1. Antecedents, objectives

The basic objective of my work was to describe the *landscape evolution of the Hortobágy at the end of the Pleistocene and in the Holocene*. I carried out researches on three macroform-groups of the landscape with the aim of drawing up the main stages of landscape evolution. The three macroform-groups represent different absolute height levels, different ages and different genesis:

1. I studied the absolutely natural oldest (30-35000 BP years) **abandoned riverbeds** lying on the lowest terrain (<85mBf) for a *palaeoenvironmental reconstruction*.
2. The **river levees** which were of the same age as the riverbeds but represented the next terrain level (86.0-88 mBf) partly meant the stages of the *palaeoenvironmental processes* and partly the natural and anthropogenic *alkaline (szik) erosion processes*.
3. I followed the traces of the most striking *anthropogenic landscape image transformation* through the study of **tumuli (kunhalom)** which can be found on the highest terrains of the Hortobágy (>89 mBf) and represent the youngest group of macroforms but were formed by artificial processes.

I set out the **following aims** while doing research on these forms:

- Classification of the abandoned riverbeds on the area of the Hortobágy on a morphometric basis, the inference of the absolute and relative ages of the main riverbed types.
- Drawing up of the palaeoenvironmental features (palaeoclimatic, palaeohydrographical, palaeobotanical data) of the Hortobágy at the end of the Pleistocene and in the Holocene.
- Researching of the environmental conditions and traces of the natural alkaline lands (palaeoalkalines).
- Determination of the pace of evolution of the szik microforms among natural and anthropogenic circumstances.
- Establishment of the age of the salt berms and drawing up of the szik terrain development.
- Definition of the relationship between the landuse and the development level of the szik forms.
- Description of the geographical situation, geomorphological and stratigraphical endowments of the tumuli.
- Survey of the condition and value categorisation of the tumuli in the Hortobágy and in the neighbouring microregions.
- Proposal for the practical protection of the tumuli still in existence.

2. Applied methods

I started my researches in all phases with the studying of the relevant special literature.

2.1. Field sampling, data collection

I used the data of two **riverbed boreholes** and one **sediment profile** for the reconstruction of the palaeoenvironmental conditions. The soil and rock samples were taken by a motor twist drill and an Eijkelkamp-type hand drill in compliance with the fine-stratigraphical rules. We collected 282 samples in total from the three places for the laboratory experiments. I used data from **12 tumuli drillings** for the stratigraphical description of the tumuli and the determination of their construction methods. The drill profiles entered the bodies of the tumuli and the circular shaped ditch surrounding them as deep as the "C" level of the buried original soil.

I prepared the **geomorphological map** of the Agota Puszta as part of my szik geomorphological studies. I made exact **erosion measures** between 1997 and 2000 on four sample areas and studied the changes in the **vegetation cover** of these areas.

We used a laser theodolite for the **cartographic presentation** of the terrains with salt bems and with the various tumuli types. The **survey of the condition of the tumuli** was based on a datasheet prepared especially for this purpose.

2.2. Methods used for the testing of materials

The collected soil and rock samples were processed in the laboratory of the Institute of Geography at the University of Debrecen with taking into consideration the relevant regulations.

As part of the palaeoenvironmental researches, dr. Enikő Patak-Félegyházi carried out **palynological experiments** on the samples taken from the riverbed boreholes. We made **malacological experiments** on the large number of mollusc shells derived from the sediment profile of Nyírőlapos with Dr. Pál Sümegi. We complemented the palaeoenvorinmental studies with **radiocarbon and isotope-geochemical measures** in the Environmental Analytical Laboratory of the ATOMKI.

2.3. Data processing, plotting

I used the **Tilia** and **TiliaGraph** softwares for the presentation of the results gained from the pollen analysis and for the primary study of the soil and sediment samples. The data of the erosion measures were fixed in and evaluated by the **Microsoft Excel 97** programme. I used the **Surfer for Windows 8.0, AutoCAD 2000** and **ArcView GIS 3.2** softwares to prepare the various types of maps. I fixed the data concerning the state survey of the tumuli in the **Registration System of Tumuli 1.1** software which was prepared especially for this purpose.

I used 10000, 25000 and 50000 scale military maps and Landsat TM satellite images for my geomorphological studies.

3. Results

3.1. <u>Natural landscape evolution in the Hortobágy Region</u>

3.1.1. Palaeoenvironmental researches – study of the abandoned riverbeds and of the infusion loess levees

<u>*Riverbed morphometry*</u>

The determining landscape forming agents on the Hortobágy were the fluvial activities before man appeared here. The evidences of this fluvial landscape formation are the numerous larger and smaller **abandoned riverbeds** in the Hortobágy region which were grouped into five categories from a morphometrical point of view and on the basis of the extent of their sedimentation:

1. The first group consists of the **current meanders of the** living **Tisza** and the mature **meanders** which **were cut off** during the flood regulation works.
2. The smallest meanders of the Hortobágy whose parameters do not even reach one-tenth of the size of the River (**Király, Selypes, Árkus** and the **Hortobágy rivulets**) were listed in the second category.

3. I listed those beds into the third category which were two or three times larger than the ones in the previous category. I distinguished between two subtypes:
   3.a. Some of them may be seen in the continuation of the **Sajó and Hernád Rivers**. These riverbed structures may not be detected on the contour maps because of the vigorous sedimentation and their dim contours may only be recognised on satellite images.
   3.b. Riverbeds of similar size may also be found along the **Kösely**. Most probably these are younger beds because their mature meanders and oxbows may be easily detected and studied both on the topographic maps and on the field.
4. Those larger riverbeds were put into the fourth category which may be found directly along the River Tisza and east of it from Polgár as far as to Kunmadaras (**Halas-fenék**).
5. Finally, those largest but least perceivable riverbeds belong to the fifth category which lie along the **Tiszavasvári-Nagyiván line** in a northeastern-southwestern position. Only the studying of the satellite image reveals their situation

<u>The age and genesis of the riverbeds</u>

The absolute **age** of the **Halas-fenék** – which was listed in the fourth category – may be taken between **33000-30000 BP years** on the basis of the radiocarbon and palynological analysis. This corresponds to the milder climate of the **Stillfried B** or the **Denekamp interstade** of the **Middle Würm** period. It concludes from this that the riverbeds which are buried and can be only seen on the satellite image are definitely older than this.

These large riverbeds in the Central Hortobágy region were most definitely formed by the **systems of the Ancient Sajó and Ancient Hernád rivers** coming from the northern mountain ranges in the wet, rainy periods of the Pleistocene. These were able to discharge even five times more water than the present Middle Tisza. The following data support the above statement:

- The **material of the alluvial fan of the Sajó-Hernád**, in the underground layers, may be found as far as in the southern parts of the Hortobágy.
- The **micromineralogical analysis** carried out on the sand material from the 33000-30000 year-old bottom of the riverbed of the Halas-fenék renders probable the origin of the riverbed from the Sajó-Hernád river system.

After the drainage of the River Tisza was shifted to the western part of the alluvial fan in the Nyírség and it appeared on the western edge of the Hortobágy, the riverbeds of the former Ancient Sajó and Ancient Hernád might have had an important role in the drainage of the floods of the Tisza.

<u>Sedimentological and palynological evaluation of the sediments of the riverbeds</u>

A common feature of the two riverbeds in the Hortobágy region – which were studied from the aspects of sedimentology and palynology – is that **their pollen retaining abilities is very poor**. The Kanász-lapos in the southern Hortobáby and the Halas-fenék in Zám were both filled up with almost 9 meters thick argillic silt layers variegated with *ferrous, manganese and calcareous concretions* preserving the memory of **repeated desiccation**.

On the basis of the palynological analysis, we managed to reconstruct for the end of the Pleistocene a **dead water lacustrine**, then later a **sphagnum paludal** state, while in the environs of the riverbeds we found **pine-forest** (Pinus silvestris and Picea) **mixed with frondiferous tree species** (Betula, Salix). Later, when the Picea, Betula and Salix species were supplanted from the forest stand it led us to conclude that there was an extremely dry and cool climate. This brought about the degradation and desiccation of the marsh. Following it, the riverbeds became unsuitable for conserving pollen.

Sedimentological and malacological analysis of the material of the infusion loess levees

During the Pleistocene, the large amount of silicate and carbonate fluvial sediment with different size and age accumulated by the rivers mixing with Aeolian loess led to the formation of flood plain sediment with high calcareous content on the flood plains of the Hortobágy, called **infusion loess**. At some places this contains considerable amounts of *Mollusc shell*. The large number of non-redeposited intact Mollusc shell observed in the infusion loess layers on the Hortobágy shows that the theory of the Ancient Tisza destroying the surface of the Hortobágy in an east-west direction lacks ground because it would have led to the destruction of these sensitive mollusc shells.

The sedimentological and malacological analysis of the material of the loess profiles from Nyírőlapos allowed us to draw the following conclusions:

- At the end of the Pleistocene, **the alternation of microstade** and **micro-interstade** may be detected which transformed the composition of the flora and fauna for a short time. On the basis of the dominance-changes of the temperature-indicator mollusc species, it may be stated that **at the end of the Pleistocene the average temperature in July was alternating between 12 and 20°C**.
- Due to the low number of sylvan species specimen (Perforatella bidentata) findings, which perished at the end of the Pleistocene, the **afforestation** of the Hortobágy **during the Holocene cannot be proved**. Mainly the **open flood plain meadows** and on the higher parts maximum a **woody steppe** state could have characterised the vegetation at that time.
- Mainly **temporarily desiccated marshy habitats** with dead water could be reconstructed; the flood of living rivers could have been only a minimum on the eastern part of the Hortobágy.

3.1.2. Szik geomorphologcial researches

Demonstration of the environmental conditions of the formation of alkaline soils

We may conclude from the results of the palaeoenvironmental studies that the most important environmental conditions for the formation of alkaline soils were already present on the Hortobágy at the end of the Pleistocene and the beginning of the Holocene. These may be summed up in the following points:

- The end of the Pleistocene was characterised by **climatic fluctuations**.
- The **temporary floods of the Tisza and desiccation** following them resulted in **fluctuating groundwater movements** which led to the formation of the **capillary zone** in the sediment and soil layers.
- The dissolved calcareous content of the **infusion loess** created **alkaline pH** as it was migrating upward through the capillary zone towards the upper layers of the sediment. This led to the disintegration of the silicates, that is it led to siallitic weathering. As a result of this, mainly **illite and montmorillonite clay minerals, amorphous silica** and **alkalis** (Na^+, K^+, Mg^{2+}) were formed.
- With these, the **main geocomponents of alkaline soils** were already formed by the end of the Pleistocene and beginning of the Holocen, therefore various types of alkaline soils could be formed. ***Since the upper "A" level of these soils became easily vulnerable due to the disintegration of the silicates, therefore the cutting up of the alkaline soils – formation of salt berms – by the erosion started.***

Environmental conditions of the formation of salt berms

On the basis of my researches done on Ágota Puszta, it may be established that the areas with salt berms most often occur on the sloping edges of the levees in the height domain between 86.5-87.5 meters. This may be explained by the fact that the **solonietz alkaline soil types** cracking during the dry periods were formed in this narrow zone and the **relief differences** here were indispensable for the erosion processes.

The study of the relative relief map and the spatial distribution of the salt berms show that the often only **10-50 cm** difference between the summit level of the levees and the local erosion base is **enough for the formation of salt berms** but the formation of more developed forms need a relief difference of 50-100 cm.

The **amount of precipitation** and the **intensity of precipitation** are also very important conditions for the alkaline erosion process. On the alkaline soil surfaces the precipitation water creates larger and smaller *alkaline veins with linear* and *backward erosion* along the cracks formed in the dry periods which may be regarded as salt berms. The surface of the berm tops is mainly destroyed by *areal erosion*. This **alkaline erosion process is the most rapid in the periods of heavy summer showers with high intensity**. As a consequence of the often 6-8.3 mm/30 minutes precipitation intensity of the summer months in the years of 1998 and 1999 with an unusually high amount of precipitation (646-773 mm) the surface was eroded twice as quick as in the periods of the soft autumn or early spring rains. ***Thus, the summer may be regarded as an active, while the winter may be taken as a passive period from the aspect of the formation of salt berms.***

Besides, the pedological differences, the heights and slope angles of the berms primarily depend on the general inclination conditions of the terrain. The asymmetry in the berm edge caused by the cardinal exposition could not be proved on the studied area.

Determination of the development pace of the alkaline microforms among natural conditions

During the mappings on Ágota Puszta, I distinguished between two subtypes of the berm profiles. **No erosion could be shown** on the ***gently sloping salt berms without staggered breaking-offs*** (Sample area 6) in three years but instead a "filling" could be measured due to the thick, alkaline meadow grass association. On certain points of the staggered breaking-offs developing among natural or nature-close circumstances (Nagy-Dögös), **a 1.4-7.8 cm backing of the berm edge could be detected in three years**. On the whole of the berm edges, however, the extent of backwarding was only 0.7-2.1 cm/3 years on average.

The **sample areas used for measuring erosion** on the Ágota Puszta developing among natural circumstances belong to the **mature (maturus) state** in my alkaline development line which is characterised by the **mergence of the szik veins resulting from the cracks and the closed-drainage depressions and consequently by the formation of larger and smaller eroded terrains**.

Age of the salt berms developing among natural circumstances

According to the calculations made on the basis of the three-year-pace backwarding of the berms on the Nagy-Dögös and the extent of the eroded terrain without "A" level, the **age of the salt berms** on this area **may be estimated to between *750 and 6550 years***. The value depends on whether we calculate the age with the maximum or the average backing index. Most probably, the salt berm formation process might have started on the area somewhat earlier than *3000 years ago*. Consequently, the assumption that these erosion microforms came into being exclusively as a result of anthropogenic interventions following the river regulation works (secondary alkalisation) does not stand its ground.

3.2. Anthropogenic landscape evolution on the area of the Hortobágy

3.2.1. The anthropogenic salt berm formation

Researching of the anthropogenic factors influencing the development of salt berms and their form shaping impacts

It was the **extensive animal keeping** that basically left its mark on the development of alkaline processes since the **regular treading of the stock intensifies the alkaline erosion process**. Until 1945 we may talk about a **100000 animal stock** on the pusztas of the Hortobágy with a strong fluctuation of the number which must be handled as a significant form shaping factor.

The **river regulatory and water management works** started in the mid-nineteenth century led to the formation of terrains of new types of salt berms and had a significant impact on the development of the already existing forms. On those areas where *drainage canals*, *borrow pits* were deepened into the surfaces covered with solonetz soils, **intensive erosion processes started on the edge of the artificial negative forms** due to the "large" relief differences. As a consequence of this, at some places there are not only one but two berm edges on top of each other backing at the expense of the alkali pastures. This process, further intensified by the tread of the animals (sheep), results in the **most rapidly forming salt berms of the Hortobágy**, which I could trace on the sample area in Makkod.

The largest **berm backing movement** on the sample area in Makkod in three years was **25-26 cm** which was accompanied by **3-6 cm areal surface wearing on the top of the berms** and with **2-10 cm areal and linear erosion** experienced **on the berm slopes**. The accumulation work of the alkaline veins may be studied in the form of "alluvial fans" being built on the edge of the erosion base.

Traffic may also cause the formation of anthropogenic salt berms. The "busy" parts of the grassland, which are cut up by the wheels of the vehicles in the wet periods, may be taken as alkaline erosion affected terrains.

The salt berms, therefore, may not be regarded as purely natural formations because their development is highly influenced by the treading of the fluctuating number of animals, by the relief increasing impact of the relief differences in the artificial negative forms and by the intensive traffic. This is clearly supported by the berm formation processes experienced on the sample areas in Makkod and in Frakas-sziget where it is three times more intensive. It was manifested in the intensive clearing of the vegetation on the tops of the berms, in the changes, and in many cases the deterioration in the composition of species, in the quicker areal erosion and in the more intensive backwarding of the berm edges.

3.2.2. Results of the researches on tumuli

Types of the tumuli an dthe general regularities in their location

I extended my researches in connection with the tumuli to the neighbouring microregions (Hajdúság, Nagykunság) besides the Hortobágy region. This made it easier to establish some general regularities:

- The **horizontal spatial distribution** of the tumuli, and within this especially that of the tells, **is characterised by linearity** – that is, they are mainly located along the external arch of the living streams and their abandoned meanders. The distribution of the kurgans and watch-mounds may be characterised by *linear* and *scattered* settlement structure as well.
- The regularity in their *vertical distribution* is reflected in the fact that **they were built over the floodless level of the landscape in all cases**. Thus, the average height level of the tumuli in the

Hortobágy region is 90 mBf while there is not one tumulus under 86.5 mBf which is the actual height endangered by floods.

- From a stratigraphic point of view, the tumuli may be simple **with an unstratified inner structure (krgans, watch-mounds)** or may have a **complex structure (tells)** interrupted with one or more cultural layers. The kurgans and watch-mounds were usually built in one phase from the humous surface soil of the surrounding terrain and no base formation was used for the building. In the case of these mound types, the borrow area usually cannot be seen due to the levelling caused by the tilling of arable land. As opposed to this, the tells reached their present heights during centuries (and even millennia) as a consequence of the slow accumulation and thickening of the cultural layers in addition to the low amount of earth transportation between some of the settlement levels.
- The **circular shaped trenches** – in the case of the fortified tells: **trench systems** – may be still recognised at the foot of the larger tells which served as **borrow pits** for the heightening of the mounds and at the same time had protective and cultic roles as well (Polgár – Nagycsősz mound) These trenches are **suitable for the reconstruction of the former settlement environment** through the sedimentological, palynological and malacological surveys of the lacustrine sediments found in them (Szakáld – Test mound).

<u>*Most important results of the state survey of the tumuli*</u>

Joining to the national cadastering programme of the tumuli, **I carried out state survey researches on the areas of the Hortobágy, Hajdúság and in the northern half of the Nagykunság** and drew the following conclusions:

- According to sources back in the eighteenth century, there were 1638 mounds on the above named areas, <u>**70% of which disappeared without leaving a trace behind**</u>. Thus, I could study only **503** tumuli. On the basis of the oldest data, there are only 213 out of the earlier existing 649 tumuli **on the area of the Hortobágy** which means that **only one-third of them remained**. 85 of these can be found on the area of the Hortobágy National Park.
- <u>**Their reduction in number**</u> accelerated especially from the second half of the nineteenth century as a consequence of the *increase in the area of arable lands, development of agricultural technology, construction of embankments, roads, railways and extension of the settlements*.
- I examined the <u>**geomorphological endowments of the bodies of the tumuli**</u> during the state survey. Fortunately, the **intact** symmetrical **tumuli are still in majority** in all three regions (58-72%). It is noteworthy that this value is the lowest on the area of the Hortobágy which may be in connection with the unfavourable soil endowments (the tumuli could have been humus mines) and the large-scale construction works (fish-ponds, canals, embankments). The rest of the tumuli have asymmetrical bodies which may be categorised as **disturbed, ravaged and levelled**. The disproportional tumuli primarily developed as a consequence of anthropogenic impacts (borrow pits, amateur archaeology, road and canal works, military objects, intensive tilling, etc.). Nevertheless, we may talk about **natural asymmetry** as well in the case of the tumuli built right beside the riverbeds caused by the lateral erosion of the rivers.
- The <u>**dominant vegetation type of the surface**</u> of the tumuli is in close connection with the applied economic methods. In the three landscapes, **on 48% of the tumuli, there is farming**, thus the field cultures are taken as dominant vegetation types. Besides these, the ratio of the tumuli covered with weedy, disturbed grassland, groves of species strange to the landscape and woods is also considerable. **Primeval grasslands** occur in larger and smaller patches on only 18% of the studied tumuli, but only **5.1% of the tumuli count as dominant vegetation types**.

- During the anthropogenic landscape transformation of the past century, the tumuli suffered considerable **scenic depreciation**. As a consequence of this, only **19% of the tumuli** on average **may be called remarkably valuable while 28% of them are absolutely valueless** from the aspect of scenery. On the basis of the categorisation by the scenery value, the tumuli on the area of the Hortobágy are in the worst situation which may be explained by the high proportion of the disturbed and ravaged tumuli, the smaller relative height on average and the considerable number of disturbing objects.
- I found **archaeological findings** (pieces of bone, earthenware fractions, mud-flake pieces) on **23%** of the surveyed tumuli (118) which signify the dwelling-place (tell) type of tumuli. Only **6.3%** (32) of the studied tumuli were **excavated by archaeologists**. These excavations concerned primarily the tumuli on the area of the Hortobágy and Hajdúság.

I found it necessary to select those from the studied 503 tumuli which have no value at all by now, so that the effective protection of the still valuable tumuli could be started as soon as possible. ***I selected the valuable tumuli according to the geomorphological, botanical, scenic, archaeological and other culture-historical values***:

- On the basis of the above criteria, almost **75%** (375) **of the tumuli may be regarded valuable** from at least one but in some cases even three or four aspects. The remaining 25% suffered such damage that I do not see a realistic ground for their rehabilitation (over-tilling, removal, destruction, building up, etc.). **In absolute terms, the highest number of valuable tumuli can be found on the area of the Hortobágy (144) but when looking at the ratios, the Hajdúság proves to be the richest in these tumuli (78.9%)**. When studying the area of the Hortobágy National Park separately, we found the highest ratio of valuable tumuli there (82.3%).
- I elaborated a **point system** for the determination of the ranking within the valuable tumuli and I gave points to the certain value categories. Theoretically, each tumuli could collect 36 points at the maximum. The 375 tumuli which were qualified as valuable collected 4943 points out of the attainable theoretical maximum (13500 points). Studying the points by the micro-landscapes, I found that **most of the values related to the tumuli occurred on the area of the Hajdúság** (1938 points – average: 13.9). The Hortobágy region follows with more than one hundred points less (1828 points – average: 12.7), while the Nagykunság region has a considerable disadvantage on the third place (1177 points – average: 12.8).
- The structure of the points given to the tumuli of the two landscapes with the highest points shows that **on the area of the Hortobágy there are tumuli mainly with smaller relative height which are botanically more valuable, while on the area of the Hajdúság there are higher tumuli which are richer in archaeological finds in spite of the large-scale tilling of arable land**. It concludes from this that the Hortobágy preserved tumuli which are in a little bit worse condition and have a different nature than those in the neighbouring Hajdúság region Although more than 80% of the tumuli on the area of the Hortobágy National Park proved to be valuable, their points were not outstanding. This demonstrates that **nature conservation only partly means an advantage as opposed to the tumuli which remained outside the protected areas**.
- For the realisation of the long-term protection of the tumuli it would be recommendable to **expropriate** them by an about 100x100 m buffer zone, to **harmonise the farming methods** with the protection of the form, to widespread **education** related to them and to **initiate them into tourism** more effectively (e.g. transformation of some tumuli into open-air museums, riding tourism).

I hope that my research results provided new pieces of information to the often contradictorily interpreted natural and anthropogenic landscape evolution and it will help the more thorough cognition of the values of the landscape and thus it will provide a basis for the nature conservation activities of the Hortobágy National Park. Hopefully these results will be also applicable when handing in the next tender for obtaining the nomination of the World Heritage in which after getting the “World Heritage” nomination in the cultural landscape category the Hortobágy will get the honourable “World Heritage” in the *natural and cultural landscape mixed category* – which would actually better suit the real features of the landscape.