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THE ANALYSIS OF SEDIMENT ACCUMULATION AND SILTING-UP OF A CUTOFF CHANNEL ON RIVER MAROS NEAR THE CITY OF MAKÓ

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Introduction

During the quest of reasons underlying the extraordinary floods on the rivers of the Great Hungarian Plain, which occurred in the past few years, investigations of the processes and changes prevailing on the floodplain has become more and more important. On the one hand, these involve the understanding of the process es, and degree of sediment accumulation on the floodplains and the silting-up of the cutoff channels. Because of the different degree of sediment accumulation on the active and protected floodplains, the cutoff meanders located behind the artificial levees on the protected inactive floodplain still dominantly form open-water oxbow lakes with differential characteristics. Meanwhile their counterparts, located on the active floodplain in front of the artificial levees are sometimes entirely filled up. A good example of these filled up oxbow lakes can be found at the city of Szolnok in the form of a part of the cutoff channel of the Tisza of Alcs, which is located on the active floodplain in front of the artificial levees (SOMOGYI, 2000). Nevertheless, the oxbow lakes of river Maros and cutoff meander at Szeged also belong to this latter group.

The major aim of our investigations involved the analysis and reconstruction of the process and speed of sediment accumulation and silting-up in an artificial cutoff channel created during the river control works, and located on the floodplain of river Maros near the city of Makó. The reconstructions were mainly based on the historical analysis and interpretations of maps from the area, as well as the application of pollen analytical methods. A special type of pollen analysis, aimed at the determination of the pollens of invasive plant species with a known date of appearance and frequent occurrence, has been utilized in order to determine the relative age of the individual sediment horizons in the sedimentary profile, and thus the annual rate of sediment accumulation and silting-up.

During the course of our investigations presented herein, we were seeking answer to the following questions:

1. What sort of environmental changes and transformations occurred during the past 300 years in the pilot area?
2. What is the degree of silting-up in the cutoff meander?
3. Is the application of the pollen analysis of invasive plant species suitable for absolute age determination of recent sedimentary profiles?

The found answers to these questions might help us to enhance our understanding of the processes and changes prevailing on the active floodplain, and their indirect influences on flooding as well.

The pilot area and the methods applied

The pilot area of our study is located on the right banks of river Maros SE of the city of Makó between fluvial kms 27-30. The area forms a tiny embayment on the active floodplain with a width of approximately 1 km (**Fig. 1.**) This area was placed under protection within the framework of the Körös-Maros National Park in 1999. The former overdeveloped meander, known as the Goszpod bend was cut off between 1842-1850. Since then the cutoff channel has been completely filled up and is surrounded by the floodplain and point bars. The discharge of the river Maros at the profile of Makó is 40 m^3/s at low water, while it can reach a rate of 1800 m^3/s during flooding (VÍZRAJZI ÉVKÖNYV). The average annual deposit transportation capability is 2.73 million t, the largest rates during the highest waters may reach as much as 6000-12000 kg/s as well.

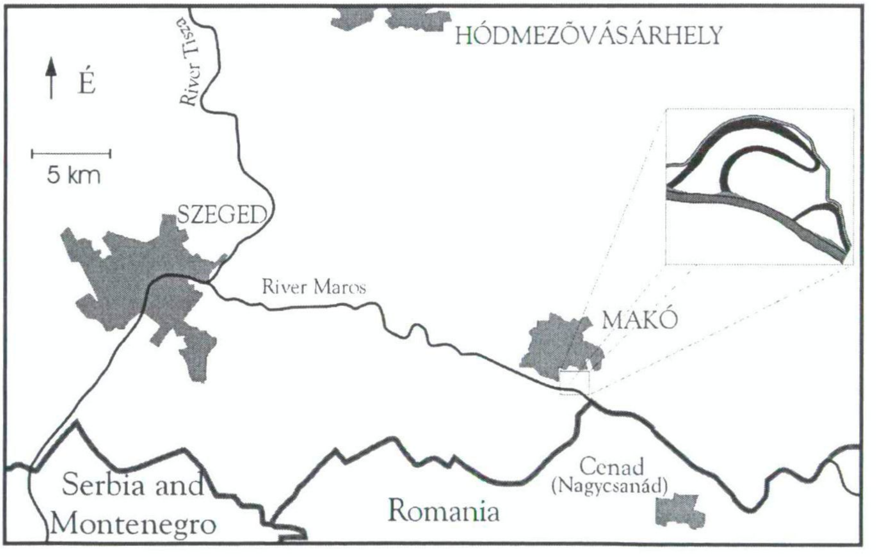

Figure 1. The location of the pilot area with the site of sampling marked

As a first step in our investigations the relevant maps and detailed descriptions published have been collected (TÓTH, 1972, 1988, 1992). In parallel, sediment samples were taken at an interval of 10 cms from the former bed of the Goszpod bend with a hand-driven Földváry type auger until the coarser material of the active channel was reached (420 cm).

The collected samples were analyzed for grain-size composition via simple sieving and using a Köhn pipette. The carbonate content of the samples was determined by Scheibler calcimetry. Finally, the organic content was determined by spectrophotometry following a digestion with sulphuric-acid and potassium-bromate.

During pollen analysis, the Zólyomi-Erdtman zinc chloride acetylation method was utilized for sample preparation followed by the determination of the sporomorphs under the microscope at a magnification of 400-600 times (FAEGRI–IVERSEN, 1988). The obtained results were used for the construction of pollen diagrams depicting percentage and absolute values with the help of the softwares Tilia and Tilia Graph 3.0.

Results

Maps and descriptions

The first map of the area under investigation was prepared by WALTNER in 1699 (**Fig. 2/A**). In this map, the river Maros is characterized by several branches and islands above the village of Nagycsanád, however below the settlement there are numerous meanders. The author speaks about arboraceous vegetation prevailing along the river bends.

The 1753 map of Steinlein depicts an arboraceous, marshland vegetation in the area of the Goszpod bend along with two islands within the riverbed of Maros. The tracks of the artificial levees protecting the city of Makó are well traceable along the western side of the meander. The thin line on the eastern side running into the meander may represent a drainage channel referred to later on as the „Pallagi-fokja" ("Pallagi crevasse").

The following maps more or less depict the general conditions of a given period: the map of J., Vertics (1778); the map of the first military survey (1784). Another, professional river navigation map prepared in the late 1780s can be attributed to Vertics as well. In these there are no signs of the formerly mentioned islands above the Goszpod bend, even though only two or three decades had passed since their first mentioning. As depicted in the map of the first military survey the left banks of the river are covered by arboraceous vegetation.

The city of Makó was surrounded by woodlands at a larger distance, which turned into vineyards and hemp fields closer to the city. The earlier depicted site of crevasse is missing, a drinking site is indicated instead.

There are six ship mills on the river Maros in the 1804 map of Horváth, the meander neck is cut through by an artificial levee. The arboraceous vegetation was displaced by grassland areas in the area of the Goszpod bend and that south of it.

The site of the same crevasse splay is depicted again on the 1805 map of Vertics on the "inner pasturelands of Makó", which might be a rejuvenation of the 1753 crevasse event and is also referred to as the „Pallagi Fokja" ("Pallagi crevasse"). The planned sites of cutoff are clearly observable on the 1:28 800 maps created in preparation for the river control works on Maros in 1827.

The narrow meander of the Baranya bend necessitated their implementation. A description dated from 1835-36 tells about scant willow-poplar woodlands and sporadic hardwood areas with intercalated gardens and orchards.

The spring floods of 1838 and 1841 enhanced the negotiations on the necessity of control works due to the high vulnerability of Makó. A supplement of the 1842 report of Mátéffy on the progress of the river control works is depicted on **Fig. 2/B**

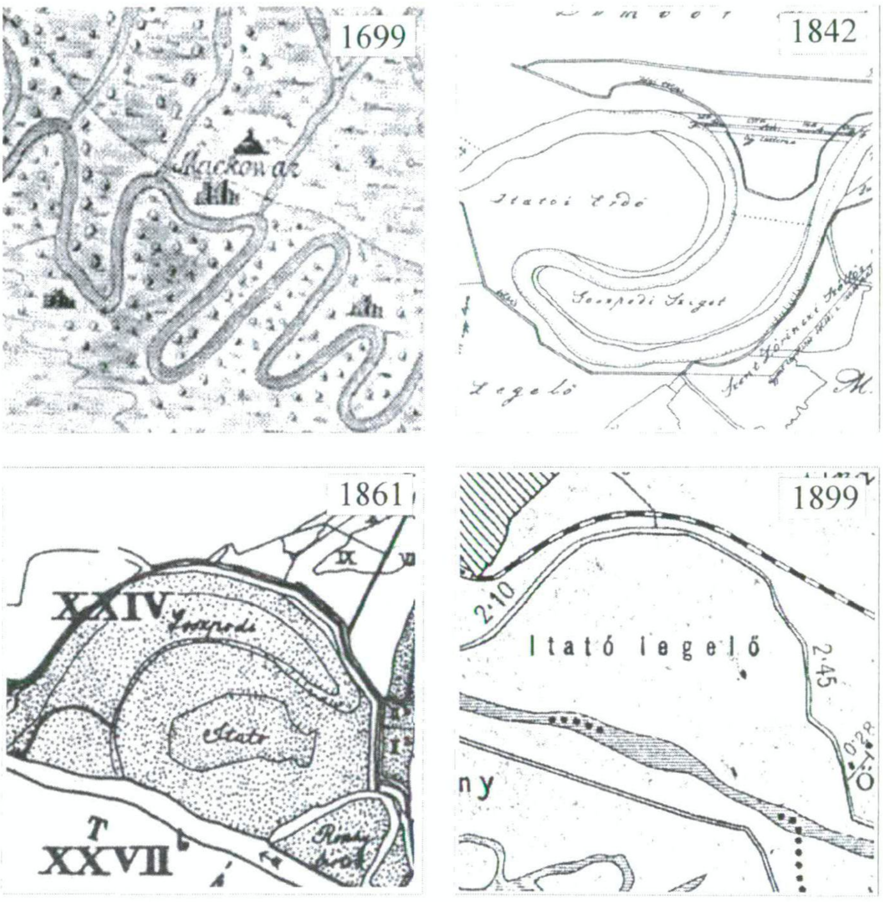

Figure 2. Changes in the environment of the pilot area based on maps
A: 1699, B: 1842, C:1861, D: 1899

Though the majority of the work was complete, it took some time for the natural river to occupy its new artificial bed (TÓTH, 1992). Following the implementation of the cutoffs, finished by 1850, the establishment of artificial levees and other flood protection work started.

The pilot area has been referred to as Dead Maros on a general field survey map from 1854 (unknown scale and author) for the first time. According to Tóth (1992), a series of lime-burning furnaces were located near the willow woodlands of Lúdvár in 1860, not too far from our pilot area. Furthermore, a shallow-draught steamboat, the „Kaiser Ebersdorf" was a means of transprtotation between the cities of Szeged and Arad from 1852 onwards. The produced ash might have been preserved in the sediments as shown by pollen analyis. The 1861 map of Breuer G. with a scale of 1:14 000 depcits the distribution of the inner pasturelands of the city of Makó (**Fig. 2/C**). On this map the branch of the Goszpod bend located closer to the active riverbed is narrower in contrast to the other one. This narrow section must have acted as some sort of a sediment trap for the finer deposits reaching the area during flooding since this was the first deep trench on the floodplain from the direction of the channel. Conversely, water movement in the other branch located closer to the artificial levee must have been reduced resulting in the accumulation and deposition of less sediment to that area.

According to the 1899 map from the area (**Fig. 2/D**), the cutoff channel was totally infilled during a period of about 50 years (bw. 1850–1899). The important differences in the relief were soon leveled off thanks to the large carrying capacity and volume of load of the river Maros since there are no open water areas in the pilot area on this map, however even the network of minor creeks is depicted on the other side of the Maros as well. The disappearance of the oxbow-lake resulted in a complete melting of the Goszpod bend with the former „Itató" (Watering place). The floodplain of the Maros becomes narrower downstream the pilot area and widens up again afterwards damming up waters again resulting in increased accumulation rates.

There were no significant changes in the pilot area up to 1914, characterized by pasturelands and sweep pole wells and trees lining the margin of the artificial levees. Traces of initiating bar and island formation in the active riverbed can be observed as well. According to a detailed map from 1970 the area is between 81 and 84.5 m asl., with the deepest point being the holes dug by the groundmen. Wet meadows and willow woodlands occupy the lower-lying areas while apple orchards and pastures can be found in the higher regions.

The results of the analysis of the sedimentary profile

A. Grain-size composition

The prepared diagram depicts the percentages of sand (2-0.02 mm), silt (0.02-0.002 mm) and clay fractions (0.002> mm) in the sediment along with their cumulative values (**Fig. 3.**). The amount of ash along with the carbonate and organic matter content is also depicted here. The profile can be divided into three major units according to the characteristics observed on the diagram:

Unit 1: (420-380 cm) This unit is dominantly made up of sand (77-92%), with the appearance of medium sized sands at a considerable amount alone here throughout the profile (0.63-0.2 mm). The proportions of clay and silt fractions are minimal. These samples correspond to the the coarser, sandy deposits of the active channel of the Maros with a high ash content and low organic matter content as the deposition of organic materials was not possible within the active riverbed.

Unit 2: (380-170 cm) This unit is characterized by alternating layers rich in sands (40-75 %) and clayey-silty beds. The ash content is still very high between 230-340 cm following an initial fluctuation. The organic matter is highly fluctuating as well its peaks corresponding to the ones of the clay and silt fractions.

Unit 3: (170-0 cm) Here the amount of sand is reduced to a rate of 30-50%. The clay content is very often around 50-55% with hardly any changes in the silt fraction. This unit is characterized by a significant drop in the ash content accompanied by a slight increase in the carbonate content, but still with rates of 3-4% only. The humus content is not so capricious regarding its former peak values here, however it reaches considerable amounts in the upper 40 cm of the section.

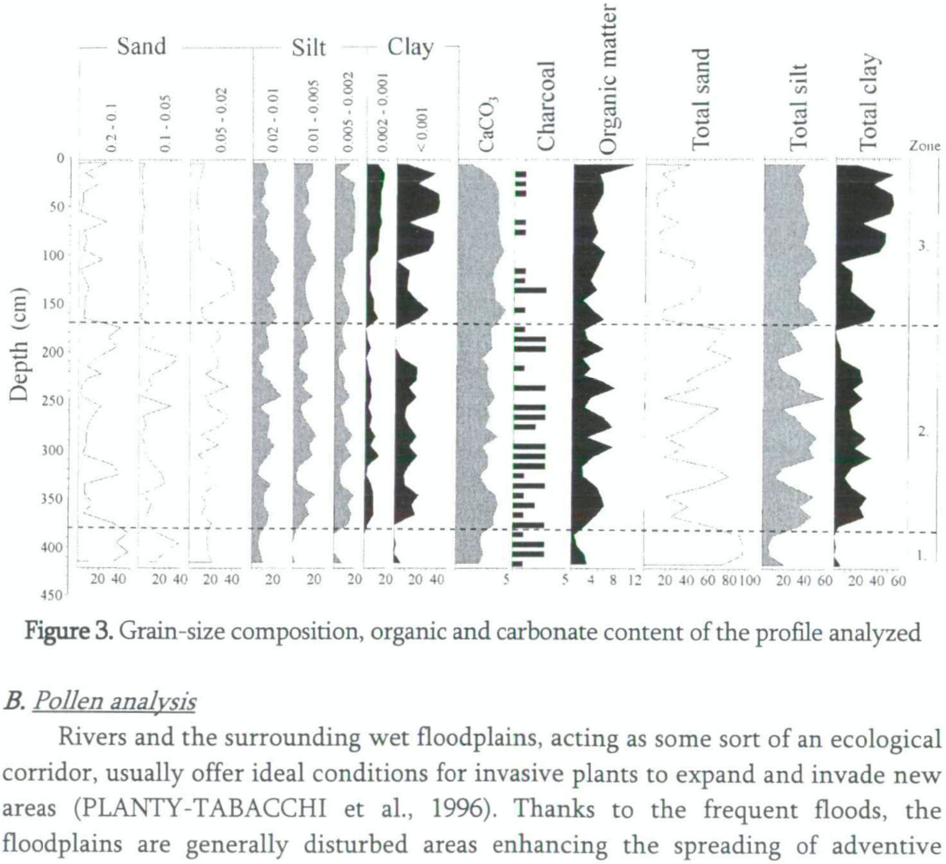

Figure 3. Grain-size composition, organic and carbonate content of the profile analyzed

B. Pollen analysis

Rivers and the surrounding wet floodplains, acting as some sort of an ecological corridor, usually offer ideal conditions for invasive plants to expand and invade new areas (PLANTY-TABACCHI et al., 1996). Thanks to the frequent floods, the floodplains are generally disturbed areas enhancing the spreading of adventive plants as well. Thus the identification of invasive species via pollen analysis, with a known date of appearance, might be utilized as an absolute dating method for determining the speed and rate of silting-up and sediment accumulation on the floodplains.

A multipurpose selection of, as well as the determination of the exact date of appearance of these invasive species in Hungary is important prerequisites of the analysis. The most promising species are those, whose known distribution areas overlap with the lower reach of the river Maros. Furthermore, they must be capable to expand to the woodlands, high-weed areas, mud vegetation areas, marshlands and dry and wet meadows of the floodplain, based on their ecological needs and habitat preferences (SOÓ, 1973). As a second step, we have to determine how massive the species is regarding its appearance, and how many close relatives or non-invasive subspecies it has in Hungary. These factors highly influence their ease of determination.

The following species have been utilized after multi-level selection with the first date of Hungarian occurrence marked (PRISZTER, 1960, 1997):

1870	water-weed	*Elodea canadensis*
1872	negundo	*Acer negundo*
1880	water breeze	*Wolffia arrhiza*
1889	marsh-mallow	*Althea officinalis subsp. pseudarmeniaca*
1904	echinocystis	*Echinocystis lobata*
1907	amorpha	*Amorpha fruticosa*
1908	helianthus	*Helianthus decapethalus*
1916	erucastrum	*Erucastrum nasturtiifolium*
1922	Italian bur-weed	*Xanthium italicum*
1932		*Typha laxmannii*

However, these dates of PRISZTER (1997) do not necessarily indicate the first date of immigration or appearance, but rather the first date these species are mentioned in the literature, or the first specimen from a botanic garden. Thus on one hand, there is a chance that some species had immigrated to Hungary well before they were found and mentioned in the literature. On the other hand it might be also possible that certain species had been described at a given date, however they appeared on the floodplain of the maros only at a later time many years or even decades afterwards. In order to somewhat eliminate these errors, the results of botanical analysis carried out in the pilot area have also been utilized in our work (HALÁSZ, 1889; TÍMÁR, 1948, 1950; TÓTH ,1967; MAKRA, 2002; OBRADOVIC et al, 1979)

When preparing the diagram a new clustering method was used, different from the traditional approaches, to make the process of evaluation easier. The determined species were clustered into groups following the plant coenological classification of SIMON (1994). Arboreal pollens were divied into two groups (AP): *allochtonous* deriving from the larger discharge area of the Maros, and the local species of the pilot area (*autochtonous*). Then the remaining non-arboreal pollens were determined (NAP): tangle plants (*Lemnetea*), marshland vegetation (*Phragmitetea*), plants of the wet meadows (*Molinio-Juncetea*), dry pastureland vegetation and arable weeds (*Festuco-Brometea + Chenopodietea*), the group of non-arboreal plants characteristic of the willow woodlands (*Salicetea NAP*), and finally the invasive and allochtonous NAPs. As the number of pollens was not statistically evaluable in all of the samples an absulote value pollen diagram has been constructed. According to this, the profile can be divided into four major units (**Fig. 4.**).

Unit 1: (420-380 cm) This unit is characterized by the presence of tree pollens and those of water plants, as welll as spores. The plants of wet meadows and dry pasturelands are not typical here and no invasive forms have been found. However, the large amount of allochtonous NAPs and APs deriving from larger distances (*Juniperus, Pinus, Abies* and its corroded version) is quite conspicuous.

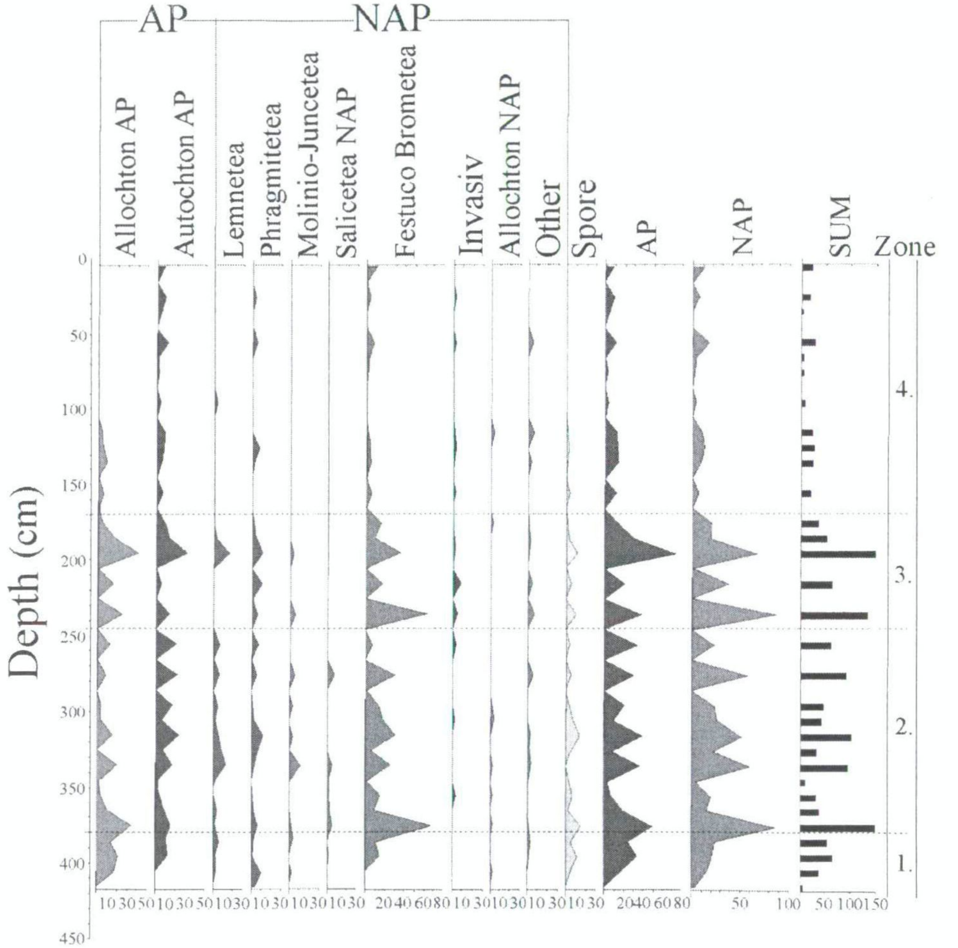

Figure 4. Cummulative absolute pollen diagram for the profile analyzed

From the local trees the species of willow (*Salix*) oak (*Quercus*) as well as hazelnut (*Corylus*) are dominant. The proportion of these local APs is lower compared to the allochtonous ones. All these seem to indicate the presence of an active channel and fluvial processes in the area. This is how the pollens of plants indigenous to Transylvania could reach the area, very often in a corroded form. A dominance of gallery forests characterized the floodplain at this stage.

Unit 2: (380-240 cm) The appearance of allochtonous APs is not continuous but the autochtonous APs become gradually dominant in this unit, mostly those of willow, oak and hazelnut as well as poplar (*Populus*) and elm (*Ulmus*). From the NAPs the species *Lemnetea* appear here (*Myriophyllum, Potamogeton, Nymphea).* Besides these, marshland plants are also frequent in this unit (*Carex).* The appearance of NAPs characteristic for the gallery forests is restricted to this zone alone. From the plants of dry pasturelands the family of gramineae and plantain (*Plantago*) indicating signs of treading in the area, as well as the arable weeds (*Chenopodium*) are present here in larger quantities. The spores are dominantly *Pteridophytae*. From the sporadic appearances of invasive plants, the first occurrence of negundo (*Acer negundo*) (260 cm) occurred here, whose appearance in Hungary is dated to 1872 by PRISZTER (1997). This appears in the 1889 species list of HALÁSZ, meaning that its spreading period may correspond to these two decades.

This unit most likely represents an open-water cutoff channel, created by the river control works, slowly silting up turning into a marshland and thus offering ideal conditions for the trapping and preservation of pollens. Its direct neighborhood is characterized by the presence of gallery forests and arables, as well as pasturelands. Pollens deriving from larger distances on the discharge area of the Maros must have been deposited during the floods. The high ash concentrations observable in several horizons (340-230 cm) may refer to the activities of lime burners mentioned from 1860 in the area.

Unit 3: (240-170 cm) A short periodic maximum of allochtonous APs related to floods is observable in this unit as well. The local woodlands were composed of oak, willow, hazelnut and poplar howver APs are no longer dominant compared to NAPs. The tangle vegetation is only dominant periodically, rather the representatives of the marshland vegetation are prevailing (*Caltha, Carex, Lycopus*). The pollens of cereals, goose-foot (*Chenopodium*), choke-weed (*Orobanche*), plantain (*Plantago*), and Artemisia (*Artemisia*) deriving from dryer areas under cultivation indicate an increasing human activity and influence in the area. The spores are dominantly *Pteridophytae* here as well. From the invasive species the pollens of *Amorpha fruticosa* appear between the depths of 240-250 cm, its first appearance in Hungary is dated for 1907 (PRISZTER, 1997).

This unit represents a marshy, swampy area with shallow water coverage and the inwash of coarser material on top of the finer clayey sediments of the cutoff channel during floods, as a result of increased water velocity and capacity. The presence of *allochtonous AP* and the species *Lemnetea* indicate still-water conditions following the floods.

Unit 4: (170-0 cm) The number of pollens is significantly decreased in this zone. The autochtonous APs appear only sporadically and the tangle (*Lemnetea*) as well as the marshland vegetation almost compelety disappear here. Among the NAPs of pasturelands the pollens of the following species appear with other dry pastureland preferring forms: *Gramineae, Orobanche, Trifolium.* The spores are almost totally missing in this zone. From the invasive species the first appearance of ragweed (*Ambrosia artemisiifolia*) is observable from a depth of 140 cm in several horizons. Further invasive species can be identified from a depth of 130 cm like robinia (*Robinia pseudo-acacia*) and sweet-flag (*Acorus*). The presence of ragweed along the river Maros is not indicated in the 1967 work of TÓTH, however JÁRAINÉ-KOMLÓDI (1999) puts its first appearance in this area into the 1960s. The pollens of robinia (*Robinia pseudo-acacia*) and sweet-flag (*Acorus*)are not suitable for chronological purposes in our case as their first Hungarian appearances date back to times preceding the river control works.

The drastical changes in the pilot area's vegetation can be explained by a gradual aridification of the area resulting in the complete disappearance or periodic emergence of habitats suitable for hygrophilous species. No permanent water coverage is present in the cutoff channel, the short periods of water coverage are linked to the floods greatly reducing the pollen trapping and preserving capacity of the system. In the neighborhood of the infilled cutoff channel gallery forests could have been found at a larger distance with pasturelands and arables under cultivation in the direct neighborhood.

Summary

The following environmental changes can be summed up for the area of the analyzed cutoff channel (**Fig. 5.**): The pilot area used to form an overdeveloped bend of the river Maros before the river control works thus the primitive system of levees along the rivebed were not able to prevent waters from reaching the floodplain during floods. Thus, this bend was cut off between 1842 and 1850 because of the increasing insecurity of the city of Makó from floods. The area referred to as the "Goszpodi-hajlás" (Goszpod bend) was covered with gallery forests up to the beginning of the 19^{th} century. However, these gallery forests were present along the Maros afterwards as well. Later these extensive gallery forests were gradually exchanged for pasturelands, meadows and orchards. This was a period when many allochtonous pollens were transported into the pilot area by the river.

The pilot area formed a part of the active floodplain of the Maros even after the river control works as well and started rapidly silting-up thanks to the large load-carrying capacity of the river into this area during floods. As the amount of sediment deposited by the river on the floodplain is decreasing with increasing distances from the active riverbed the branch of the cutoff channel located closer to the riverbed was more rapidly and significantly infilled, serving as a sedimentary trap of coarser materials. The deposition of finer sediments was dominant among still-water conditions after the floods on the floodplain. The periods of floods marked the accumulation of allochtonous, while the intermittent periods marked the preservation of local or autochtonous pollens.

The final stage of aggradation can be placed to the beginning of the 19^{th} century, when the cutoff channel was almost completely silted-up with only period water coverage and soon fully drying out. The former channel was used for grazing in the first half of the 20th century, then it was turned into a hayfield, thus the pollen trapping and preserving capacity of the original cutoff channel was greatly reduced.

The rate of silting-up for this cutoff channel was determined with the help of the collective evaluation of map data and the results of pollen analysis of invasive plants as well as the grain-size analysis of the deposits.

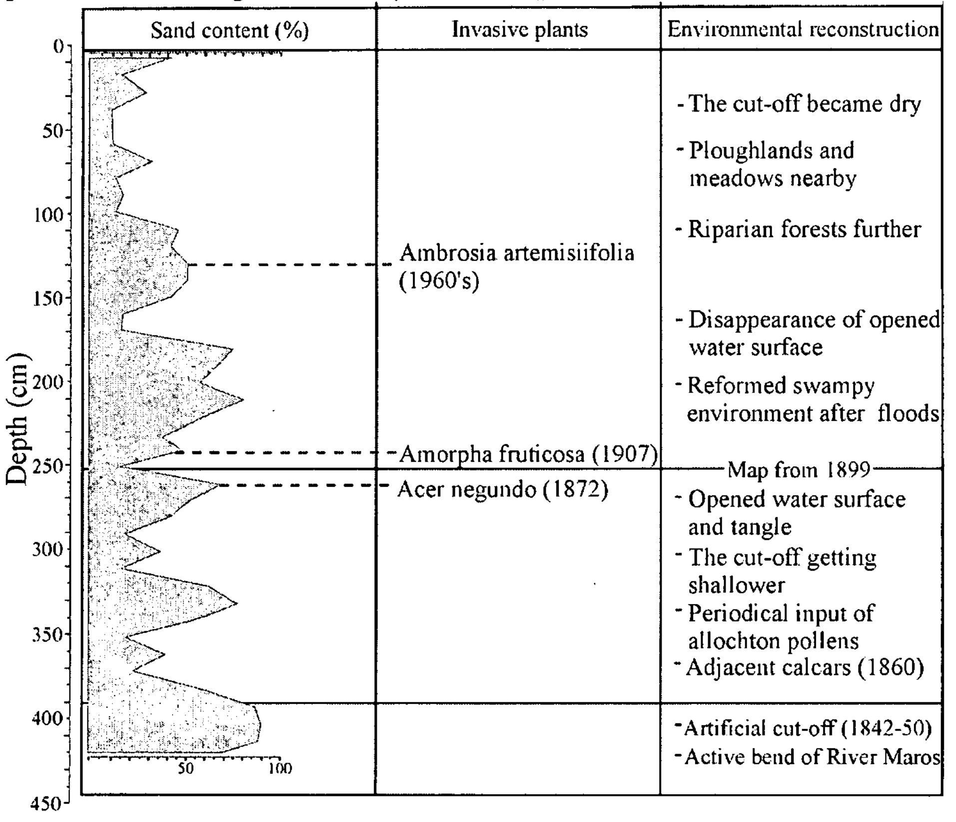

Figure 5. Correlations of the results of the analyses

The annual rate of deposition and silting-up following the cutoff (1842-50) and lasting about the almost complete silting-up of the channel (1899) was 2.5 cm/year. Afterwards the deposition of the remaining sediments (240 cm) lasted approximately 100 years which corresponds to an annual rate of sediment accumulation of 2.4 cm/annum. The rate of deposition was only slightly reduced following the large-scale silting-up of the channel; however there might be significant differences in this period (if we accept the date proposed by JÁRAINÉ (1999) for the first appearance of ragweed in the area then the average annual silting-up must have been around 3.5 cm/year for the past 40 years. This latter must be the outcome of partly a smaller degree of compaction or the changes of the carrying capacity of the Maros, or even the larger environmental changes on the greater discharge area)

An attempt was made for the absolute dating of sediments deposited in the channel, as well as the determination of the rate of silting-up by the collective evaluation of grain-size, geochemical data and results of a pollen analytical method rarely used in Hungary. For this only three invasive plant species with a known date of first Hungarian appearance were suitable: ragweed from the 1960s (*Ambrosia artemisiifolia*), amorpha (*Amorpha fruticosa*) from 1907 and finally negundo (*Acer negundo*), from 1872. This pollen analytical method is suitable for absolute dating, however only collectively with other methods and for areas with permanent water coverage (cutoff channels, interbar depressions).

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