EÖTVÖS LORÁND UNIVERSITY – FACULTY OF SCIENCE

DEPARTMENT OF PHYSICAL AND APPLIED GEOLOGY

ÁGNES CSERKÉSZ-NAGY

Reconstruction of a Pleistocene meandering river on UHR seismic profiles in the Middle Tisza Region (NW Hungary)

Morphometric variations of point bars as a climate proxy

PHD THESES

Supervisor: **Dr. Orsolya Sztanó**, PhD, associate professor

PhD School of Earth Science
Head of the PhD School: **Prof. Dr. József Nemes-Nagy,** DSc

PhD Program for Geology and Geophysics
Chair of the PhD Program: **Prof. Dr. Andrea Mindszenty**, DSc

BUDAPEST
2014

Introduction

High (HR) and ultrahigh resolution (UHR) shallow water single-channel seismic profiling has been carried out in Hungary since the middle of 1990's by the Geomega Ltd. cooperating with Eötvös University (Budapest), with the first surveys being conducted on the middle part of Tisza River, important in several geological points of view. The profiling crosses the Mid-Hungarian Shear Zone as well as the Jászság Basin, one of the intensively subsiding sub-basins in the Great Hungarian Plain (GHP) filled by thick alluvial deposits. The area also coincides with the course of the hypothetical third-axis of the palaeo-drainage system of GHP in the late Pleistocene (Gábris 2002). Neotectonic results obtained by seismic surveys are summarized by Tóth & Horváth (1999), while the internal architectures of alluvial Quaternary sediments below the recent channel of the river were delineated by Sztanó et al. (2002). Sztanó & Mészáros (2003) made the first paleohydrological estimation proposing climate fluctuation. Sedimentation of the modern Tisza was described by Nagy et al. (2005, 2006).

Despite of the promising preliminary results, neither a systematic seismic and sedimentological analysis, nor further specific profiling and age determining was undertaken on the alluvial architectures. Hence several important questions remained open:

- River style: How is the distribution of the units? All the inclined series belong to meandering rivers? Can we observe the deposits of the same river in the entire area?
- Do the long sets of inclined reflections compose a point bar complex or do they reflect several periods of fluvial activity?
- How large is the "large river"? What dimensions (width, depth, discharge) do characterise the ancient river deposited the studied sediments? Are there any signs for extreme discharges?
- Do the morphometric variations displayed on the seismic profiles reflect discharge fluctuations or autocyclic meander migrations?
- What is the age of the ancient river?
- How many depositional phases can be recognised?
- What kind of climate is suggested by the paleohydrological features of the ancient river?

The first aim of this work is to improve our sedimentological understanding of the single-channel seismic record, which can prove the existence of the third palaeo-hydrological axis of the GHP (cf. Gábris 2002). As a second step, detailed quasi-3D (single-channel lines in 2D grid) seismic acquisition was conducted in 2006 along the point bar complexes in order to: (1) map the true dip directions of inclined surfaces for refining the dimensions of the ancient river; (2) reconstruct the spatial variations in meander development; (3) distinguish the potential braided pattern from the meandering one and obtain an alluvial history. A further goal was to gain lithological information, which can support the seismic interpretation, and assign ages to the investigated sediments. Shallow drills were deepened for this purpose. Getting acquainted with geochronology is necessary for investigation of the relation between sedimentation and climate.

Data and methods

The study takes advantage of UHR shallow-water, single-channel seismic data. Two surveys were acquired on the Tisza River: the first ca. 200 km-long single-channel seismic profiling was carried out in 1995, from Tiszadob to Martfű. The southern part, downstream to Szolnok was re-surveyed in quasi-3D at four reaches in 2006, resulting in 48 km of new single-channel UHR seismic images. During data acquisition an IKB-Seistec (Simpkin & Davies 1993) catamaran was used, which carried the source (Geopulse Boomer – 1–10 kHz) associated with the receiver (6 hydrophones in a focusing cone) on the same catamaran with a constant offset of 0.8 m. UHR seismic data provided an outcrop-scale resolution – 0.5 m horizontally and 0.1–0.2 m vertically (Tóth et al., 1997) – for the riverbed and underlying sediments to the depth of ca. 7–15 m. Processing of seismic data was achieved by using the ProMAX system. Interpretation of the seismic profiles was made by using Landmark's GeoGraphix and HIS Kingdom 8.8 software. For time-to-depth conversion, a mean value of 1550 m/s was applied for water and water-saturated sediments based on geological consideration. Interpretation of the UHR seismic images is presented by following the nomenclature of seismic stratigraphy (Mitchum et al. 1977).

The quality of the recorded profiles allowed the interpretation of third and fourth order sedimentary structures of Miall's (1985), morphometrical analysis of macroforms and their accretion elements were carried out. Natural migration of meandering channels results in the formation of lateral accretion (LA) surfaces (Allen 1965), the geometry of which reflects the parameters of the stream. The length of inclined surface sets was used to calculate the width (w), and thickness of the storeys is equal to the depth (d), and from these the channel-forming discharge (Q) can also be estimated (Bridge & Diemer 1983, Olsen 1990). This way of quantitative analysis presents reliable results only on data derived from the axial zone of the meander, so the spatial reconstruction of development of point bar complexes was executed by the mapping of the dip direction of point bar surfaces. By specifying of section-position on the reconstructed point bar complex, the confusing effect of autocyclic meander migration (cf. Willis

1989, Sztanó & Mészáros 2003) was eliminated giving way to climatic estimations from the improved channel-forming discharge data.

In order to gain detailed lithological, sedimentological and geochronological data shallow drillings were made. In 2006 two cores (7 m and 10 m deep) were drilled at Martfű in the recent channel of the Tisza River at low water level by an Eijkelkamp percussion borer. In 2009 a 21 m-deep drilling was achieved from an artificial low-level bench at Szolnok (Tiszaliget) by using an UGB 1 – VSZU type dry-borer. The upper 10 m was drilled by spiral-borer with casing; the macroscopic description was done on the field. The lower 11 m was drilled by coring. The undisturbed core samples (both from Martfű and Szolnok holes) were taken in dark, opaque plastic tubes to avoid sunlight exposure.

OSL dating was carried out by Dr. Edit Thamó-Bozsó at the Geological Institute of Hungary according to the SAR-OSL (Single Aliquot Regenerative Dose Optically Stimulated Luminescence) protocol (Thamó-Bozsó & Nagy 2011). Luminescence measurements were made by using RISØ TL/OSL DA-15C/D automatic reader with a calibrated $^{90}Sr/^{90}Y$ beta source (Bøtter-Jensen et al. 2000). OSL dating determines the last time when the sediments were exposed to daylight; hence it provides the generation date of the architectures. The obtainable accuracy is about 5-10%. The method supplies reliable ages from a few ky to 100-150 ky.

In cases when no direct evidence was available about the ancient river, literature data as well as the sedimentation characteristics of the modern Tisza were used as the best available analogues in the interpretation. Meander migration rate, development of meanders and channel bed were determined partly during the PhD research and are partly based on previous results (Nagy et al. 2005, 2006).

New scientific achievements and conclusions –Theses

Based on the UHR seismic interpretation and evaluation of shallow cores from the 7–15 m thick alluvial sediment under the riverbed of the modern Tisza River, the following statements are made:

1. Seven frequently occurring seismic units were interpreted based on UHR single-channel water seismic profiles on the Middle Tisza River. Among these the most important units are the 300–3000 m long, 5–7 m thick series of inclined reflections appearing consequently in the same depth level. This unit was interpreted in terms of laterally accreted point bar complexes of a meandering river. Other seismic units in the same depth level were interpreted as extended floodplain

deposits, abandoned cut-off channel fills and large erosional scours; these elements also fit into the facies model of a meandering river.

2. The spatial and temporal variations of the point bar geometry were investigated on the basis of the quasi-3D resurveying of four sub-reaches along the spectacular long point bar complexes. Analyse of the dip directions of erosional and onlap surfaces within the inclined sets proved that the development units showing unidirectional progress within a point-bar complex reflect natural meander migration. In regard to that the meander development was reconstructed.

3. Evaluation of the dimensions of channel-fills and of the width and length of the inclined surfaces proved that the ancient meandering river was comparable to the modern Tisza in term of size and discharge. Average width and depth were between 350–520 m and 6–7 m, respectively. Channel parameters were used for the calculation of channel forming discharges by applying empirical equations (Bridge & Diemer 1983, Olsen 1990). Estimated channel-forming discharge varied from 400 to1800 m^3/s.

4. The autocyclic effects of natural migrations were eliminated from the paleo-discharge curve by specifying the position of the sections within the reconstructed point bar complex of Martfű. As a result, the discharge curve shows a primary periodicity comparable to the sub-Milankovitch cycles: after a longer period of increasing the discharge got up to its maximum value at about 1300 years, which was followed of a ca. 800 year long decreasing period. The primary periodicity is superimposed by lower ones: ca. 500 year cycles reflect the phases of unidirectional meander development, while the smallest ones reflect the recurrence interval (150–200 years) of the highest floods.

5. The sandy–silty lithology observed in the cores supports the interpretations of the seismic units. The Tiszaliget core drilled in the channel of the modern Tisza penetrated a 8 m thick medium sand to silt and clay upward fining succession of a point bar and the overlying floodplain fines correlating well to the nearby seismic lines.

6. The OSL ages of samples derived from the Tiszaliget core associated with ancient point bar show ages of Middle Pleniglacial (MIS3), 46–47 ± 4.6 ky. The duration of meander development is about 2–3 ky, considering the pre-engineering migration rate of the modern Tisza in the calculation.

7. By the reconstruction of the high discharge ancient meandering river, the existence of the third hydrological axis ("Palaeo-Bodrog") – besides the ancestors of Danube and Tisza – was proven in the Middle Tisza region during the Middle Pleniglacial confirming the previous hypothesis (cf. Gábris 2002). The results also infer a new period of its presumed intermittent fluvial activity. The dimensions of the revealed alluvial architectures support that the river is considered reasonably as the third paleo-hydrological axis of the GHP.

8. Comparing the presumed catchment area of the Palaeo-Bodrog to its estimated discharge supports that the climate was mild and wet during MIS3. Furthermore, it infers that the north-eastern part of the Carpathian Basin received locally more precipitation than the basin in general, and the run-off coefficient might have been also higher than today due to the lower forestation compared to the Holocene. The theory fits well into the environmental and climatic reconstruction of the Middle Pleniglacial in the Carpathian Basin (e.g. Novothny et al. 2011).

9. Detailed morphometrical analysis of the Martfű point bar complex indicates millennial scale discharge fluctuations during MIS3, reflecting the climate variability. The river responded to that primary by incision and infilling of the riverbed. Incisions happened step-by-step related to extreme floods, when the meander development also changed. The smaller-scale and more rapid fluctuations within a development unit were represented in variations of the channel width.

10. Under the mild climate of MIS3 the sustained meandering system responded to the millennial scale climate oscillations by the changes of channel parameters contrary to river pattern changes observed in MIS2 (e.g. Vandenberghe 1995).

11. Besides the development of the large ancient meandering river, the subsequent alluvial history of the area is also revealed by the seismic lines and the drills. The results provide new climate proxies in alluvial sediments, uniquely from the earlier part of MIS3 in Hungary.

12. The main elements of the alluvial history of the revealed succession fits well into the glacial–interglacial/stadial–intersatial climate model (Vandenberghe 1995, Boogart et al. 2003), and supports the deterioration of the climate described for the Carpathian Basin (Novothny et al. 2011).

- 12/1. Sustained (several ky) meandering of the high-discharge Palaeo-Bodrog (eroding into previous floodplain deposits) proves the mild and wet climate in the first part of MIS3.
- 12/2. Subsequent aggrading storeys with meandering character reflect a decrease of discharge, which implies the desiccation of climate.

12/3. Incising channels followed by rapid infill suppose a sudden cold period, but the subsequent meandering phase indicates climate re-amelioration.

12/4. Towards MIS2, the transition of river pattern from meandering to braided may reflect the permanent deterioration of the climate.

References

Allen, J.R.L., 1965. A review of the origin and characteristics of recent alluvial sediments. Sedimentology 5, 89–191.

Bogaart, P.W., Van Balen, R.T., Kasse, C., Vandenberghe, J., 2003. Process-based modelling of fluvial system response to rapid climate change - I: model formulation and generic applications. Quaternary Science Reviews 22, 2077–2095.

Bøtter-Jensen, L., Bulur, E., Duller, G.A.T., Murray, A.S., 2000. Advances in luminescence instrument systems. Radiation Measurements 32, 523–528.

Bridge, J.S., Diemer, J.A., 1983. Quantitative interpretation of an evolving ancient river system. Sedimentology 30, 599–623.

Gábris, Gy., 2002. A Tisza helyváltozásai. In: Mészáros, R. Schweitzer, F., Tóth, J. (szerk), Jakucs László, a tudós, az ismeretterjesztő és a művész. MTA FKI – PTE SzE kiadása, Pécs, pp. 91–105.

Miall, A.D., 1985. Architechtural-element analysis: a new method of facies analysis applied to fluvial deposits. Earth Science Reviews 22, 261–308.

Mitchum, R.M. Jr., Vail, P.R., Sangree, J.B., 1977. Seismic stratigraphy and global changes of sea level. Part 6: Stratigraphic interpretation of seismic reflection patterns in depositional sequences. In: Payton, C.E. (ed.), Seismic Stratigraphy. Applications to hydrocarbon exploration. AAPG Memoir 26, 117–133.

Nagy, Á.T., Vajk, Ö., Tóth, T., Sztanó, O., 2005. Természetes folyófejlődés a gátak közé szorított Közép-Tiszán. Hidrológiai Közlöny 85, 55–62.

Nagy, Á.T., Tóth, T., Sztanó, O., 2006. Új, kombinált módszerek a Közép-Tisza jelenkori mederképződményeinek jellemzésére. Földtani Közlöny 136, 121–138.

Novothny, Á., Frechen, M., Horváth, E., Wacha, L., Rolf, C., 2011. Investigating the penultimate and last glacial cycles of the Süttő loess section (Hungary) using luminescence dating, high-resolution grain size, and magnetic susceptibility data. Quaternary International 234, 75–85.

Olsen, H., 1990. Astronomical forcing of meandering river behaviour: Milankovitch cycles in Devonian of East Greenland. Palaeogeography, Palaeoclimatology, Palaeoecology 79, 99–115.

Simpkin, P.G., Davis, A. 1993. For seismic profilin in very shallow water, a novel receiver. Sea Technology 34, 21–28.

Sztanó, O., Mészáros F., 2003. Variation in dip of lateral accretion surfaces in subrecent fluvial deposits, Pannonian Basin, Hungary: a reflection of climatic fluctuations or just meandering excursions? In: Analogue and numerical forward modelling of sedimentary systems; from understanding to prediction (abstract volume), Utrecht, pp. 55–60.

Sztanó, O., Tóth, T., Magyari, O., Magyari, Á., Horváth, F., 2002. Alluvial architecture from ultra high-resolution single channel seismic survey of meandering Tisza River, Pannonian Basin, Hungary. 16th Int. Sediment. Congr., Pretoria, pp. 357–359.

Thamó-Bozsó, E., Nagy, A., 2011. Késő-negyedidőszaki üledékek betemetődési korának meghatározása kvarcszemcsék lumineszcens (OSL) vizsgálatával. Földtani Közlöny 141, 41–56.

Tóth, T., Horváth, F., 1999. Van bizonyíték a negyedidőszaki tektonizmusra Paks környékén. Földtani Közlöny 129, 109–124.

Tóth, T., Vida, R., Horváth, F., 1997. Shallow water single and multichanel seismic profiling in a riverine environment. The Leading Edge 16, 1691–1695.

Vandenberghe, J., 1995. Timescales, climate and river development. Quaternary Science Reviews 14, 631–638.

Willis, B.J., 1989. Palaeochannel reconstructions from point bar deposits: a three-dimensional perspective. Sedimentology 36, 757–766.

Research-related papers and conference abstracts

Papers

CSERKÉSZ-NAGY Á.T., THAMÓ-BOZSÓ E., TÓTH T., SZTANÓ O., 2012. Reconstruction of a Pleistocene meandering river in East Hungary by VHR seismic images, and its climatic implications. Geomorphology 153-154: 205-217.
(IF2012: 2,552)

CSERKÉSZ-NAGY Á. T., TÓTH T., VAJK Ö., SZTANÓ O., 2010. Erosional scours and meander development in response to river engineering: Middle-Tisza region, Hungary. Proceedings Geololists' Association, 121: 238-247.
(IF2010: 2,156)

NAGY Á.T., TÓTH T. & SZTANÓ O., 2007. A "harmadik folyó" - Pleisztocén folyóvízi üledékek ultranagy felbontású szeizmikus szelvényeken a Tisza Tiszadob-Martfű közti szakaszán. Földtani Közlöny 137/2: 239-260. (with English summary)

NAGY Á.T., TÓTH T., SZTANÓ O., 2006. Új, kombinált módszerek a Közép-Tisza jelenkori mederképződményeinek jellemzésére. Földtani Közlöny 136/1: 121-138. (with English summary)

NAGY Á. T., VAJK Ö., TÓTH T., SZTANÓ O., 2005. Természetes folyófejlődés a gátak közé szorított Közép-Tiszán. Hidrológiai Közlöny 85/5: 55-62. (with English summary)

Conference abstracts

CSERKÉSZ-NAGY Á. T., TÓTH T., SZTANÓ O., 2008. Reconstruction of a Pleiscocene meandering river and its climatical background in the NE part of Great Hungarian Plain by using UHR seismic images. FLAG Biennial Meeting, Budapest, Abstract Book: 20.

CSERKÉSZ-NAGY Á. T., TÓTH T., VAJK Ö., SZTANÓ O., 2008. River bed morphology of a regulated meandering river: Middle-Tisza Region. FLAG Biennial Meeting, Budapest, Abstract Book: 9.

NAGY Á.T., TÓTH T., SZTANÓ O., 2007. Channel morphometry indicates humid climate in the Late Pleistocene: UHR seismic images from the Great Hungarian Plain. 25th IAS Meeting of Sedimentology, Patras, Book of abstracts: 280.

NAGY Á.T., 2005. A jelenkori üledékképződés egyes sajátosságai ultranagyfelbontású egycsatornás szeizmikus szelvények alapján a Közép-Tiszán. 36. Ifjú Szakemberek Ankétja. Sarlóspuszta. Abstract Volume, 20-21.