Carpathian Journal of Earth and Environmental Sciences, May 2013, Vol. 8, No. 2, p. 201 - 208

ESTIMATION OF THE CORIOLIS-FORCE SIZE FOR TISZA RIVER

Zoltán UNGER[1] & István NÉMETH[1]
[1]*University of West Hungary, Institute of Mathematics and Physics, Department of Physics, 4th Károlyi Gáspár square, 9700 Szombathely, e-mail: ungerzoltan@freemail.hu*

Abstract: We tried to estimate the size of Coriolis force for Tisza River, which we consider responsible for the westward shifting of the river. We do not deny the tectonic footprints of the river courses, which have mostly locally, well encountered effect, but due to the regional course change we consider that Coriolis force can reach sizes, which long lasting effect change the course of the rivers especially in low land regions, like Great Hungarian Plane. Our estimations refer to the different segment of the Tisza River. In the Great Hungarian Plane where the capacity of work of a river is close to minimum, this can increase in case of rainy periods where foods used to appear. These estimations proves that in such rainy and flood periods, due to the increased density and flow speed, the Coriolis force riches a size, which force work and power depends on the flowing speed following square low. This power is responsible for the bank erosions.

Keywords: Coriolis-force, power estimation, river network, SRTM interpretation

1. PREAMBULUM

It is common knowledge that moving objects change their trajectory in a rotating system due to the inertia thereof and therein. This phenomenon had been named after the French mathematician, Coriolis, who had described this force in year 1835. In 1851 Foucault used this phenomenon in order to prove the rotation of the Earth by a pendulum hung up in the Pantheon in Paris. His genial idea conceived that during that movement, the oscillation plane of the pendulum will change and this event can be attributed to the rotation of the Earth. The second successful attempt for this experiment was performed in Hungary, in the year 1880 in Savaria – Szombathely by Adolf KUNCZ and his disciples (the Gothar brothers) by a pendulum hung up in the dome of the Roman-Catholic cathedral.

It has been commonly approved albeit that the rotation of the Earth has relevant impact upon geological processes as well. This phenomenon can be traced by watching the course of the river flows. For instance in Hungary one can witness either in field inspections or by interpreting the remote sensing images that our two major rivers flowing from North to South, the Tisza and the Danube, project west-bound channel migration.

2. INTRODUCTION

It is called an inertial reference frame, in which the first principle of Newton is true, i.e. a body's velocity cannot change if no net force acts on the body. Due to inertia, in a rotating frame, such as the rotating Earth, a force acts upon the bodies, affecting their state of motion.

This vector has a horizontal (xy) and a vertical (z) component. If we have a real inertia system, then no trajectory change can be noticed, but due to the vertical and the horizontal component the object will be affected by these. The effect of the vertical component is named Eötvös-effect, after the discoverer, Roland Eötvös, which acts together with the weight of the moving body. He also made a rotating balance to prove the existence of this effect. It was also shown that the weight of a man of 70kg, when going toward east weighs less with 1g, the walking speed being 1m/s. This strength of this impact is numerically defined as follows: $2v\omega/g$.

The horizontal component generates the well-known Coriolis-force, applied by Foucault to prove the rotation of the Earth in 1835 (Tasnádi et al., 2004). This Coriolis-effect is widely used in meteorology (i.e. geostrophic wind), in artillery (i.e. ballistic error during the Falkland War), in planning the abrasion of the rails. Moreover, this force is considered universal, because it was identified by the satellites on other planets (Mars, Jupiter, Saturnus and Neptunus) in our solar system.

The rotation of the Earth:

$$\omega_E = \frac{2\pi}{1\,\text{day}} = \frac{2}{86164\text{s}} = 7.292 \cdot 10^{-5} * \cdot 1/\text{s}$$; is a vector see figure 1.

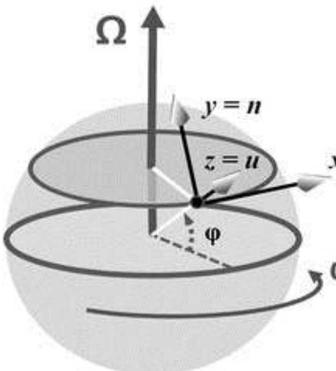

Figure 1. The Earth as a rotating system

We consider that this phenomenon can be traced by watching the course of the river flow, therefore it cannot be neglected, especially if it acts on a geological time scale. Some of the specialists consider that this impact is extremely weak, and without any influence upon the river flows.

3. THEORETICAL BACKGROUND

The first principle of Newton is valid in the inertial reference frame, only. In these frames we wouldn't have any deviation of the object during their movement. Thus the rotating Earth can't be looked as an inertial reference frame. Thus we had to count with Coriolis-force upon the objects. It is expressed by the following formula:

$$F = -2 \cdot m \cdot \omega \cdot \times \cdot v$$

The Coriolis-force will generate asymmetric banks of the river flows, moving the channel to the right.

In the ***northern hemisphere, this kind of elevated right side riverbank we have on the following rivers: Ob, Yenisei, Lena, Nile etc.***

The physical mechanism, which generates this channel shifting, is a complex system. One reason for neglecting the Coriolis-effect is due to the common view, that the existence of a friction force was considered higher. But, exact this friction helps the degradation of the banks of the rivers.

We drew a simplified case of a river channel (Fig. 2), and we consider only the lateral friction force, being the key force for highlighting the Coriolis-effect. We use this simplified channel profile, because we are investigating the effects on horizontal (x,y) plane.

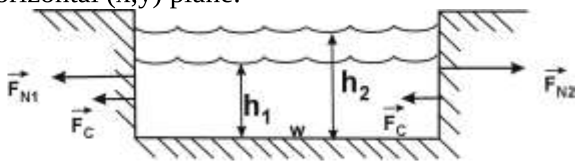

Figure 2. The simplified channel of a river

The size of the $\vec{F}_{N1}$ and $\vec{F}_{N2}$ normal forces comes from the sum of hydrostatical pressure $\vec{F}_H$. The normal forces are responsible for the size of the friction force occurring on the wall of the channel. If we are in an inertia system we can state that the:

$$\vec{F}_{N1} = \vec{F}_{N2} = \vec{F}_H$$

But, the Earth being a rotating system the normal forces will be changed by the Coriolis force as follows (Fig. 3.):

$$F_{N1} = F_H + 2\, m\, v\, \omega \sin\varphi$$
$$F_{N2} = F_H - 2\, m\, v\, \omega \sin\varphi$$

The banks of a river will be eroded by the friction forces F_{S1} and F_{S2} forces generated by the F_{N1} and F_{N2} normal forces:

$$F_{S1} = F_{N1} \cdot \mu_k$$
$$F_{S2} = F_{N2} \cdot \mu_k$$

The banks of the river will be eroded by the physic/mechanical work of the total/sum of the forces on a unit length (1m). Also if we consider this work on a unit time (1s), than the power of the forces depends on the flowing speed of the water as follows:

$$P_{S1} = F_{S1} \cdot v_{river}$$
$$P_{S2} = F_{S2} \cdot v_{river}$$

The difference of the mentioned powers will generate the channel shifting, as follows, using the formulas above:

$$\Delta P = P_{S1} - P_{S2} = 4\, m\, v^2\, \omega\, \mu_k \sin\varphi =$$
$$= 4\, h\, w\, \rho\, v^2\, \omega\, \mu_k \sin\varphi$$

According to this formula we can state that the bank erosion linearly depends on the water depth ***(h)***, wideness of the channel ***(w)***, density of the water ***(ρ)***, rotation of the Earth ***(ω)***, friction coefficient ***(μ_k)***, position/latitude on the Earth, and the most important: **the flowing speed follows square low!**

The weather, the rains (water amount) and the transported sediments (density of the water due to clay and sand content), are the factors influencing the value of the **ΔP**. Doing an assumption for river Tisza on its segments [1] we consider that Coriolis-effect has an important role in the erosion of the banks:

We considered **ω = 7,29E-05** *[1/s]*

[1] The segments are those determined and used by the Hungarian Water Authority

Table 1. Segments of the Tisza River with its powers

Division of Tisza	Δ P *[watt]*	d *[m]*	w *[m]*	ρ *[kg/m³]*	v^2 *[m/s]²*	μ_k
segment 1.	**6,2**	3	100	1000	1	0,1
segment 1.	**7,5**	3	100	1200	1	0,1
segment 1.	**16,6**	5	160	1000	1	0,1
segment 1.	**36,4**	5	160	1100	1	0,2
segment 1.	**134,2**	5	160	1200	2,25	0,3
segment 1.	**31,1**	3	100	1000	1	0,5
segment 1.	**119,3**	6	200	1200	4	0,1
segment 2.	**39,8**	6	160	1000	1	0,2
segment 2.	**149,1**	10	200	1200	1	0,3
segment 4.	**24,5**	3,5	150	1000	2,25	0,1
segment 4.	**153,8**	6	250	1100	2,25	0,2
segment 4.	**1 163,0**	13	400	1200	9	0,1
segment 4.	**3 489,1**	13	400	1200	9	0,3

The values from the table 1 number convince anybody that there are situation when Coriolis force cannot be neglected.

When the water amount (level, wideness), the sediment transport increases, the ΔP can reach a value close to 3.5 kW in the lower course, segment 4 of the Tisza river. The lowest values of the table 1 show those calm, dry periods of the flow when any erosion is at its minimum, the water is clear without sediment is suspension, and the level is on the bottom of the channel, having an extremely low flow speed.

This phenomenon we can identify on the Danube and Tisza river actual bank situation, identified on the channel-, flooding plane profiles, and on the coloured SRTM surfaces.

Danube- and Tisza River flow

Balla (2007a) describes the relation between the Baer-law and the Coriolis-effect, but the relevant item of the publication for us is where it refers to the westward Danube-valley migration. He also presents a W-E cross section (Fig. 3.) to illustrate this phenomenon.

West **East**

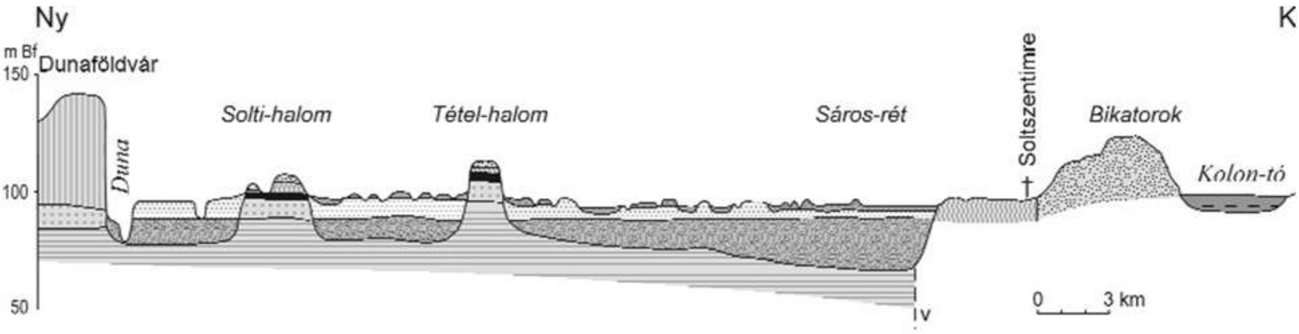

Figure 3. The transversal cross section on the Danube-valley (Balla 2007b)

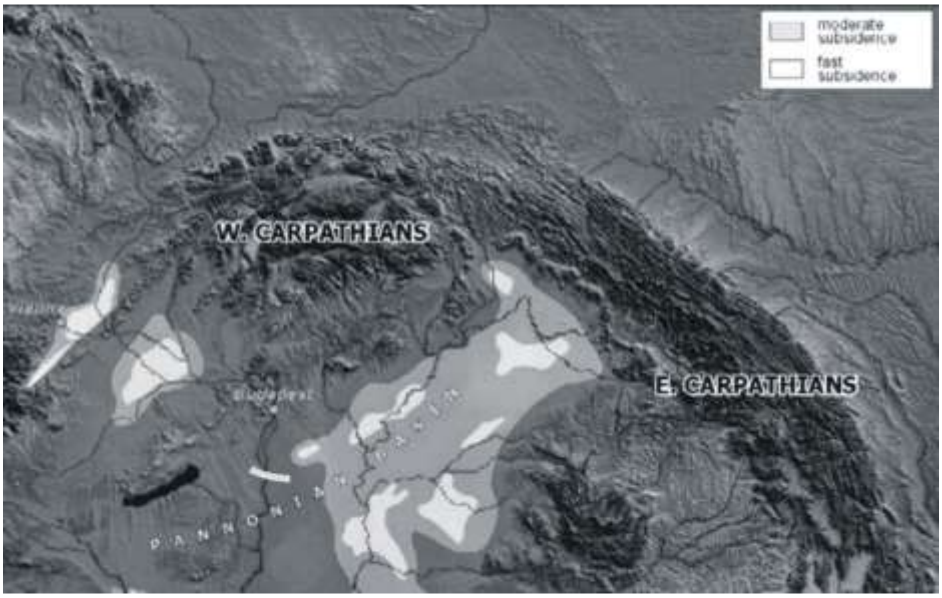

Figure 4. The main subsidence areas (light colours) in the Pannonian Basin according to Bada (2004)
(the little white segment marks the position of the profile from figure 3.)

Considering the subsidence areas in the Pannonian Basin (Fig. 4) after Bada (2004) no one can state that the subsidence area influenced the migration to the west. It seems to have been moved due to other force, i.e. Coriolis-effect.

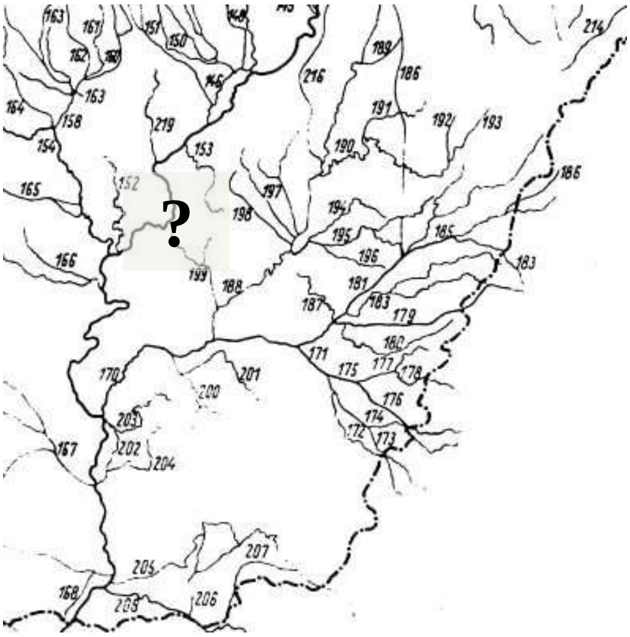

Figure 5. River network in the Hungarian Great Plane (Somogyi 1956 - VITUKI)*(**?** shows where Tisza could possibly have a confluence with Körös River, close to the minimum point of the Körös subsided basin.)*

On the same figure we can also identify the subsidence effect upon the river flows in the Great Hungarian plane. The Körös Rivers, and the Berettyó meet in the same minimum point of the Körös Basin. Anyone can ask: Why is it that Tisza River does not join Körös Rivers in the fast subsidence, minimum potential region (Fig. 5.).

If we look at the SRTM (Timár et al., 2003), a special display (Fig. 6.) indicates that there must be a reason why Tisza River took a western route, instead of joining the Körös Rivers in the minimum point of the subsidence - centre (ref: map by Bada 2004).

Sümeghy outlines a paleoriver network of the last interglaciation period (Fig. 7) where the Danube- and Tisza River had different channels than currently (Vágás 2000). By that time the subsidence area pulled (thick lines) them to the minimum potential zone. The actual flow of the rivers shows a westward shifting of the channels (dashed lines), presumably due to the impact of Coriolis-effect

Similar paleoriver network is published by Gábris&Nádor (2007), moreover they are described based on paleoenviron-mental changes, which help us in supporting our idea in this new view catching some elements of the Coriolis-effect.

Gábris (2001) and Gábris&Nádor (2007), presents the middle course of the Tisza River, the confluence with Sajó River (Fig. 8.), where the left-side channels are shown. The abandoned meanders of Tisza can be found on the eastern bank. The authors highlight that the alluvial fan of the Sajó-Hernád river was cut by the rivers flowing in the southern foreland ranges of the Carpathians, i.e. Paleo-Bodrog and afterward Tisza River, and determine VI. fluvial phases in their evolution.

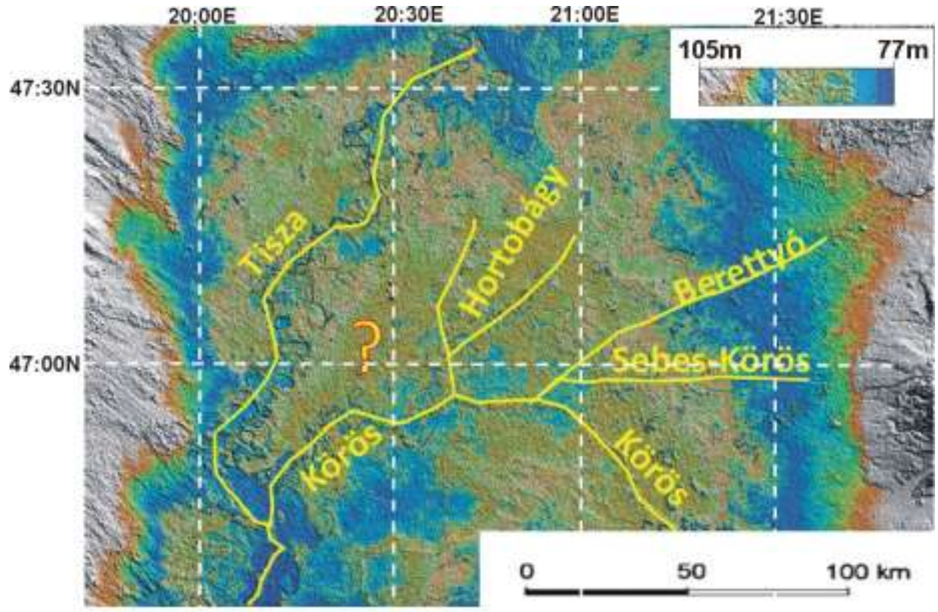

Figure 6. The SRTM display with the main valleys (displayed by Z.Unger)
(The colours highlight de tiny surface elevation automatically generated by the ER Mapper sofware)

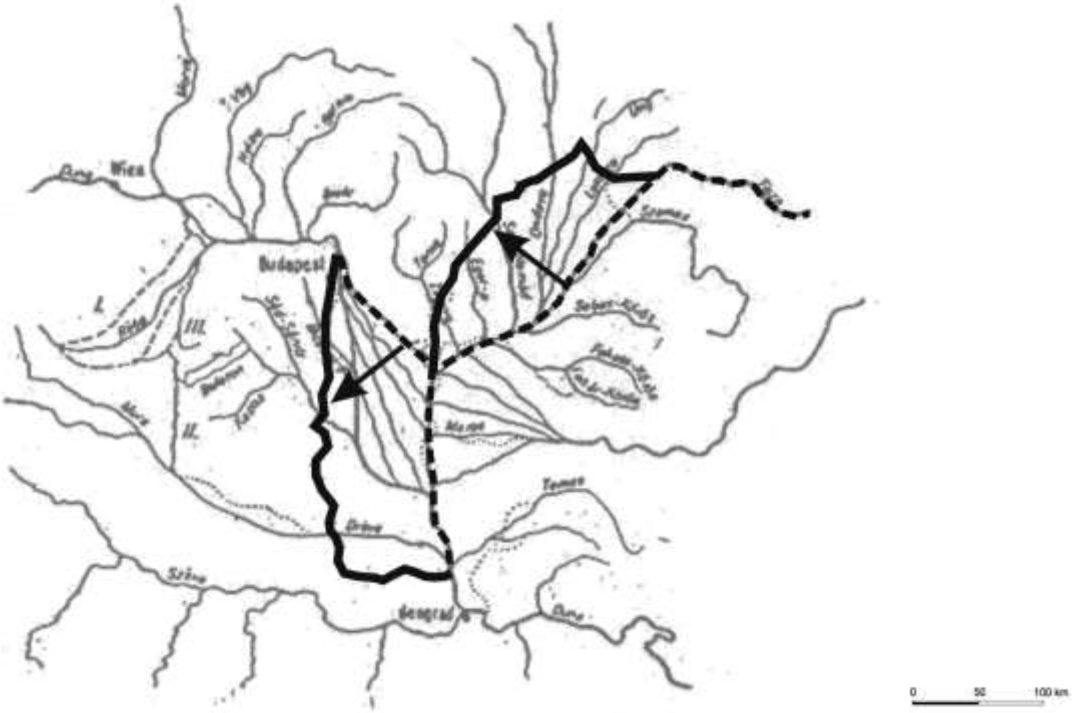

Figure 7. The paleonetwork of the rivers on the Hungarian Great Plain during the last interglacial period (Vágás 2000)

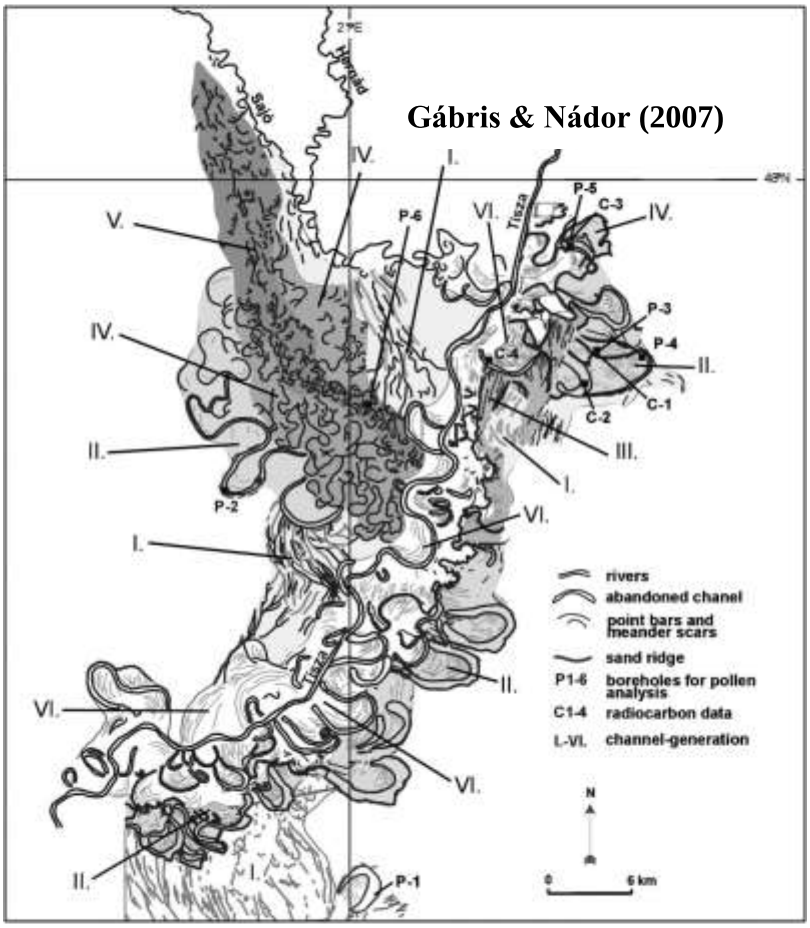

Figure 8. The region of the confluence of Tisza- and Sajó Rivers

This detailed evaluation of the spatial distribution of these phases neglected the westward shifting of the channels. The mentioned tectonic event in the article is only supposed. This was partly proved (on more southern regions) by Timár et al., (2005) on Great Hungarian Plan (GHP). Here in the foreland, near vicinity of the Bükk Mts. (having an uplifting rate even nowadays) the westward tilting of the region is less plausible. The westward shifting of the channels, in this particular area, in our view is more due to the Coriolis-effect.

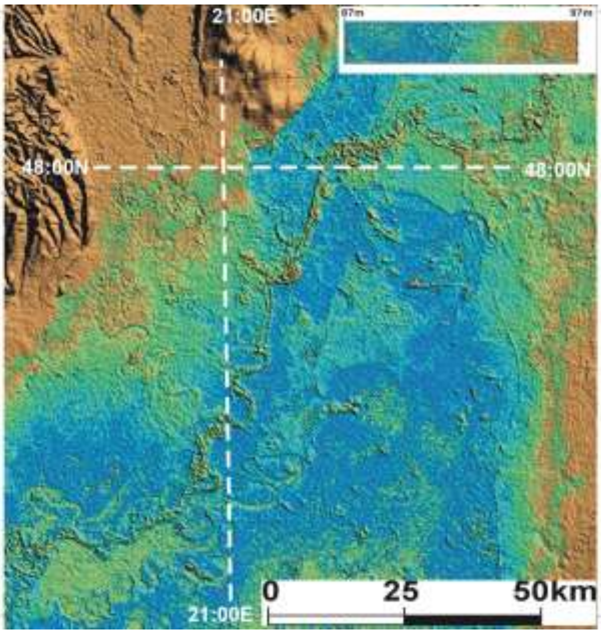

Figure 9. SRTM display highlights the confluence of Sajó- and Tisza River *(displayed by Z.Unger, automatic coloured by ER Mapper)*

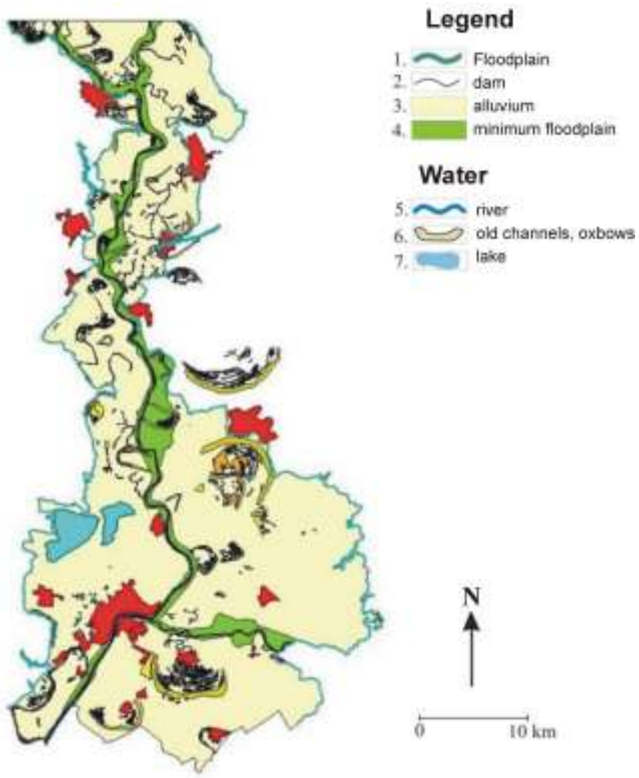

Figure 10. The Lower Tisza course, with almost exclusively left bank positioned paleomeanders and the oxbows (Hernesz 2010).

The following SRTM display (Fig. 9.) highlights the confluence of Sajó- and Tisza River area mapped by Gábris (2001) and Gábris&Nádor (2007), where the left meanders and oxbows can be identified.

According to Timar et al., (2005) these elements are coming from the westward tilting and differentiated subsidence of the GHP. We do not deny the effect of the tectonics upon the river courses, especially Tisza River, but even Timar et al., (2005) confirms that this tilting is not uniform process over the whole GHP, these can have only minor scale toward west, right in the foreland of the highs and hills, this way Coriolis-effect can get power.

Recently, Hernesz (2010) had presented the geomorphologic map of the Lower Tisza course (Fig. 10). He is the one who mentions in his study that the abandoned channels and the oxbows are situated exclusively on the left side of the river, but albeit leaving the statement without any explication.

The area of figure 10 shows most of the geomorphologic elements identified by Hernesz (2010) on the 2D display of the STRM (Fig. 11).

Additionally we present a further SRTM display of the south course of Tisza River, its confluence with Danube River near the Titel-Highs (Fig. 12). On these maps the abandoned channels are visible mostly on the left side (the eastern bank of the river) on the other side we have the high bank. Hernesz (2010) made the elevation diagram of the Tisza valley presented on figure 13. Based on the remote sensing displays, it is not surprising that the right bank (low and high floodplain) is higher than the left bank (low and high floodplain).

4. DISCUSSION

In spite of the fact that the Danube and Tisza River suffers westward shifting, the scientists neglect the effect of Coriolis-force. We can assume that the Tisza River follows a different, unpredicted course, remaining on the margin of the intensively subsided Körös basin. According to the paleonetwork of the rivers Danube and Tisza valley were shifted to the west. Most of the abandoned channels and meanders are on the left, lower bank of the river.

The middle course of the Tisza River has several tributaries from the North Hungarian Range. These have been transporting considerable amount of sediments from west–northwest. This high sediment influx ought to have forced the Tisza valley course to east, nevertheless it happened vice versa. The cold wet climate at the end of Quaternary, kept the Tisza River water volume at an increased level, thus the sediment transporting energy was also elevated.

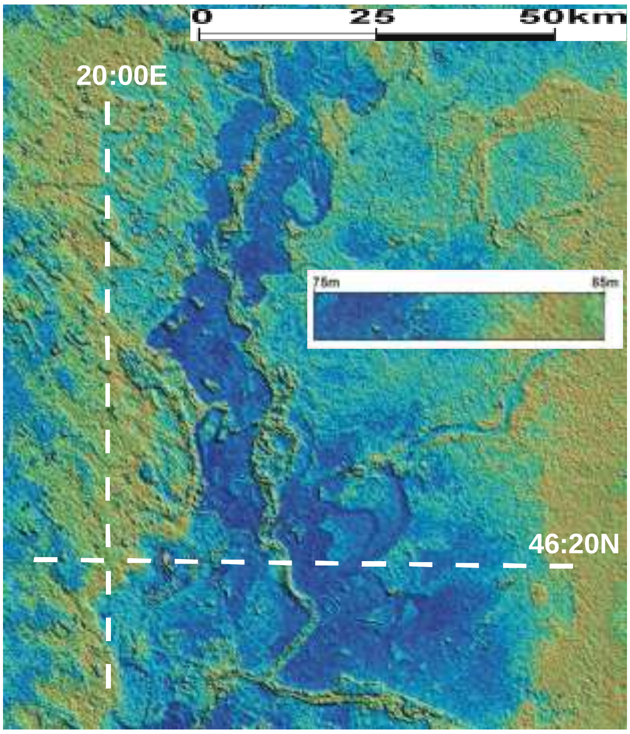

Figure 11. The SRTM display highlights the elements of the figure 10. *(displayed by Z.Unger, automatic coloured by ER Mapper)*

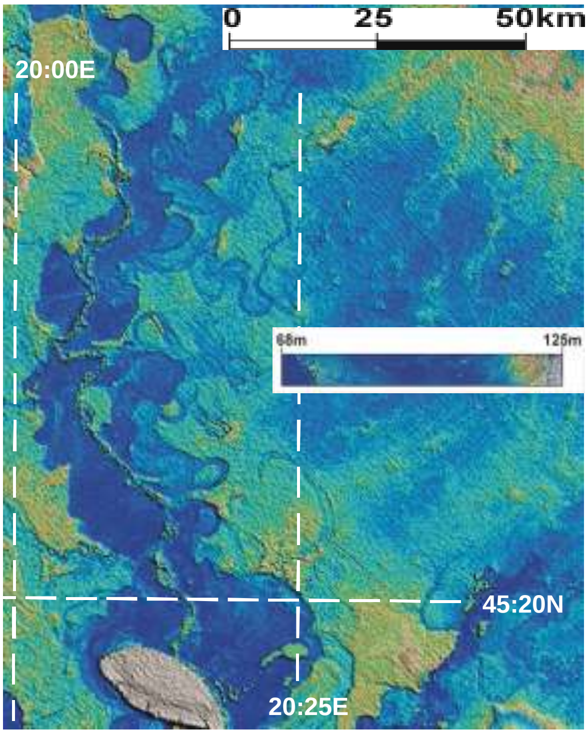

Figure 12. The SRTM display highlights abandoned channels of Tisza near Titel-High *(displayed by Z.Unger, automatic coloured by ER Mapper)*

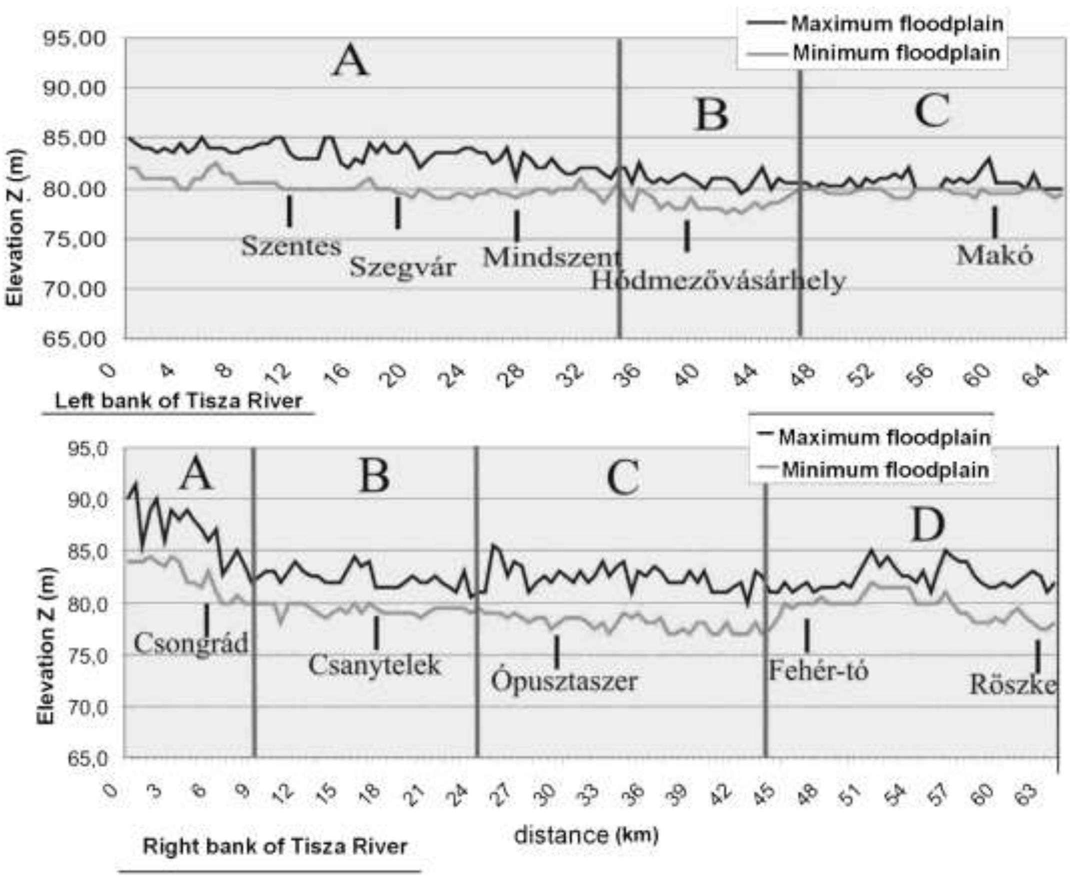

Figure 13. It is evident that the right bank is higher than the left bank along the Lower Tisza course

This facilitated sediment transport to a longer distance, thus the material carried by the tributary was taken further by the Tisza River. This capacity was also increased by the Coriolis-force acting in the same direction, aiding the sediment transport, furthermore, and the westward shifting of the valley.

Doing a brief assumption of the power of the erosion (on unit length and duration) we can state, that in wet, rainy periods the erosion of the west bank can get considerable strength (Table 1.).

It is well-known that the clear and low-stand water has a minor erosive effect. The strong damage of the banks is generated by the floods, especially when the bankfull discharge occurs, with important sediment transport, when the water density (related to *m*) is bigger than 1 g/cm^3 even closer to 1.5 g/cm^3. This means that the Coriolis-force gains in power in case of high-stand waters, during floods and increased speeds of flow.

This assumption creates the basis for further assumptions on for channel migration.

The remote sensing (SRTM) database displays/images confirming this result of the assumption, described in the previous studies (Gábris & Nádor, 2007 and Hernesz, 2010), but no one interprets them as being linked with the Coriolis-effect. The comparison of the bank heights by Hernesz is also supported by the SRTM database displays.

5. CONCLUSIONS

According to those mentioned above, we can state that the Coriolis-force cannot be neglected either in geology or geomorphology:

1. Among the numerical proofs in order to highlight the importance of Coriolis effect, hereby we present one for the segments of Tisza River in Hungary.
2. The calculation proves an important power of the Corilis-force, on the segment where the working capacity in at minimum level, but in case of rainy and flood periods the power depends on the flowing speed following square low.
3. We do not deny tectonic events influencing river courses, but we are aware about the effect of the Coriolis force.

REFERENCES

Bada G, Windhoffer G, Szafián P, Dövényi P., 2004. *Feszültségtér Európában és a Pannon-medence térségében: adatok, modellek és geodinamikai alkalmazások* ELTE Geofizika Tsz. (English: Stress field in Europe and in the Pannonian Basin: data, models and geodynamic application, ELTE Geophysical Department) 2012. júl.21.: (http://geophysics.elte.hu/dolgozok/feszultsegter%20europaban%20es%20pannon-medenceben.pdf)

Balla Z. 2007a. *A Coriolis hatása folyókra és a Baer-törvény. Történeti áttekintés,* Magyar Állami Földtani Intézet Évi Jelentése 2007, (English: The Coriolis force effect upon the river flow and the Baer-law. Historical review. Annual report of the Geological Institute of Hungary from year 2007)

Balla Z. 2007b. A *Coriolis-erő hatása folyókra a magyar szakirodalomban*, Magyar Állami Földtani Intézet Évi Jelentése 2007. (English: The Coriolis force effect upon the river flow met in the Hungarian professional literature. Annual report of the Geological Institute of Hungary from year 2007)

Gábris Gy., 2001. River meanders and Lateglacial–Holocene Palaeohydrology in Hungary. Revue Géographique de l'Est 41, 149–156 (in French with English summary).

Gábris Gy. & Nádor Annamária, 2007. *Long-term fluvial archives in Hungary: response of the Danube and Tisza rivers to tectonic movements and climatic changes during the Quaternary: a review and new synthesis*, Quaternary Science Reviews 26, pp: 2758–2782

Hernesz P. 2010. *Az Alsó-Tisza-vidék holocén ártérfejlődése geomorfológiai vizsgálatok alapján* - TDK-dolgozat. (English: The Inferior Tisza-River region development in Holocene for the flood plain based on the geomorphological studies. – Student Chapter Symposium)

Somogyi S. *(szerk.)* 1956. *Magyarország Hidrológiai Atlasza I. (folyóink vízgyűjtője) sorozat adataiból* – VITUKI, (English: The Hydrological Alas of Hungary I. (the catchment area for our rivers)) see also:*(http://mek.niif.hu/02100/02185/html/101.html (2011.júl.26.)*

Tasnádi P., Skrapits L., Bérces Gy., 2004. *Mechanika I.,* Dialog Campus Kiadó, Budapest-Pécs, pp. 256-290. (English: Mechanics I. – course for students)

Timár G., Telbisz T., Székely B. 2003. *Űrtechnológia a digitális domborzati modellezésben: az SRTM adatbázis*. Geodézia és Kartográfia 55(12): 11-15. (English: Extraterestrial technology in the generation of the dogotal terrain model: the SRTM database, Geodesy and Cartography).

Timár G., P Sümegi, F. Horváth., 2005. *Late Quarternary dynamics of the Tisza River: Evidence of climatic and tectonic controls,* Tectonophysics, 410: 97-110

Vágás István 2000. *Belvizeinkről ismét - aligha utoljára*, Magyar Tudomány, 2000/6 (English: Again about inland inundation – as likely as not for the last time – Hungarian Science – Periodical of the Academy)

Received at: 09. 11. 2012
Revised at: 14. 04. 2013
Accepted for publication at: 22. 04. 2013
Published online at: 26. 04. 2013