soils are physiologically dry and the ordinary plants are incapable to take up the salty porous water.

ad 4. The experience acquired during the geological mapping of the Great Hungarian plain and the most recent agrogeological observations have proven unambiguously that groundwater is the most important transmitting agent of the nutrients and the eventual contaminants as well. Therefore, the nutrients and contaminants occurring in the groundwater cannot always be found in geological sequences close to the surface or to the source of pollution, but they can migrate in the groundwater far away accumulating finally in geochemical traps (e. g. in river valleys and flats between the hills).

Groundwater flows in the pores between the grains of the soil forming sediment. Apart from the slope of its table its velocity is controlled by the granulometric composition and sorting of the enclosing complex. In the coarser sediments of buried river valleys it moves fairly faster than in the mainly fine-grained floodplain deposits. In these channels soluble materials can migrate in the water long and they may accumulate in sites where they could not even have been suspected on the basis of the surface conditions.

Under suitable geological–geographic conditions the sediment can even be cleared by the quickly flowing groundwater: it can dissolve both the chemical fertilizers released with great expenses and the contaminants as well. A good example of the latter is the already dismantled industrial estate in North Pest under which no pollution could be revealed some years after the stopping of the production either in the groundwater or in the water storing sequences. Groundwater flowing comparatively quickly in the related coarse fluvial sediments (gravel, sand) towards the Danube washed through the beds and removed the contaminants into the river.

It can be stated with good approximation that water infiltrates in more elevated areas and upwells in the less elevated ones. Consequently, the eventual contamination of the groundwater of higher terrains does not mean solely that the pollution passes downslope to deeper areas but also that it can infiltrate downward and — unless it precipitates — it rises again and reappears following some years, decades or even centuries in the depth of the utilised domains (e. g. in the filtered aquifers). In this case it is even impossible to assume the original source of pollution. The question that can be posed is how far the ions having passed in the groundwater can migrate in a certain time and what happens to them. To answer it, it has to be distinguished between the regional, local and land-unit flow systems since there is a considerable difference not only in the distances covered but in the physico chemical parameters of the related aquifers and the exerted effects as well.

As it was revealed by TÓTH et al. (1985) the water flowing in the regional upwelling system under the Great Hungarian Plain is in continuous interaction with the enclosing sequences: most of the ions dissolved at depth precipitate during upwelling (Figure 49). The main part of the dissolved ions of the waters tapped in the upper part of the profile is not brought by the upwelling water but by the (medium-sized) land-unit near-surface flow systems.

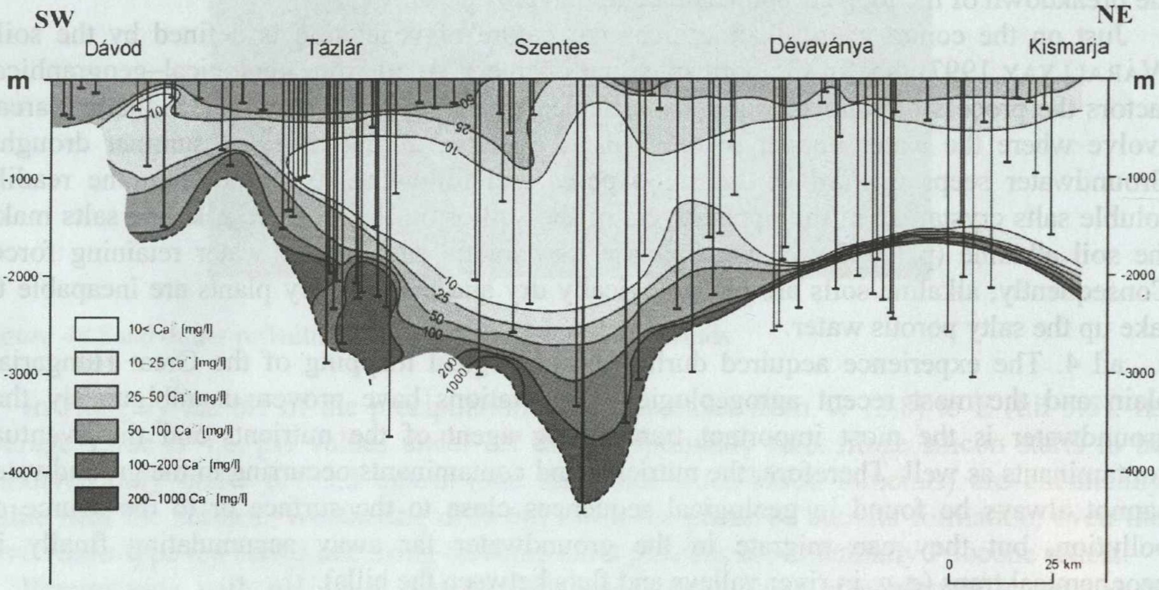

Figure 49 Calcium content in the subsurface waters in a profile of the Great Hungarian Plain (TÓTH et al. 1985)

The chain of alkaline lakes lining up along the two sides of the ridge in the Danube–Tisza interfluve formed as a result of the interaction between the regional and land-unit flow systems (MÁDLNÉ SZŐNYI et al. 2005) (Figure 50).

Local flow systems are characteristic of the environs of local depressions (flats between sand dunes, etc.). Their importance lies in the local circulation of material: dissolved ions migrate to the flats with the water flowing towards the area without outlet and evaporation occurs there. It is the way in which small lime-accumulation spots evolve (KUTI et al. 2002) located most characteristically in the Tiszántúl.

Similarly, contaminants are also transported by local flow systems from different waste repositories in the geological medium.

If waste repositories and other pollution sources are improperly isolated and they do not possess suitable engineering protection system the contaminants washed out of them can directly pass in the groundwater. This process is controlled by the groundwater depth below the surface, the thickness of the overlying beds as well as their granulometric composition, filtering capacity and bedding characteristics.

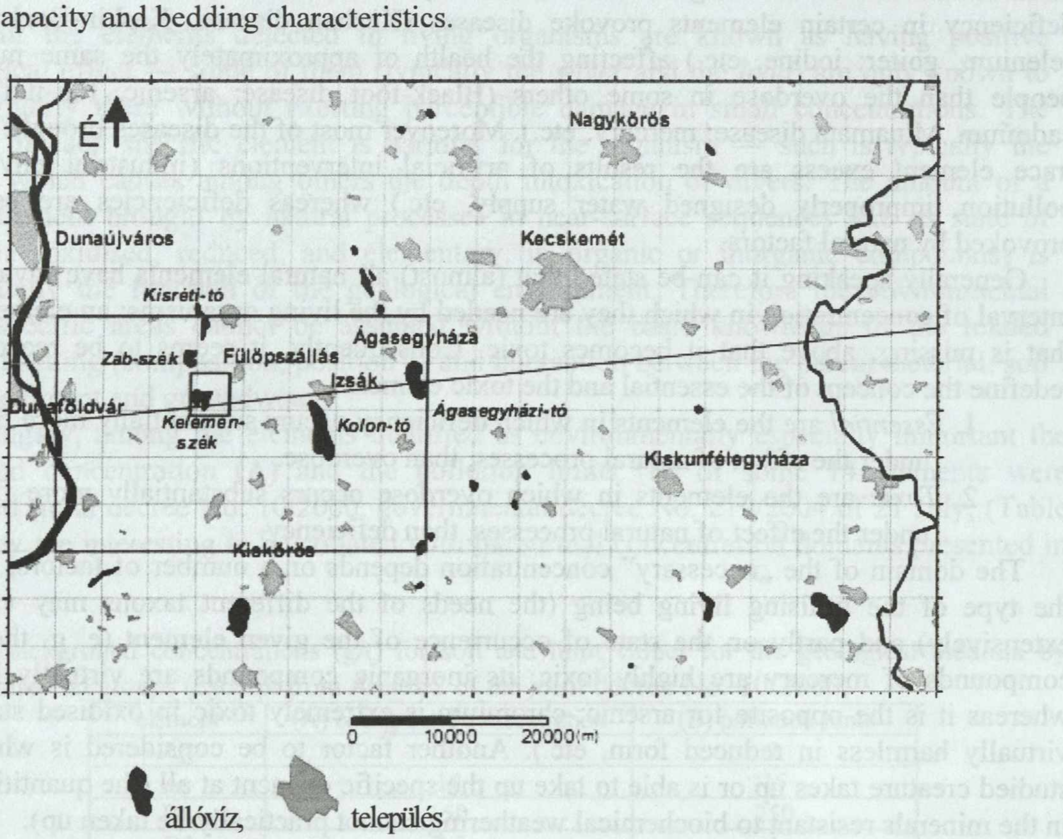

Figure 50 Alkaline lakes in the central part of the Danube-Tisza interfluve (MÁDLNÉ SZŐNYI et al. 2005)

Field observations justify that the sand of proper granulometric composition (generally fine- and small-grained sand) filters the liquid seeping across it and its grains become cemented by the material precipitating from the liquid. It results in the formation of a subsurface impervious layer that protects the horizons underneath.

The series of observations and studies proves that some contaminants — especially the derivatives of different hydrocarbons — are built in the clays modifying their structure and properties including their permeability. The latter poses a problem also for the reason that a clay layer of suitable thickness is ordered by the laws in force to ensure proper engineering protection of waste repository facilities.

„Harmful" and „useful" materials, elements in the soils of Hungary relevant for agriculture

„Micronutrients are the elements required by the plants in a very small amount, but their deficiency may result in different deficiency diseases occurring as perturbations in metabolism (ZENTAY 1993). Similarly to deficiency problems occur also if they are available in the soil in excess for their overdose may result in poisoning.

The traditional concept according to which the elements can be divided in physiologically „useful" (essential) and „harmful" (toxic) collapsed by the end of the 1980s. Until recently the presence of some 82 of the periodic system's 92 elements have been detected in most organisms (TAKÁCS 2001). They are needed by the living beings in more or less quantities to ensure normal functioning. Much more physiological problems are caused by the deficiency of certain elements in specific regions (e. g. the deficiency of iodine in Austria and that of the selenium in the Great Hungarian Plain) than by their eventual overdose. The regional deficiency in certain elements provoke diseases (Keshan disease, Kashin-Back disease: selenium, goiter: iodine, etc.) affecting the health of approximately the same number of people than the overdose in some others (Black-foot disease: arsenic, Itai-itai disease: cadmium, Minamata disease: mercury, etc.). Moreover most of the diseases brought about by trace element excess are the results of artificial interventions (industrial environment pollution, improperly designed water supply, etc.) whereas deficiencies are essentially provoked by natural factors.

Generally speaking it can be stated that (almost) all natural elements have invariably an interval of concentration in which they are needed by the living organisms: an element below that is missing, above that it becomes toxic. Consequently, it seems to be reasonable to redefine the concept of the essential and the toxic elements.

1. *Essential* are the elements in which deficiency occurs substantially more frequently under the effect of natural processes, than overdose.
2. *Toxic* are the elements in which overdose occurs substantially more frequently under the effect of natural processes, than deficiency.

The domain of the „necessary” concentration depends on a number of factors, partly on the type of the utilising living being (the needs of the different taxons may vary quite extensively) and partly on the state of occurrence of the given element (e. g. the organic compounds of mercury are highly toxic, its inorganic compounds are virtually harmless, whereas it is the opposite for arsenic; chromium is extremely toxic in oxidised state but is virtually harmless in reduced form, etc.). Another factor to be considered is whether the studied creature takes up or is able to take up the specific element at all (the quantities bound in the minerals resistant to biochemical weathering cannot practically be taken up).

Accordingly, at least the same attention is required to specify the sufficient concentration of various elements (lower limit) than to ordering and observing the authorised concentrations (upper limit). Concerning environment protection and health the compensation of deficiency is at least as important as the elimination of damage. It is obviously harmful to address these two activities separately since – as we will see on the Hungarian example – the elements qualified as toxic due to their high concentration are missing of the soils elsewhere (FÜGEDI and KUTI 2005).

As a result of the sedimentary basin-type nature of the Carpathian Basin the most part of its area is covered by young fluvial and aeolian sediments. Their material derives essentially of distant regions (from the surrounding mountains) and they occurred in their present position by several phases of redeposition (deposition, soil development, new transport). During these processes not only was the material of originally extensively varied composition mixed but it was also leached on several occasions. As a result, only the minerals most stable in surface conditions were preserved in the young sediments covering most of the country. Consequently, the natural supply of our soils in the Great Hungarian Plain in nutrient element is commonly below the intermediate level and this situation deteriorated further by millennium-long agricultural activities. With harvested crops unambiguously more nutrients – especially micronutrient elements – are removed of the soil than brought in by natural- and chemical fertilizers.

Some important, essential micronutrient elements (copper, zinc, and nickel together with the non-essential lead) occur in the humic „A” horizon of the topsoil essentially in organic complexes. Downwashing of this basically reductive environment results in the breakdown of the complexes and the metal ions become bound to clay minerals. The balance of such elements was essentially negative even in the period of intense crop production (GYŐRI 1984) having become even more negative recently.

Physiological effects of environmentally important elements

Not all the elements detected in living organisms are known as having positive physiological effect — some of them (typically the *silver* and the *lead*) are only known to occur regularly there without exerting perceptible damage in small concentrations. The overdose of each specific element is harmful for the organism — such is typically the *nitrogen*, which causes among others the depth intoxication of divers. The amount of a specific element brought by natural processes in near-surface sequences like its state of occurrence (oxidised, reduced, and elementary, in organic or inorganic compounds) is fundamentally the function of the geological environment. Therefore the environmental state of specific areas cannot be assumed without the basic knowledge of the related geological setting (composition, position of and interaction between the parent material, soil forming sediment and groundwater).

In Hungary, among the elements qualified as environmentally especially important the background concentration (A) and the pollution limits (B) of some 14 elements were determined (joint decree No. 10/2000, governmental decree No. 219/2004 of 21 July, (Table 13) — they are interesting to be collated with the virtual concentration domains presented in Table 15.

Table 13 Background concentrations (g/t) for soil and limit values for the geological medium by material groups (excerpt from Annex 2 of the joint decree No. 10/2000)

element	(A) background concentration	(B) pollution limit
Ag	0.3	2
As	10	15
Ba	150	250
Cd	0.5	1
Co	15	30
Cr	30	75
Cu	30	75
Hg	0.15	0.5
Ni	25	40
Pb	25	100
Zn	100	200
Mo	3	7
Se	0.8	1
Sn	5	30

The „limit value" refers to the upper limit value, none of the elements' lower limit (needed amount) is determined by the Hungarian low, and even the concept is unknown. Therefore it seems reasonable to make at least a sketchy overview of the physiological effects of the elements qualified in the law as especially important with limit value (based on the Environmental and Nature Protection Cyclopaedia I-II and SZABÓ et al. 1987).

Silver (Ag) is not known to have a positive physiological effect but it is extremely toxic for lower organisms (especially microbes) as well as fishes. It is much less harmful for most of the higher organisms (mainly by hindering the intake of copper and selenium). The daily average silver consumption of man is 0.06–0.08 mg, it becomes toxic above 60 mg (some of its salts already in less amount). Some of its compounds are carcinogenic even in very small doses.

Arsenic (As) is essential in a very small amount but its toxic effects are rather important. The human organism needs a daily amount of 12–25 µg arsenic. The compounds of the considerably more rarely occurring As(III) are much more toxic than that of the As(V). Its organic compounds are less toxic than the inorganic ones.

It damages essentially the digestive system, the bone marrow and the nerve system (in higher doses it is a poison with rapid effect). Its average content is 0.05 mg/kg in the human body — most arsenic can be taken up by smoking and the consumption of marine organisms. The daily average arsenic consumption of man is assumed between 0.01–0.3 mg. Above the value of 5–50 mg/day it becomes toxic, whereas in the domain 100–300 mg/day it turns fatal. This amount can be increased by accustomation, the person who got used to it can consume a daily amount of as much as 0.5 g arsenic without the least harm to his health.

The way in which living creatures react to arsenic varies extensively — the plants are mostly much more sensitive than the animals (except for freshwater fishes). Biotransformation can both increase and decrease its effect. For instance the unicellular fungus species Penicillum brevicaule transforms arsenic to very toxic trimethyl arsenic but in the food chain of the warm seas the arsenic is transformed to arsenic betaine harmless to the fauna which then empties of the organism without any additional biotransformation. Just therefore the fishes, crabs and mussels populating the seas are able to accumulate an incredible amount of arsenic – as much as 10 mg/kg – without the least harmful effect.

Barium (Ba) accumulates mainly in the bones replacing calcium (or magnesium). In small amount it is essential for many living organisms but in higher concentration it causes damage, therefore its chloride ($BaCl_2$) is used as rat poison and insect killer as well.

The main risk of cadmium (Cd) is that in living organisms it replaces the chemically quite similar and for all creatures essential zinc but it does not performs its function. Respiring it attacks the lungs, swallowed with the food it harms the digestive system then the liver. The normal daily cadmium load of the human organism is 0.5 mg; the symptoms of poisoning may occur already above 3 mg/day. According to the stance of the WHO (1996) its allowable quantity in the human organism is at most 7 µg/kg.

Cobalt (Co) is essential in small amounts, among others it is the vital component of the vitamin B_{12}. The normal daily cobalt intake of the human organism is 0.3–2 mg; its minimal need is 0.2 mg/day. Its average concentration in the human body is 0.02 mg/kg. Taken up in larger amount some of its compounds may be toxic (they can damage the lungs, the digestive system and eventually the heart) or they are carcinogenic. The symptoms of poisoning can appear at the daily consumption exceeding 500 mg but its deficiency is much more frequent than its poisoning effect.

Chrome (Cr) is an element of changing valence: in nature it occurs mostly in the form of Cr^{3+}, more rarely Cr^{6+} Its latter-type compounds are poisoning and carcinogenic even in very small concentrations. Therefore a separate limit value (1 g/t) was defined for it. In the soil Cr^{6+} is transformed comparatively rapidly to Cr^{3+} which is essential in small concentrations and poisoning only in large doses (it deteriorates the stomach, the liver, the organs of respiration and the kidneys). It can provoke allergic symptoms as well. Its average amount in the human organism is 0.05 mg/kg. The normal daily chrome consumption of man is 0.15–0.4 mg; its minimally required daily amount is 0.02–0.03 mg. The symptoms of poisoning occur at the consumption of 200 mg/day, whereas the limit value of the fatal poisoning is 3 g/day.

Copper (Cu) is an important essential element. It is the constituent of a number of enzymes — but its overdose hinders the intake of the *zinc* and the *molybdenum*. The capacity of its intake (especially for animal organism) depends very largely on the kind of the compound in which it is present (in the food or water). Its intake is affected by the *zinc* overdose, whereas *molybdenum* overdose provokes copper deficiency by its increased depletion.

It accelerates photosynthesis and the formation of anthocyanin in plants and additionally it is the component or activator of several enzymes controlling essentially metabolism. The so-called crop production disease (the plant grows in shrub but it is incapable of developing stems) and the top desiccation of the fruit trees are provoked by the deficiency of copper. In the case of more important copper deficiency corns cannot even develop grains anymore.

In animals it is the component of numerous proteins and enzymes; it is the central atom of hemocyanin playing an important role in the oxygen transport of lower animals (e. g. crabs). Its deficiency affects essentially the ruminant animals. The copper intake of animals is reduced by *calcium* and strongly reduced by *sulphur* (with which it constitutes insoluble *copper sulphide* very poorly sucking up).

Its average amount in well-developed mammals and in the human body is mostly 1.5–2.5 and 1 mg/kg, respectively. It is stored mainly in the liver. The normal copper consumption of man is 2–5 mg/day; the minimally needed daily amount is 0.5–1 mg. According to the stance of the WHO (1996) its allowable daily intake is 12 mg. Some of its compounds are poisoning or carcinogenic in extreme concentrations, the symptoms of poisoning appear at the daily load exceeding 250–500 mg.

Mercury (Hg) is only slightly toxic in elementary state, but some of its salts (like e. g. the *mercury chloride*, $HgCl_2$) and organic compounds (chiefly the *methyl mercury*, CH_3Hg and *dimethyl mercury*, $(CH_3)_2Hg$) are very poisonous. Similarly to other heavy metals it is prone to accumulation (it empties mainly with cutaneous tissues). It damages first of all the nerve system. The daily average mercury consumption of man is 0.001–0.02 mg; it becomes fatal in the domain 150–300 mg/day.

Nickel (Ni) is an important essential element in small amount. The daily average nickel consumption of man is 0.07–0.15 mg; its minimally required daily amount is 0.04 mg. Its compounds are carcinogenic and toxic in larger quantities: first they can provoke skin allergy and asthma for the more sensitive individuals followed by damaging the stomach and the kidneys.

Positive physiological effects of the lead (Pb) are unknown, it is considered as unambiguously toxic heavy metal. Initially, the lead happening to occur in the human organism becomes bound to the red blood-cells, it accumulates in the parenchymal organs then and finally it gets stored in the bones. Most lead is taken up by respiration through the lungs but it can also pass through the skin. Exposure of the digestive system is very rare. It empties of the organism essentially by urine and stool but very slowly.

Acute lead poisoning is very rare. Its main symptoms are as follows: pain in the abdomen, puke, diarrhea, shock. Chronic poisoning is characterised by tiredness, lack of appetite, so-called lead colorite, lead colic, arthralgia, paralysis of the innervation area of the nervus radialis, lead-encephalopathy and the formation of tooth lead. The clinical symptoms are accompanied by characteristic changes in the results of laboratory tests like hypochromic anaemia with the appearance of red blood-cells with basophile granulocytes, increasing lead content in the blood and depletion of increased amounts of lead, delta aminolevulitic acid and coproporfirin III. The exposition to lead-bearing compounds can be an occupational hazard: previously typographers, metallurgists, etc. were especially exposed to its risk and the population by using lead-containing crockery.

Its numerous compounds are proven to be carcinogenic. Its average content in the human organism is 1.7 mg/kg.

Zinc (Zn) is one of the most essential elements. Its physiologically most important compound is the carbonic anhydrase enzyme regulating the carbon dioxide- and water balance. It is the fundamental constituent or activator of several other enzymes controlling metabolism and it also plays a role in the formation of the chlorophyll as well as in the prevention of its breakup. Its deficiency provokes deficiency diseases in most plants and animals — in humans it leads to the slowing of the growth and the deterioration of the sense of taste, the immune system and the sexual performance as well as to the formation of ulcers. The boundary cells of the leafs of plants subjected to zinc deficiency become elongated, the leaf itself will be small and elongated and their roots will also develop abnormally. Its intake may be restricted by the overdose of phosphorous.

One of its well-known deficiency diseases is the parakeratosis of pigs. It is important in the metabolism of glucose, in the maturity of spermiums and — similarly to the plants — in the functioning of a number of enzymes and the production of several hormones including insulin. The wounds of animals with zinc deficiency heal and their bones grow slower.

Its average amount in the human organism is 33 mg/kg. In extreme concentrations some of its compounds can be toxic or carcinogenic. At that time it hinders the living organisms in the intake of *copper* (and vice versa). Its minimally needed daily amount for the human organism is 2–3 mg; the optimal one is 7–10 mg.

In small amount molybdenum (Mo) is essential for all living organisms (especially in the enzymes controlling the nitrogen cycle). Its intake can be reduced by the overdose of tungsten, copper and zinc.

It is especially important for the nitrogen fixing bacteria (Azotobacter sp.) and thus for the pulses. The leafs of the plants with molybdenum deficiency are more yellow, they become enriched in nitrate and the amount of proteins drops. The main part of the area of Hungary is deficient in molybdenum. Therefore, the symptoms of deficiency can frequently be observed on the plants needing more molybdenum (beside the pulses on grass species, tomatoes, summer cabbages, spinaches, salads and cauliflowers).

Concerning the animals molybdenum plays an important role in specific enzymes but it is less significant than for the plants. In areas covered by granite its toxic (and carcinogenic) effect is known. Cattle react extremely to molybdenum load whose forage (concerning dry material) may at most contain 5 mg/kg Mo, whereas sheep and goat can comparatively easily support a load of 30 and 300 mg/kg, respectively. Overdose of molybdenum reduces the capacity for the intake of copper (and zinc), it can provoke a so-called secondary copper deficiency.

Its average concentration in the human body is 0.1 mg/kg. The daily average consumption of molybdenum of the humans is approximately 0.09–0.16 m; its minimally required daily amount is 0.02–0.04 mg. Its persisting overdose provokes diarrhea, lack of appetite and joint gouts; it can be compensated by the intake of *copper*.

Selenium (Se) is essential for most of the living organisms in small quantities: it exerts its influence mainly in metabolism and the defence of the organism against intoxication by radical oxidants and heavy metals. It is indispensable for the operation of several enzymes. It is harmless in elementary state, but a number of its compounds, like the hydrogen selenite (H_2Se) are toxic even in small quantities. Its daily average consumption by man is 0.06–0.08 mg. Deficiency symptoms (their most serious form is the so-called Keshan disease) occur below the daily consumption of 0.015 g, whereas it becomes toxic above the daily value of 3.0 g (mostly in some regions of China). In Hungary its toxic accumulations are unknown. Quite on the contrary, first of all our southern and south-western counties are deficient in selenium.

Tin (Sn) is essential in extremely small amounts but rather its toxic nature is known. The daily average normal intake of tin by the human organism is 0.6–1.5 mg; its minimally required daily amount is 0.01–0.02 mg. As a metal it is not toxic but its different (mainly organic) compounds are highly toxic to an extent that some of them are used as germ- and fungus killers.

Macronutrient supply of the soils in Hungary's agricultural fields

Traditional investigations and calculations of nutrient balance involve solely the uppermost horizon of the soil including commonly the top 20–50 centimetres.

According to the summarised data the macronutrient (N, P, K [NPK]) balance of the soils involved in agricultural cultivation in Hungary was negative approximately till 1970 becoming positive between 1970 and 1990 and having turned to negative again since then. (The reason for the latter is that more nitrogen, potassium and phosphorous are extracted from the soil by different harvested crops than delivered by various fertilizers.). Obviously, large differences occur within the country due to the intensification of farming and (not independently thereof) to the variable economic state of the farmers. In general terms it can be stated — apart from some sporadic exceptions — that the NPK-surplus accumulated in some locations before 1990 has been more than used up by today by farming cultures giving rise to macronutrient deficiency in most of the soils of the country. The evolution of deficiency was largely promoted by delivering the regarded elements in soluble form in or on the soil — just for facilitating its intake by the plants — resulting in the rapid downwash of their eventually „extra" amount by overland flow.

Table 14 Usual amount of environmentally vital elements in the soil — in Hungary and throughout the world (g/t)

	usual amounts in Hungary			
	interval of values		expected value	world
element	from	to	(median)	average*
As	< 2.5	230.37	7.17	0.1–20
Ba	19.5	258	95.3	300
Cd	< 0.5	12.8	<0.5	2.2
Co	1.5	17.8	8.9	13.4
Cr	2.7	473	19.7	79
Cu	4	400	19.2	18
Hg	< 0.02	1.11	0.08	0.056
Ni	5	58	21.2	46
Pb	4.2	286	16.9	18
Zn	12.4	2166	63.3	79

Co, Cr, Ni: fluvial sand soils
Cd: soils developed on loess
As: typical domain of values

Meso- and micronutrients: the main geochemical regions of Hungary

The main geochemical regions of Hungary (Figure 51) were delineated on the basis of the geochemical atlas of the country (ÓDOR et al. 1998) as a result of principal component analysis. The specific principal components correspond to the main regional and young (Pleistocene-Holocene superficial–near-surface) geochemical processes. It is the reason why the most important geochemical problem affecting the country, namely the effects of the geological processes resulting in the formation of arsenic waters do not figure in the atlas compiled upon the sampling of floodplain deposits, they will be addressed separately later.

The background values of the specific elements and groups of elements (Table 15) are markedly different in the four regions.

1. In most of the area of the country it is impossible to designate any specific group of elements, it is thus regarded as an individual region. In these areas – left white on the map – the amount of the specific elements that can be taken up is determined chiefly by pedological properties (cohesion, humus content, etc.).
2. Ca and Mg, Sr, S, Cl

   In Central Hungary (Transdanubian Middle Range, Mezőföld, Danube-Tisza interfluve and their environs) the acid soluble CaO concentration commonly exceeds even 10 % in the uppermost 60 cm of the soil profile (MgO > 1.4 %, Sr > 60 g/t). Consequently, the pH of the related soils is comparatively alkaline, their porosity drops. The Ca-, Mg- (as well as S-, Cl-, Sr- and partly P-) supply of the soil is more than good; however, the other nutrients are extruded from the top horizons and they become washed down below the zone of lime accumulation (to some m depth). The decrease in the amount of Al, K_2O and Li built mainly in clay minerals as well as in Pb, Zn, Ni and Cu fixed adsorbed on the surface of the first three ones is particularly distinct. The permeability of the sediments is radically reduced by lime enrichment and the absence of free pore space result in reductive conditions. Consequently, the elements of variable valence, but less soluble in oxidised state — Fe, Co (Cr) — persist in reduced form and they are washed down with the slowly infiltrating precipitation. Manganese is not involved in this process since it is built in the crystal structure of the carbonate minerals by isomorphic replacement. In Nyírség the intensity of lime accumulation is less intense (CaO: 5.5–6 %, MgO 0.5–0.7 %, SrO 70–100 g/t). In other parts of the country the amount of the concerned elements (apart from some special cultures, like vines) is commonly proper.

   In the locations where unbroken, poorly pervious lime accumulation levels formed in some m depth below the surface considerable problems may arise concerning the water budget resulting in the deterioration of the living conditions of plants with larger root system. This process is practically missing in the floodplain of the Tisza river and in Tiszántúl and it occurs only subordinately in Nyírség.
3. Fe, Co, Ni, Al, Mn

   Along the western boundary in the soils developed on sediments of Alpine origin deposited following comparatively short transport (from Alpokalja till Őrség) iron, cobalt, chrome (which is not considered as nutrient element), nickel (as well as aluminium and manganese) occurs in somewhat larger amount than in the other parts of the country. The quantity of the elements of variable valence (especially Fe, Co and Mn) depends strongly on the actual redox conditions. As a consequence, in loose, incohesive soils their amount may significantly exceed even within a specific profile their concentrations measured in cohesive, fine-grained sediments.
4. As a result of their analogous economic-geographical position the floodplains of the rivers coming from the Transylvanian mining area and the heavy industrial centres of Slovakia are separated as an individual geochemical region featuring anomalous Ag-, Au-, As-, Cd-, Cu-, Pb- and Zn concentrations. Their several century-long environmental impact is proven in the top 60 cm of the sequence but presumably it has affected the whole profile down to the groundwater level.

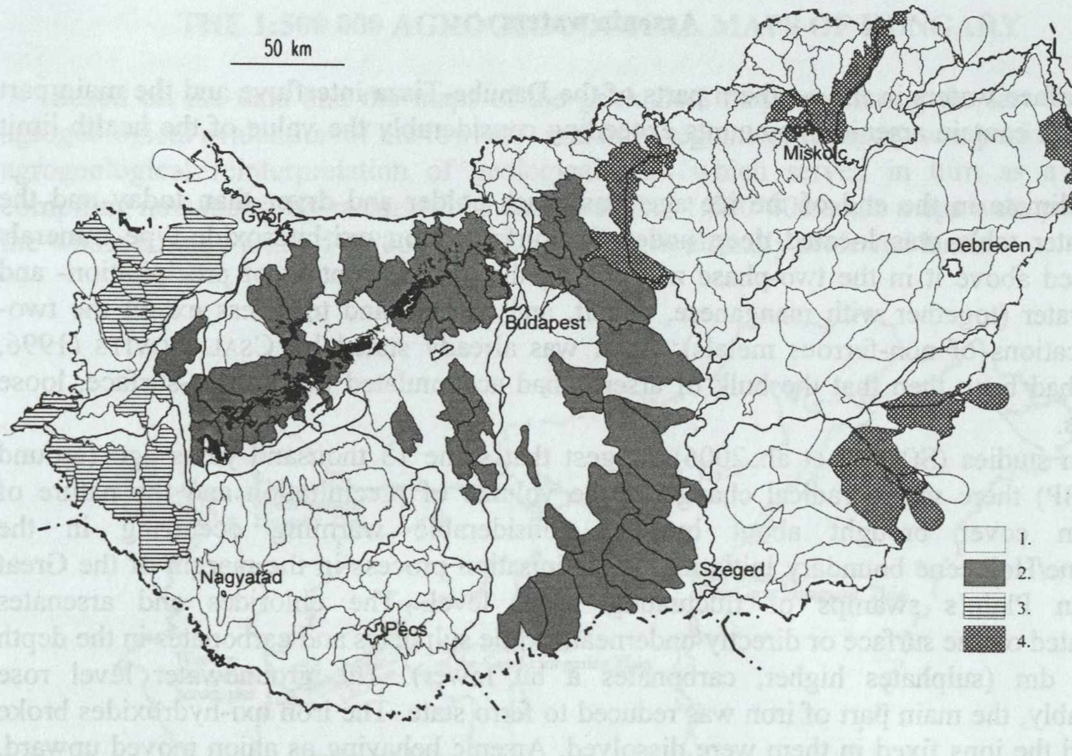

Figure 51 The main geochemical regions of Hungary
1. Area without specific element groups; 2. Ca and Mg, Sr, S, Cl; 3. Fe, Co, Ni, Al, Mn;
4. denudation areas outside the state boundary

Table 15 Average amount of environmentally vital elements in the soil of Hungary's main geochemical regions

element		region 1	region 2	region 3	region 4
As	A	< 2.5–19	< 2.5–57	5.8–13	5.4–22
	B	7.3	6.3	8	12
Ba	A	53–158	22–158	87–190	88–160
	B	95	68	135	113
Cd	A	< 0.5–1.5	< 0.5–3.4	< 0.5	< 0.5–10.4
	B	< 0.5	< 0.5	< 0.5	1.0
Co	A	4.9–13	1.7–10	10–15	9.4–14
	B	9	5.7	12.8	11.1
Cr	A	8–39	4–32	25–39	27–92
	B	21	14.5	36	36
Cu	A	8.5–42	5.5–33	18–32	21–103
	B	19	15	24	40
Hg	A	0.04–0.2	0.03–0.37	0.06–0.12	0.08–0.75
	B	0.08	0.08	0.09	0.14
Ni	A	11–36	7–30	25–37	25–41
	B	22	16	32	29
Pb	A	10–34	5.3–23	16–26	32–90
	B	17	13	18	46
Zn	A	32–150	14–180	69–96	100–600
	B	65	46	82	132

A = typical domain of values
B = expected value

Arsenic waters

Subsurface waters in the southern parts of the Danube-Tisza interfluve and the main part of Tiszántúl contain arsenic in amounts exceeding considerably the value of the health limit (10 µg/l).

The climate in the end of the ice age was much colder and dryer than today and the groundwater table was located deep under the surface. Iron oxi-hydroxide-type minerals precipitated above it in the two-phase zone fixing the arsenic content of precipitation- and porous water (together with manganese, cobalt, and chrome and to a less extent the two-valence cations of non-ferrous metals). As it was already stated by CSALAGOVITS (1996, 1999) it had been then that the bulk of arsenic had accumulated in the near-surface, loose sediments.

Pollen studies (SÜMEGI et al. 2006) suggest that some 13 thousand years ago (around 10°600 BP) there was a radical change in the volume of precipitation and the nature of vegetation cover brought about by the considerable warming occurring in the Pleistocene/Holocene boundary initiating the salinisation process in the margin of the Great Hungarian Plain's swamps of fluctuating water level. The chlorides and arsenates accumulated on the surface or directly underneath while sulphates and carbonates in the depth of some dm (sulphates higher, carbonates a bit lower). The groundwater level rose considerably, the main part of iron was reduced to ferro state. The iron oxi-hydroxides broke down and the ions fixed in them were dissolved. Arsenic behaving as anion moved upward, the two-valence cations were washed down.

The clogging of the pores resulted in the formation of a practically impervious layer near the surface (below the root system's level) the communication between precipitation and groundwater was stopped. Precipitation accumulated in smaller or greater depressions. The impervious layer formed in some locations sooner in some other ones later, the region acquired a geochemically mosaic pattern. In some flat areas the evolution of reductive conditions was largely facilitated by lime accumulation in some other ones by the development of swamps and alkaline lakes.

THE 1:500 000 AGROGEOLOGICAL MAPS OF HUNGARY

Based on the data and the maps of the geological mapping during the last decades the agrogeological evaluation of the lowland- and hilly regions of Hungary was performed by the agrogeological reinterpretation of geological data which served in turn as a basis for compiling new maps. By means of the data available 1:500°000-scale maps were prepared for the whole country and 1:100°000 ones for some agriculturally preferred lands.

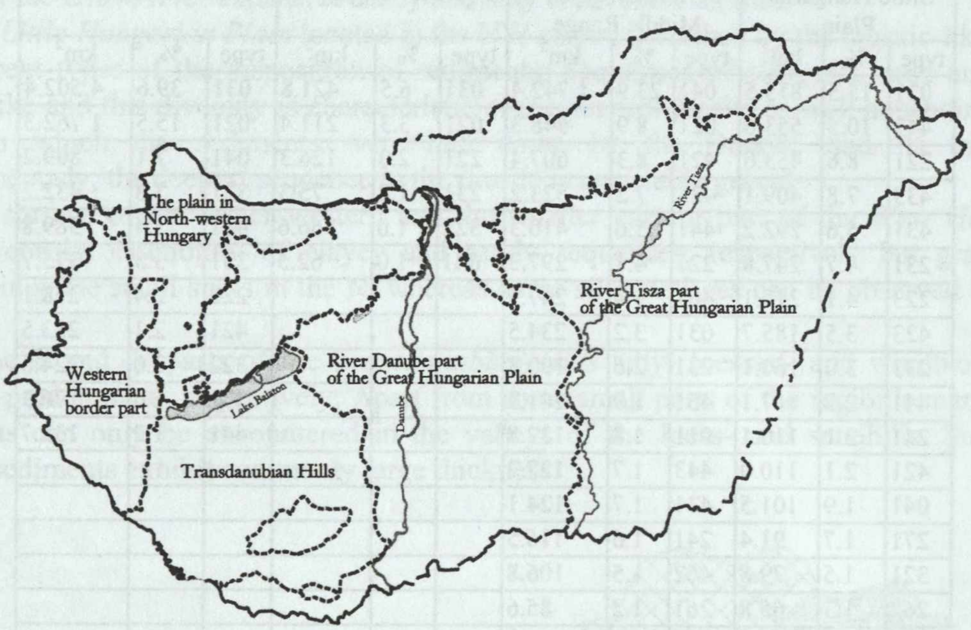

Figure 52 Location of the regions

As a first step the maps representing the occurrence of superficial–near-surface sediments as well as groundwater level and chemistry were compiled as follows: superficial sequences, types of the disposition of the superficial sequences, groundwater level below the surface, total dissolved solids content of the groundwater, chemical types of the groundwater.

In a second step the maps derived of the combination of the above base maps were produced: irrigability of the areas, excess water risk and erosion risk

Map featuring the types of the disposition of the top 10 m sequence below the surface

The map features the characteristic types of the disposition of near-surface sequences penetrated by 10-m-deep shallow boreholes. The polygons on the map represent the areas made up of sequences of similar type of the disposition (see the actual chapter). Apart from learning the sequences located on the surface or in some parts of the 10-m-thick profile knowledge can also be acquired on the approximate thickness of the related sequences, their underlying bed, the number of horizons occurring in the profile as well as their thickness and bedding characteristics.

The *Tisza Plain*, 70-80 % of which is constituted by fluvial sediments can be described essentially by the predominance of clayey deposits. Extensive sand beds can be found solely in the NE part of the area on the surface consisting of densely alternating 2-3-m-thick horizons of aeolian sand and loess. In the margins of these sandy areas loess appears on the surface in smaller or greater patches. Aeolian sand occurs there as underlying a considerably thick superficial silt deposit but it can also occur that the thickness of the latter exceeds 8-10 m. Locations made up of sand can also be observed in the N part of the region where the notably thick coarse sediments were laid down by the rivers running from the North Hungarian Range. Sand occurs also along the Tisza river and its tributaries. The clay sequence of fluvial genetics prevailing in the area is commonly several m thick but it can frequently achieve 8-10 m.

Table 16 The main types of the disposition of sediments in Hungary by geographical regions (Discussiòn of the disposition of sediments is in chapter "The most characteristic types of the disposition of sediments")

Little Hungarian Plain			Transdanubian Middle Range.			West Hungary			Transdanubian Hills		
type	%	km^2	type	%	km^2	type	%	km^2	type	%	km^2
021	15.5	815.5	041	23.9	1 742.4	031	6.5	421.8	031	39.6	4 502.4
443	10.5	553.6	021	8.9	648.3	021	3.3	211.4	021	15.5	1 762.3
221	8.6	453.0	421	8.3	607.4	221	2.0	126.3	041	7.1	809.2
433	7.8	409.1	423	7.2	523.2	231	1.2	75.3	321	3.8	432.2
431	5.6	292.2	441	5.6	410.3	322	1.0	66.6	431	3.4	389.8
231	4.7	247.8	221	4.1	297.3	041	1.0	62.5	331	3.3	375.7
223	4.1	218.1	461	3.4	247.3				222	2.4	278.1
423	3.5	185.7	031	3.2	234.5				421	2.1	233.5
233	3.0	160.1	231	2.6	190.8				322	2.0	224.6
441	2.2	117.1	451	1.9	141.2				332	1.6	176.3
241	2.1	110.1	011	1.8	132.8				441	1.2	133.7
421	2.1	110.0	443	1.7	127.2						
041	1.9	101.5	431	1.7	124.1						
271	1.7	91.4	241	1.6	116.5						
321	1.5	79.8	462	1.5	106.8						
262	1.3	65.8	261	1.2	85.6						
261	1.0	54.9	477	1.0	74.0						
478	1.0	50.3	271	1.0	73.5						
			262	1.0	72.6						

North Hungarian Range			Danube-Tisza interfluve			Tiszántúl		
type	%	km^2	type	%	km^2	type	%	km^2
385	8.2	891.4	021	32.8	6 355.3	041	41.2	12 801.8
041	7.0	765.5	031	7.4	1 425.1	241	12.3	3 818.8
321	5.2	571.0	431	7.0	1 358.0	421	8.5	2 640.4
021	2.1	232.7	222	6.5	1 262.6	431	7.5	2 338.9
441	4.2	813.6	021	5.5	1 716.3	021	5.5	1 716.3
			421	3.7	712.8	441	3.6	1 123.4
			041	3.6	701.8	031	2.2	695.3
			221	3.2	619.2	322	1.9	583.2
			332	2.9	558.8	221	1.4	445.3
			251	2.7	523.8	452	1.4	442.2
			322	2.2	422.7	321	1.4	426.3
			351	2.0	378.7	332	1.1	333.2
			223	1.9	368.4	451	1.0	319.4
			233	1.8	357.9			
			241	1.7	328.4			
			232	1.3	256.8			
			231	1.3	254.2			
			331	1.2	229.4			
			321	1.1	206.4			

The *Danube Plain* located in the Danube-Tisza interfluve bears the largest aeolian sand region of the country. The thickness of the superficial sand frequently surpasses even 10 m. It overlies a thick loess series or it alternates with 2-3-m thick loess interbeds. The Danube Valley can be described by the superficial occurrence of variably thick clay beds overlying the coarse fluvial sediments of sand and gravel. In he Transdanubian part of the area the superficial sequences are made up of aeolian complexes consisting of loess and windblown sand. Similarly, river valleys are essentially occupied by clayey surfaces but in the S, in the valley of the Drava river expansive sandy and silty areas occur as well.

The *Little Hungarian Plain* located in the NW can be described by the mosaic-like pattern of different types of the disposition of sediments. Sequences of clay, silt, sand and gravel occur alike and this diversity is characteristic of the vertical profile as well depending on the order in which the sediments were laid down by the Danube and its tributaries. Simultaneously, the deepest sequence in the profile is invariably gravel.

The surface of the larger western and the smaller eastern part of the *West Hungarian Margin* consist essentially of clayey and sandy sequences, respectively but gravel also appears in some small spots in the N, whereas some silty surfaces can be observed in the W and S.

In the E and W parts of the *Transdanubian Hills* silty- loessial- and windblown sand surfaces predominate, respectively. Apart from some small parts of the region's margin finer sediments can only be encountered in the valleys of the loess- and sandhills. Superficial aeolian sediments exhibit commonly large thickness.

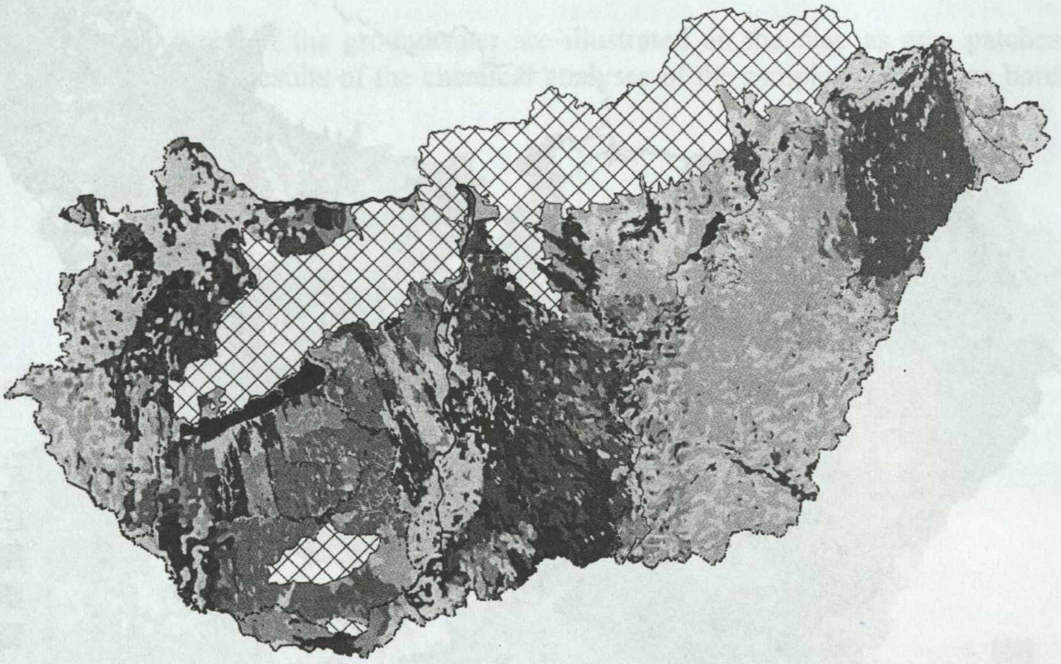

Figure 53 Superficial–near-surface types of the disposition of sediments in the lowland- and hilly regions of Hungary

1 gravel in great thickness (10 ms) or variegated layers with gravel on the surface; 2 sand in great thickness (10 ms); 3 variegated layers with sand on the surface; 4 silt in great thickness (10 ms); 5 variegated layers with silt on the surface; 6 clay in great thickness (10 ms); 7 variegated layers with clay on the surface

Groundwater depth below the surface

These maps represent the depth of the groundwater below the surface by depth isolines of 1, 2, 4, and 8 metres (Figure 54).

The surface is directly affected by groundwater if the latter is closer than 2 m to it. Areas characterised by less than 1 m groundwater depth can virtually be described as wetlands. In this case even the superficial sequences are frequently saturated with water. The risk of salinisation occurs mostly at the groundwater level between 1 and 2 m below the surface if supported by other agrogeological factors (KUTI 1999). The groundwater table in the interval of 2-4 m can still have an indirect influence on the surface i. e. surface contaminations can still reach the water in this depth. The risk of their reaching the groundwater in more than 4 m depth is quite low and this water does not affect the surface at all.

In most part of the *Tisza Plain* the average groundwater level is around 2 m below the surface. The region described by groundwater level between 2 and 4 m is also quite extensive but considerable locations are also frequent described by the depth interval of 1-2 m including those along the rivers, the W part of the NE windblown sand terrains and the valleys between the sandhills. Groundwater level is deeper than 4 m in the NE, as well as in the central part of the area E of the Tisza river with notable patches where its depth exceeds 8-10 m. Expansive areas of deeper located groundwater can be found in the N in foothill margins where its prevailing depth interval is 4-8 metres.

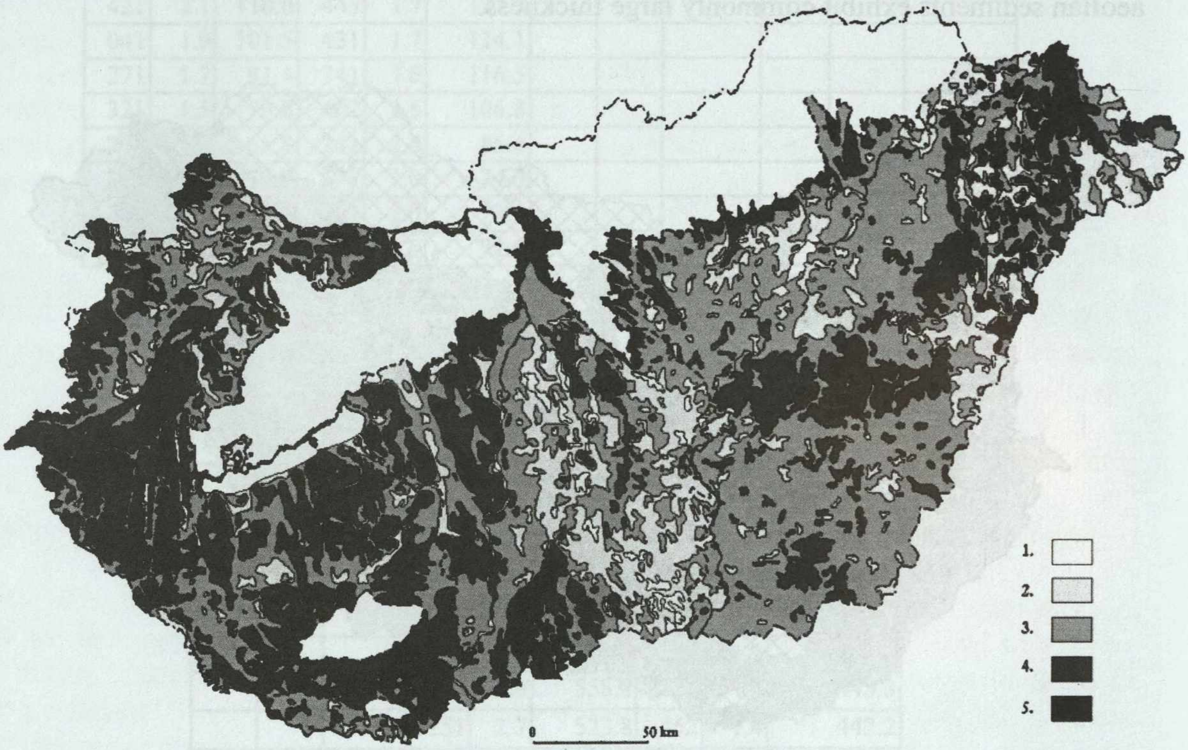

Figure 54 Groundwater depth below the surface
1 0-1 m; 2 1-2 m; 3 2-4 m; 4 4-8 m; 5 >8 m

Concerning the *Danube Plain* the regions located E of the Danube river feature average groundwater depth around 2 m and water depths between 1 and 2 m are quite frequent in the Danube-Tisza interfluve (KUTI et al. 1998). Simultaneously, in the N and S parts of this area it is between 4 and 8 m below the loess- and sandhills exceeding even 8-10 m in quite extensive areas. In the N and central parts of the region W of the Danube its level surpasses 4 m. At the same time it is below 8-10 m in extensive locations and values surpassing 20 m are not infrequent either. Obviously, the groundwater level is closer to the surface in river valleys situated between 2 and 4 m and even between 1 and 2 m. In the N, the area joining the Transdanubian Middle Range features values occasionally less than 1 m. In the S, in the Drava Valley the average depth of the groundwater level is 2-4 m below the surface.

In the *Little Hungarian Plain* the average groundwater level is between 2 and 4m. Apart from a few small spots groundwater is located between 1 and 2 m depth below the surface only along the rivers. In the E and W margins generally broken but quite expansive patches feature subsurface depths between 4 and 8 m. Moreover values exceeding 8 m occur frequently in the easternmost part.

In the area of the *West Hungarian Margin* the average groundwater level surpasses 4 m below the surface, values between 2 and 4 m occur only along the rivers. In one measurement point it was closer than 1 m to the surface. On the contrary, areas with groundwater level exceeding 8 m occur quite often. Extensive patches of terrains with values surpassing 8 (but often even 10-12) m can be encountered in the elevated, hilly domains in the W, E and S.

Similarly to the afore-mentioned region groundwater located deeper – below 4 or even 8 m – is characteristic in the chief part of the *Transdanubian Hills*. At the same time quite expansive areas with groundwater depths between 2 and 4 m occur along Lake Balaton and in river valleys (Dráva, Kapos, Sió) and in the S. It occurs closer than 2 m to the surface only in restricted areas and it was again just in one measurement point that its value was closer than 1 m to the surface.

Chemical types of the groundwater

The chemical types of the groundwater are illustrated on the map as area patches as a result of processing the results of the chemical analyses of the samples taken from boreholes (Figure 55 and 56).

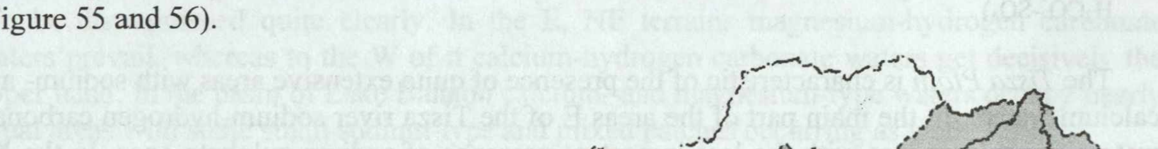

Figure 55 Chemical types of the groundwater by cations
1 sodium (Na); 2 magnesium (Mg); 3 magnesium-calcium (Mg-Ca); 4 calcium (Ca); 5 calcium-sodium (Ca-Na); 6 calcium-magnesium-sodium (Ca-Mg-Na)

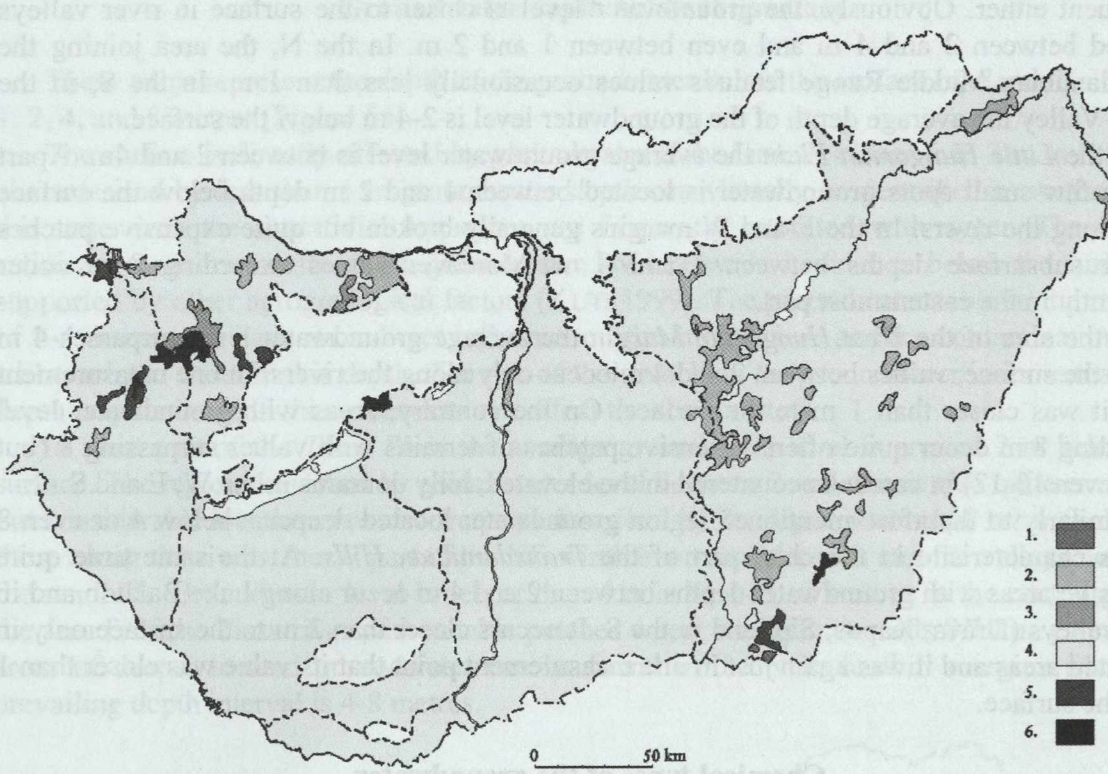

Figure 56 Chemical types of the groundwater by anions
1 chloride (Cl); 2 sulphate (SO_4); 3 sulphate-hydrogen carbonate (SO_4-H_2CO_3); 4 hydrogen carbonate (H_2CO_3); 5 hydrogen carbonate- sulphate (H_2CO_3-SO_4); 6 chloride-hydrogen carbonate-sulphate (Cl-H_2CO_3-SO_4)

The *Tisza Plain* is characteristic of the presence of quite extensive areas with sodium- and calcium waters. In the main part of the areas E of the Tisza river sodium-hydrogen carbonate waters occur in excess with the less important presence of sodium-sulphate ones. In the NE and E, as well as along the left bank of the Tisza sodium-hydrogen carbonate waters can be encountered. Similarly, the groundwater is of also sodium-hydrogen carbonate type in the N of the area bordered by hills. The same sodium is the prevailing cation to the S of the Tisza, in the right bank of the river with both sodium-hydrogen carbonate and sodium-sulphate waters occurring in considerable areas. Magnesium waters are quite scarce in this region, they can be observed in some smaller or larger spots between the North Hungarian Range and the Tisza. Mixed waters occur in patches everywhere forming partly by mixing and partly by external contamination. It can be read of the map that groundwater flows from the more elevated marginal areas towards the deeper located central parts where it becomes trapped. At the same time these domains are recharged continuously not only laterally but from underneath as well which is not only quantitative but also qualitative recharge resulting in continuous salt accumulation in the groundwater of these areas. Given that the water flowing here becomes trapped its amount diminishes only by evaporation. The water in the trap densifies thus with rising dissolved solids content. As a consequence salts precipitate of it according to the precipitation order with the salts of magnesium first followed by that of the calcium and finally sodium transforming the superficial–near surface sediments alkaline (KUTI et al. 2002c). The same scenario occurs in the locations between the North Hungarian Range and the Tisza river where the groundwater flowing from the range becomes trapped by the backwater effect of the Tisza.

Concerning the cation content of the groundwaters of the *Danube Plain* the presence of sodium, calcium and magnesium is characteristic alike. With regard to the anions hydrogen carbonate prevails. In the Danube Valley and in the flats between the sand dunes and loess ranges in the ridge of the Danube-Tisza interfluve (KUTI 1989), as well as in the E in the Tisza Valley (alkaline-type) sodium-hydrogen carbonate waters can be encountered most frequently. Their occurrences are due to their position similar to the Tisza Plain. It is here where groundwaters flowing from different directions join. On the contrary, calcium-hydrogen carbonate waters predominate in the sands of the Danube-Tisza interfluve, as well as in the S part of the Danube Valley and to the W of the Danube in the Drava Valley. Magnesium hydrogen carbonate waters are characteristic of the loess terrains in the Danube-Tisza interfluve and to the W of the Danube. Sulphate and chloride waters can only be encountered in some points. Mixed waters occur as distributed sporadically in the area in smaller or larger patches.

In the *Little Hungarian Plain* calcium and – also in large extent – magnesium are the typical cations. Compared with the Great Hungarian Plain sodium plays a quite subordinate role occurring in one sole point. Apart from the hydrogen carbonate sulphate is represented also quite extensively among the anions. In the W, NW parts of the area calcium-sulphate- and calcium-hydrogen carbonate groundwaters occur, whereas in the NE and E terrains magnesium-hydrogen carbonate waters can be observed decisively. The S part of the area can be described by mosaic-like patterns.

In the *West Hungarian Margin* the groundwater is almost definitively of calcium-hydrogen carbonate type, other chemical types of the groundwater can be encountered almost only in some small patches. In addition to calcium magnesium occurs in an extent worth of mentioning but sodium appears only in one or two patches.

In the *Transdanubian Hills* the areas described by calcium- and magnesium-type waters can be distinguished quite clearly. In the E, NE terrains magnesium-hydrogen carbonate waters prevail, whereas to the W of it calcium-hydrogen carbonate waters get decisively the upper hand. In the basin of Lake Balaton calcium- and magnesium-type waters occupy nearly equal areas with some small sodium-type and mixed patches occurring as well.

Total dissolved solids content of the groundwater

This map illustrates the total dissolved solids content of the groundwater by isolines. Waters with solids content < 1000 mg/l, between 1000 and 5000 mg/l and > 5000 mg/l are displayed with different colours.

The value of 1000 mg/l is the still acceptable drinking water limit, whereas the 5000 mg/l is the limit of extreme salinity which is e.g. characteristic of the alkaline or potentially alkaline terrains.

Concerning the *Tisza Plain* its NE part can be described by comparatively small, whereas its central and S parts by higher salt concentration. The total dissolved solids content is thus below 1000 mg/l in the NE, in the E margin of the North Hungarian Range, whereas it rises above 1000 mg/l in the central, larger part of the area. It exceeds even 5000 mg/l quite frequently, occasionally in large patches and salt concentration surpassing even 10000 mg/l can be encountered in the middle reach of the Tisza. The total dissolved solids content is generally high in the areas where the groundwater flowing from the elevated areas accumulates or it becomes trapped by backwater effect.

In the *Danube Plain* the total dissolved solids content of the groundwater is more diverse. In large parts of the area it is below 1000 mg/l and it is even less than 500 mg/l in quite notable domains. Even if it rises above 1000 mg/l it exceeds it generally only slightly. Simultaneously, its total dissolved solids content may largely surpass 1000 mg/l, occasionally even 5000 mg/l, in the N part of the Danube Valley and in the flats between the loess ranges and sandhills where groundwater is trapped like in Tiszántúl. It occurred in this region that a value exceeding 30 000 mg/l total dissolved solids content was measured in a warm August in the groundwater of an alkaline flat. In the areas situated W of the Danube characteristic values of the total dissolved solids content of the groundwater also exceed 1000 mg/l.

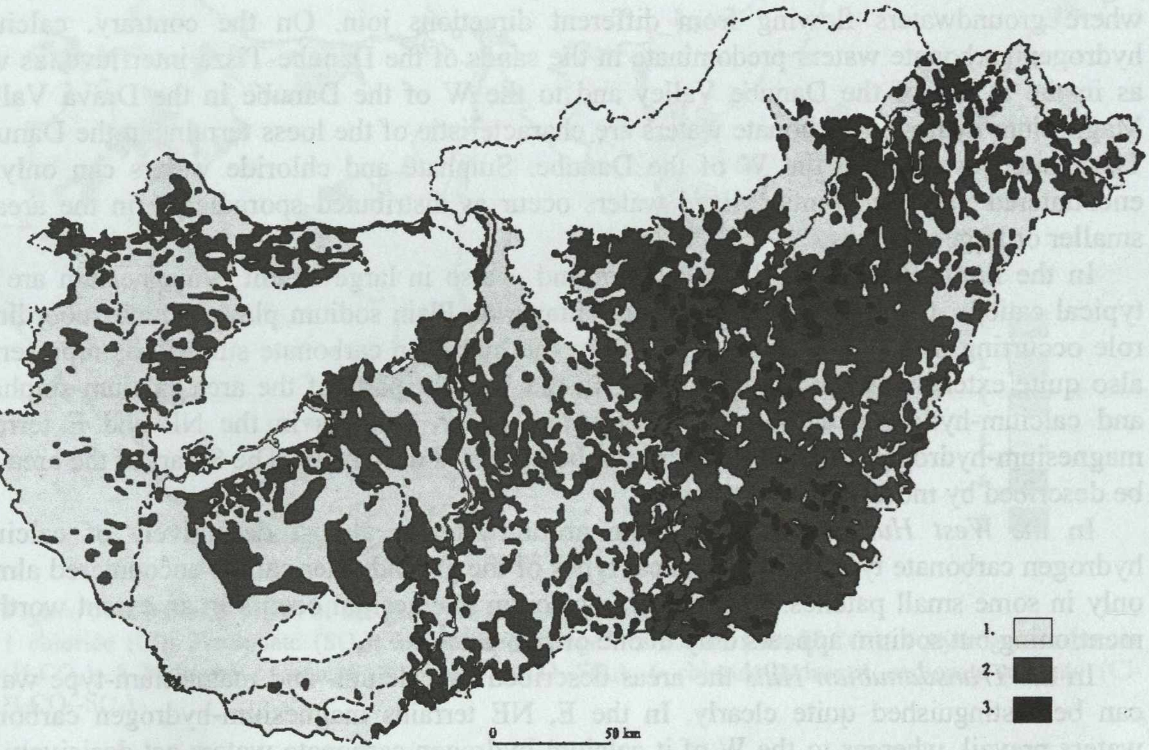

Figure 57 Total dissolved solids content of the groundwater
1 <1000 mg/l; 2 1000-5000 mg/l; 3 >5000 mg/l

In most part of the *Little Hungarian Plain* the total dissolved solids content of the groundwater remains below 1000 mg/l. Even if it rises above 1000 mg/l it does not make it considerably. If it is below that value it does not commonly reach 500 mg/l either.

The salt concentration in the *West Hungarian Margin* is even smaller than in the Little Hungarian Plain. The total dissolved solids content of the groundwater remains below 1000 (quite often even below 500) mg/l almost in the entire area. Values surpassing 1000 mg/l occur solely in some small patches especially in the N and E margins of the region.

The *Transdanubian Hills* can also be described by low salt concentration. The total dissolved solids content of the groundwater does not reach 1000 mg/l approximately in four-fifth of the area. Values exceeding slightly 1000 mg/l can be encountered in patches of restricted area S of Lake Balaton.

Qualification of the irrigability of the areas based on geological factors

The map illustrates the critical groundwater depth concerning irrigability as the relationship between groundwater level, its total dissolved solids content as well as the water retaining sequences and those of the capillary zone (KUTI and MIKÓ 1989).

The evaluation was based on the collation of the groundwater level and its total dissolved solids content. Groundwater depth was concerned in the following four intervals: 0.0-1.0 m, 1.0-2.0 m, 2.0-4.0 m and deeper than 4.0 m. The total salts content was divided at the values of 500 and 1000 mg/l. The system was further refined by taking grain size of the water retaining sediments and that of the capillary zone into account since there is a correlation between the grain size and the height of the groundwater rising in the capillary zone. Consequently, the sediments are assigned to three groups according to their grain size as follows: sand (dominant grain size above 0.06 mm), silt (dominant grain size between 0.02 and 0.06 mm) and clay (dominant grain size below 0.02; the clay and fine silt fraction were joined here).

In the *Tisza Plain* except for the flats between the hills the higher elevated sand and loess terrains can be irrigated without reservation. Due to geological factors irrigation may proceed in the larger parts of the central and S sectors of the area only with restrictions and it is strictly prohibited along the rivers and in the flattest terrains.

In the *Danube Plain* except for the Danube- and Tisza Valleys as well as the intrahill flats the geological factors do not pose any obstacle to irrigation, whereas irrigation of the listed areas is strictly prohibited.

In the *Little Hungarian Plain*, in the *West Hungarian Margin* as well as in the area of the *Transdanubian Hills* irrigation is commonly allowed but it is strictly prohibited in a considerable part of the valleys.

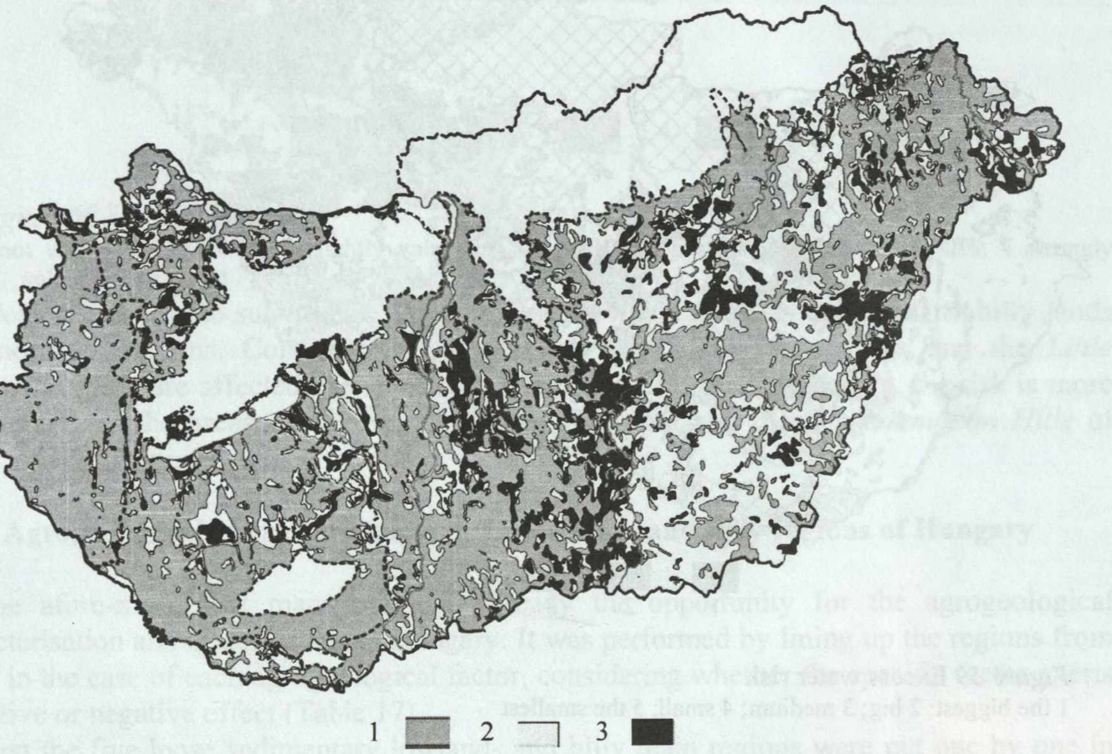

Figure 58 Irrigability
1 irrigable 2 conditionally irrigable; 3 not irrigable

Geological factors of excess water inundation

The map aimed at predicting excess water risk based on geological factors is compiled upon considering the permeability of the superficial sediments, the groundwater depth below the surface and the occurrence of impervious horizons located near the surface. Sequences are considered impermeable if the fraction below the grain size of 0.02 mm exceeds 60 %. Superficial lime mud and alkaline deposits are also qualified impervious. The presence of superficial impermeable horizons is regarded as the decisive factor in assuming the rate of excess water risk. Near-surface impervious sediments are those located until the depth of 2m below the surface in which the fraction below the grain size of 0.02 mm exceeds 60 % together with lime accumulation levels, calcretes and buried soil horizons located in the same depth interval. According to its depth groundwater level is considered as assigned to the following categories: near-surface- (0.0-1.0 m), shallow depth- (1.0-2.0) and deep- (> 2 m) groundwater.

In most part of the *Tisza Plain* excess water risk is generally high with the exception of the elevated sand regions. At the same time it is rather low in the mentioned higher terrains except for the valleys and flats.

The area of the *Danube Plain* features a rather mosaic pattern. There is no risk in the elevated parts but excess water risk is quite considerable in the intrahill flats and valleys.

In the *Little Hungarian Plain* and the *West Hungarian Margin* rather high excess water risk is to be anticipated generally with the exception of the E areas.

Most part of the *Transdanubian Hills* is not or only slightly affected by excess water risk.

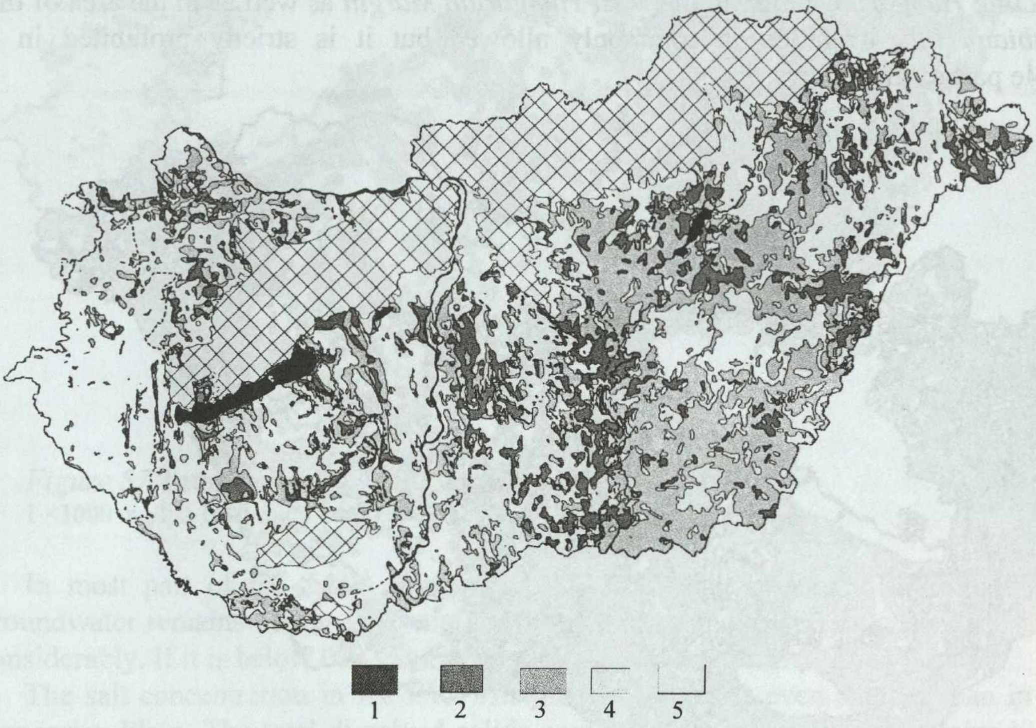

Figure 59 Excess water risk
1 the biggest; 2 big; 3 medium; 4 small; 5 the smallest

Map of erosion risk

The map serves for predicting the likelihood of erosion risk as well as its intensity. It represents at which rate the slope-, climatic- and sedimentological conditions of a certain area contribute to the evolution of the anticipated future soil degradation processes. Areas without risk, as well as of slight-, intermediate- and high risk were distinguished on the map. Within the main risk categories the rate of risk of a certain area could also be determined numerically using the Farkas formula (FARKAS 1987) on the basis of the related sedimentological-, slope steepness- and precipitation data. It is thus feasible to make further distinctions within the main categories.

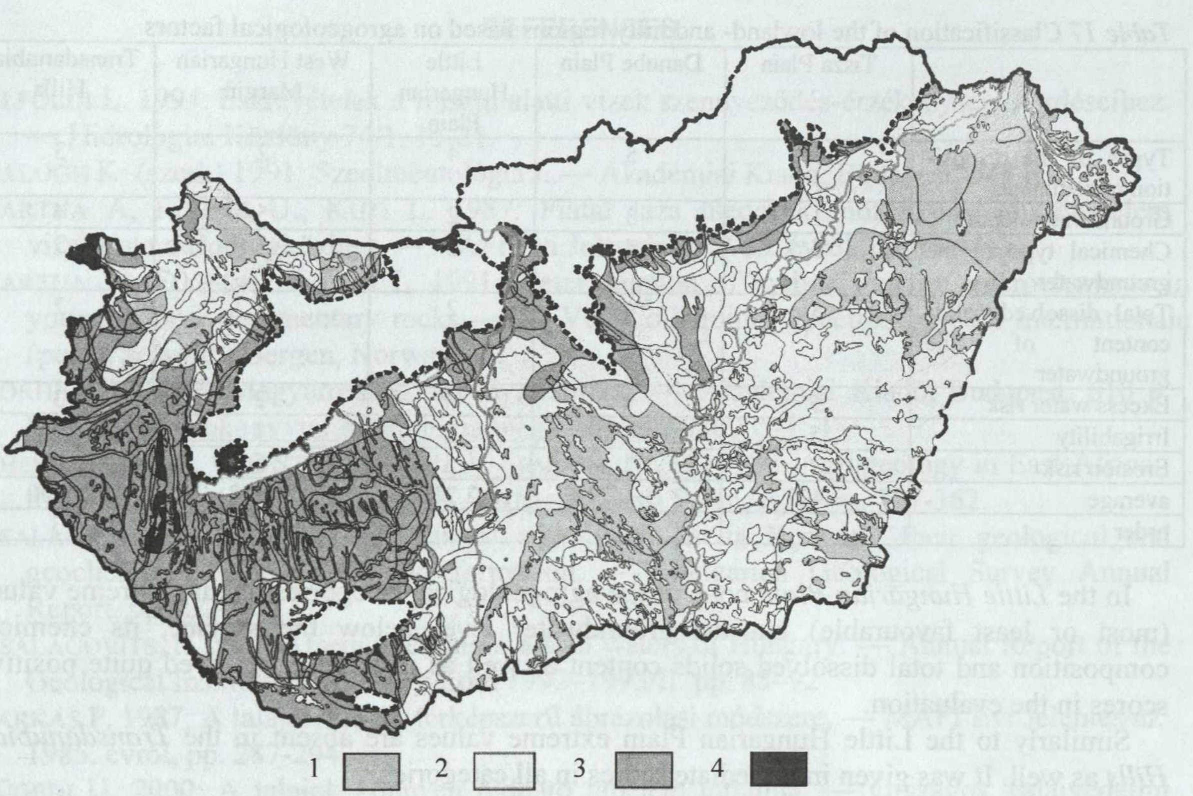

Figure 60 Erosion risk

1 not vulnerable (E_v=0-5); 2 slightly vulnerable (E_v=6-10); 3 fairly vulnerable (E_v=11-20); 4 strongly vulnerable (E_v >21)

Erosion has a quite subordinate importance in lowland areas as compared to hilly lands and mountain regions. Consequently, the *Tisza Plain*, the *Danube Plain* and the *Little Hungarian Plain* are affected only by slight erosion hazard. Simultaneously, the risk is more considerable in the areas of the *West Hungarian Margin* and the *Transdanubian Hills* of higher relief energy.

Agrogeological characterisation of the lowland- and hilly regions of Hungary

The afore-mentioned maps provided already the opportunity for the agrogeological characterisation and qualification of Hungary. It was performed by lining up the regions from 1 to 5 in the case of each agrogeological factor, considering whether the specific factor exerts a positive or negative effect (Table 17).

First the five loose sedimentary lowland- and hilly main regions were put one by one in order according to the studied agrogeological factors followed by their ranking by combining the results of the seven factors (KERÉK and KUTI 2003). Accordingly, the five main regions were ranked as follows:

1. West Hungarian Margin (the most favourable)
2. Little Hungarian Plain
3. Transdanubian Hills
4. Danube Plain
5. Tisza Plain (the least favourable)

In the *West Hungarian Margin* the groundwater depth and the erosion risk are the least favourable factors but they are compensated by the positive scores of the total dissolved solids content of the groundwater, its chemical composition and irrigability. In summary, it can be regarded as the agrogeologically most favourable region in the country.

Table 17 Classification of the lowland- and hilly regions based on agrogeological factors

	Tisza Plain	Danube Plain	Little Hungarian Plain	West Hungarian Margin	Transdanubian Hills
Types of the disposition of sediments	1	5	4	2	3
Groundwater depth	1	3	2	5	4
Chemical type of the groundwater	5	4	2	1	3
Total dissolved solids content of the groundwater	5	4	2	1	2
Excess water risk	5	1	4	2	3
Irrigability	5	4	2	1	2
Erosion risk	2	1	3	5	4
average	3.428	3.142	2.714	2.428	3.000
order	5	4	2	1	3

In the *Little Hungarian Plain* none of the agrogeological categories feature extreme values (most or least favourable) but the groundwater level below the surface, its chemical composition and total dissolved solids content as well as irrigability received quite positive scores in the evaluation.

Similarly to the Little Hungarian Plain extreme values are absent in the *Transdanubian Hills* as well. It was given intermediate scores in all categories.

The *Danube Plain* is the most unfavourable concerning the types of the disposition of the sediments but it is the most favourable if judged by excess water- and erosion risk. As for the other categories it features rather low than intermediate scores.

Due already to its size and diversity the *Tisza Plain* shows the most extreme properties. Its highest scores are associated to the factors of the type of the disposition of sediments and the groundwater depth below the surface. Simultaneously, it was ranked last concerning the chemical type of the groundwater, its dissolved solids content as well as excess water risk and irrigability.

Based on Table 17 it can be pointed out that the specific regions do not feature any major differences concerning their agrogeological properties. Simultaneously, the evaluation enabled us to detect their weak- and strong sides, respectively. Consequently, it can be stated that the results of the agrogeological interpretation on the level of main regions provides essential service by the geological consideration of regional strategies. Simultaneously, as a result of detailed surveys required for the compilation of large-scale, detailed maps of similar themes it provides assistance to the selection of crops on smaller regional- or local levels that can be produced by adapting better to the land, and it also facilitates the designation of the agrotechnical and melioration activities accommodating best to the environment.

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