The influence of the Coriolis force on the rivers in Hungarian geoscience

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Abstract

The deflective effect of the Coriolis force on the rivers can be regarded as a proven fact. Below, it will be demonstrated how this effect is realised and how it causes systematic migration of linear and curved river sections to the right in the northern hemisphere, and to the left in the southern hemisphere. Hungarian geological, geographical and hydrological literature for the last sesqui-century will be reviewed. It will be shown that this effect is usually not mentioned, and if mentioned at all it is usually accompanied with various doubts and restrictions. This is the case despite the fact that the deflective effect is frequently emphasised, but is not dealt with as an object for scientific study.

A review of the abundant geological literature on the Danube leads to the conclusion that the migration of the rivers has primarily been explained in the frame of tectonic hypotheses of two types: the fault type (usually with a "destructed zone" or trough along the fault) and the depression type (with an emphasis on the distal sucking effect). Both hypotheses looked for the answer to the question concerning how the Danube got from its original (running from Budapest to the SE) channel into the present one (running from Budapest to the S). However, neither of them explained the notorious – and very important from the practical point of view – fact (especially if the systematic slumping of the Danube banks is taken into account!) that from the time the Danube appeared in its modern valley it has migrated towards the right. Given the absence of answers but possessing global facts, the only rational explanation can be seen in the Coriolis force.

Introduction

The deflective effect of the Coriolis force on the rivers has been debated in the foreign literature for about 150 years, and the first 90 years of the debate have been summarised by NEMÉNYI (1952). "At the present state of the science" the effect of the Coriolis force on the rivers must be regarded as a proven fact (BALLA 2009).

In the Hungarian geological and geographical literature, however, the effect of the Coriolis force on the rivers of Hungary is barely mentioned, and where there is sporadic mention it is formulated in terms of doubt (see below). At the same time — and this is an interesting situation — in the non-specialised literature (e. g. 1000 kérdés…, HARDI 2008, SZEIDEMAN 2008, TAMÁS, KALOCSA 2003) this effect is treated as having been proved. Furthermore, most of those of the dozens of colleagues-geologists who were asked hold a positive opinion about the effect (although not many of them remember the source of this knowledge).

All this raises the hope that official geoscience "will read the signs of the times" and be receptive with respect to the effect of the Coriolis force on rivers. This work aims to contribute to showing how the Hungarian geological, geographical and hydrological literature is related, and relates to this question and to help in understanding why there has been a negative approach in the past.

In order to have a clear picture of the question, first an overview is needed in order to show how the Coriolis force affects rivers.

Mode of action of the Coriolis force in the case of rivers

In the case of rivers the decisive circumstance is that due to an inertial force the water in rivers tends to migrate relative to the riverbed itself. The Coriolis force is an inertial force, and its effect generates a migration to the right in the northern, and to the left in the southern hemisphere when looking down along the river. The migration is barred by the actual bank of the river, so as a result of the migration the water acts on the bank. The intensity of the bank erosion depends on how strong this effect is and how big the resistance of the bank is.

This feature is most easily understandable if meandering rivers are considered. Meanders arise when the working capacity of the river is approximately equal to the work to be done (CHOLNOKY 1934), i.e. in a state of dynamic equilibrium. In the frame of this concept initial curves result from the internal vibrancy of the water flow, and the parameters of the meanders (i.e. channel width, wave length, curvature etc.) reflect first of all the water debit.

The water flow in meandering rivers is turbulent due to the combination of the transverse centrifugal force in the curves and the longitudinal flow. The effect of the Coriolis force can be most easily imagined on the basis of EINSTEIN's (1926) model; this does not count for the longitudinal and turbulent movement and only shows the component of the latter perpendicularly to the channel. In this model, water moving under the influence of centrifugal forces is retarded by the friction along the bottom and lateral sides, so that it only acts in pure form along the free water table. This generates a secondary circulation in a plane perpendicular to the flow (Figure 1).

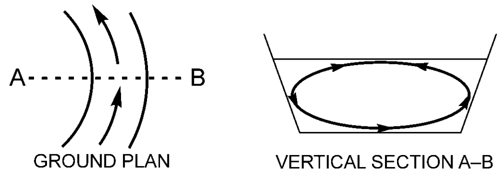

Figure 1. Secondary circulation in the river bends due to the centrifugal forces after EINSTEIN (1926)
From the left, ground plan; from the right, vertical section

The Coriolis force — depending on its direction — is either added to or extracted from the centrifugal force, the resultant depending on the relationships between these two forces. Their ratio was computed by SHANTSER (1951) for the middle section of the River Volga. He concluded that the Coriolis force is quite comparable with the centrifugal one, and therefore is not negligible. Laksha and Hudyakov (LAKSHA, HUDYAKOV 1968) found for the West-Siberian rivers that the total force acting towards the right bank is about one and a half times stronger than that acting towards the left bank.

Meanders of a river in dynamic equilibrium are clearly deflected by the Coriolis force: to the right in the northern, and to the left in the southern hemisphere.

In time meanders run down along the flow course. As a consequence, the deflection moves along the river and spreads over the whole valley. This results in gradual migration of the whole of the river — and of the corresponding slope of its valley — under the influence of the Coriolis force (to the right in the northern, and to the left in the southern hemisphere). The slope under destruction becomes steeper, whereas the other — due to abandoned meanders and sedimentation — is gentler. For example, EAKIN (1910) estimated from the map for a 450 km long section of the Mississippi that the area between the channel and the outer edge of the flood plain is 4.4 times bigger left of the channel than right of it.

The slope under destruction is composed of the older sequences, whereas on the other side it consists of the river's own sediments; the first is not only steeper but also higher. The valley becomes asymmetric. The measure of the asymmetry — i.e. the steepness and height of the slope under destruction — depends on the composition of sequences.

It is an important property of Einstein's model (Figure 1, right) that it is also valid for the Coriolis force itself: i.e. in a case in which the channel is straight, there is no curvature and no centrifugal force. Therefore it is easy to realise that the effect of Coriolis force — i.e. the asymmetry of valleys — is independent of whether there are meanders or not.

It should be mentioned that sometimes the origin of meanders is explained in terms of the Coriolis force (TAMÁS, KALOCSA 2003); however, this is an obvious error — the Coriolis force can be responsible for the lateral migration of rivers and valley slopes but not for the origin of meanders.

Earth's rotation and rivers in Hungarian geoscience

It is a formal problem of the overview given below that the influence of the Earth's rotation upon the rivers in both the Hungarian and foreign specialised literature is discussed under three different headings — Earth's rotation, Coriolis force and Baer law. There can be no doubts about the equality of the first two of these terms, and abandoning the term "Coriolis force" does not generate problems in understanding. With the Baer law the situation is different, because its erroneous nature was established a year before it was actually published, and therefore it was almost simultaneously withdrawn by its author (BALLA 2009). Therefore the use of this term after 1860 was anachronistic. In order to simplify the discussion "Earth's rotation" will be used, and the "Baer law" and/or "Coriolis force" will only be indicated if this is not clear from the title of the cited work.

Of the Hungarian rivers the Danube had already been referred to as an example of deflection due to the Earth's rotation by BABINET (1859), BAER (1860) and SUESS (1863)[1]. Of the Hungarian scientists, HANUSZ (1890) was the first to

[1] "Baer law".

do this but his opinion only was supported by HALAVÁTS (1895). In the half a century up to 1941 there only was one case found with a mention of this effect: KÖVESLIGETHY (1899)[2] wrote that the Earth's rotation may play a small role in the deflection of rivers.

In the general geographical and hydrological characteristics of the country CHOLNOKY (1923, 1926, 1929) and PRINZ (1936) did not mention effect of the Earth's rotation upon its rivers.

BULLA (1941) expressed crushing and even satirical criticisms concerning Hanusz's concept. He qualified this article as a representative of "geographical romanticism" with a "vague, popular-scientific prose, attempting to teach through an amusing style". It should be mentioned that the factual material and style of BAER's (1860) and SUESS's (1863) articles do not significantly differ from those of Hanusz and in fact can be regarded as typical for the scientific literature in German at that time. The peculiarity of the "German language" is emphasised here since the discussion in the Academy of Sciences in Paris in 1859 (see BALLA 2009) was significantly different from the German ones and was close to that usual in the XX[th] century.

The topics appeared again after a decade. BULLA (1951) mentioned the same article with no sarcasm and claimed it was concerned with an abandoned concept. Later on SCHMIDT (1957)[3] clearly — albeit without any argumentation or references — stated that the Earth's rotation deflects the courses of rivers. However, PÉCSI (1959a) remained with BULLA's (1941) concept, and in the textbooks of VENDL (1953) and VADÁSZ (1955) respectively, general outlines about the deflection of rivers are not mentioned.

In the next decade BULLA (1964)[4] adopted a thesis (again, with no argumentation) that the Earth's rotation may have some role in the deflection of rivers. This change of view had almost no consequences. Both in textbooks and general outlines (e.g. PÉCSI 1991, BÁLDI 1992, BORSY 1993, MÉSZÁROS, SCHWEITZER 2002, CSERNY, VINCZE 2005, LÓCZY, VERESS 2005, Miskolci Egyetem [with no year][5]) no mention about the deflective effect of the Earth's rotation occurs. However, a refreshing change was made by the work of GÁBRIS et al. (1998)[6]; in essence this repeats BULLA's (1964) view, and GÁBRIS (2007)[7] does in an even stronger way, mentioning the Earth's rotation as one of possible causes of the deflection of rivers.

During the almost sesqui-century after the Paris debate (1859) Hungarian geological, geographical and hydrological science has shown some development but has not reached a state such that discussion of the Earth's rotation is in harmony with its actual significance. Most of the references with respect to this field were mostly made in textbooks and general outlines; however, on the basis of the reviewing of more than a hundred other works, it can be stated that the situation is also the same in detailed works.

Following the review of foreign works (BALLA 2009) a question arises concerning the cause of this situation. The impression is given that the very detailed and probably high standard geomorphological, terrace, pebble, loess etc. studies have kept scientists so busy that they have not found the time and energy for foreign literature. This is probably why Hungarian scientists regarded works of the XIX. century in German to be authoritative in that field and avoided much more important and much more modern works in French and Russian as well as reviews in English (e.g. NEMÉNYI 1952).

The Hungarian concept of river migration

The fact that in the past the Earth's rotation was usually not taken into account does not mean that Hungarian scientists had not noticed the migration of rivers. However, Hungarian geological, geographical and hydrological literature, from the very beginning, was governed by tectonic explanations. The latter belonged to two main types: to the fault type (usually with a "destructed zone" or a "trough along the fault" explanation) or to the depression type (with an emphasis on the distal sucking effect). The difference between them consisted in postulating an active depression, for example for the whole Danube Valley south of Budapest, or only in the southern part of this section near the town of Kalocsa (Figure 2). In the first case the tectonic control affects the actual Danube section directly (running along its total length), while in the second it is only in an indirect way.

The fault version was outlined by SZABÓ (1862), CHOLNOKY (1929, 1938), BULLA (1934), PRINZ (1936), SÜMEGHY (1944, 1951), ÁDÁM (1953), ERDÉLYI (1960), RÓNAI (1964), MOLNÁR (1979, 1989) and NEPPEL et al. (1999), whereas the depression version, by PÉCSI (1959a, b, 1960, 1967), BORSY (1987), HERTELENDI et al. (1991) and MAROSI, SCHWEITZER (1997). Combination of these two types was postulated by BULLA (1951) and MIKE (1991).

The listing is obviously incomplete, but it is enough to create an impression of the followers.

It is worth mentioning that the third version known from foreign (primarily, Russian works such as, for example GERENCHUK 1960, LAKSHA, HUDYAKOV 1968, ZHUKOVSKIY 1970 and ZEMTSOV 1973) — i.e. the "fault-tilt concept" — could not be found in Hungarian works. The main point about this concept is that it gives a better explanation for the regional asymmetry of river valleys than is the case with the pure fault (i.e. fault-related trough) concept. In general it can be supposed that the sense of the "tilts concept" is constant over big regions which contain numerous river valleys.

The right-hand migration of the Danube south of Budapest was admitted by almost all the scientist but, except for the Earth's rotation (HANUSZ 1890, HALAVÁTS 1895) no

[2] "Baer's rule". In the southern hemisphere the deflection is – erroneously – westward.

[3] "Baer law".

[4] "Baer law".

[5] Presumably actual.

[6] Coriolis force.

[7] Coriolis force

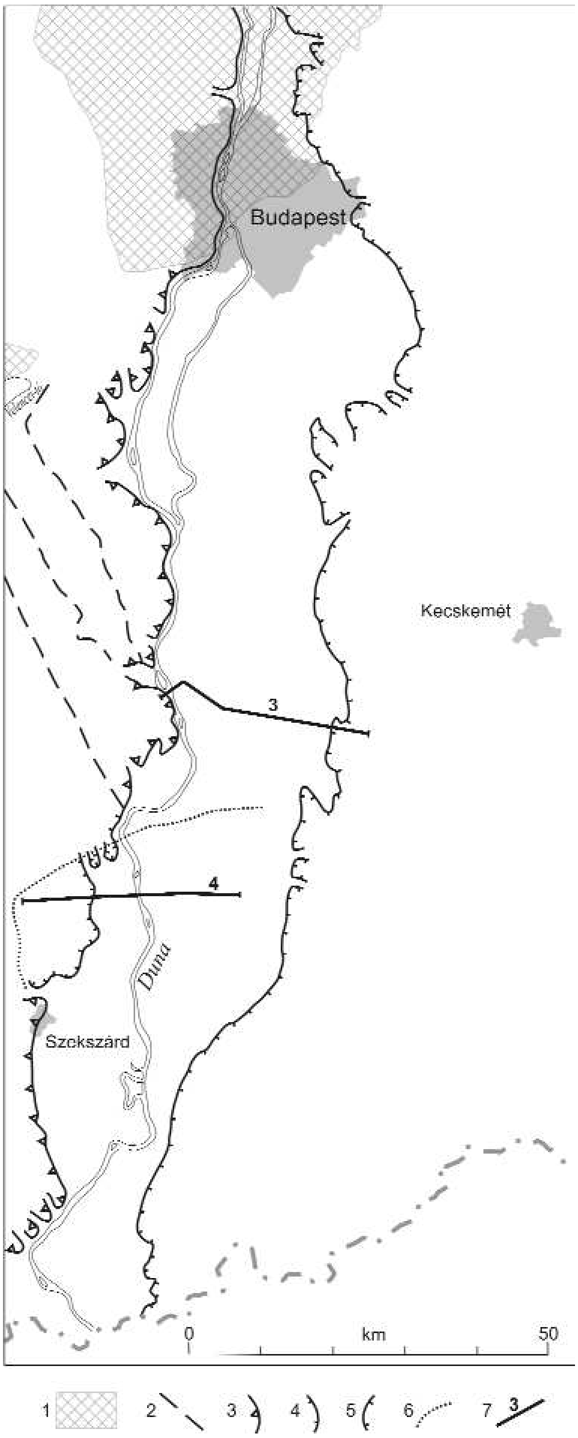

Figure 2. The Danube Valley and the Kalocsa Depression in a geomorphological sketch

Simplified from Figure 59 in MÉSZÁROS, SCHWEITZER (2002) using their Figure 57.

1 – contour of pre-Quaternary rocks form the geological map of Hungary, scale 1:500,000 (FÜLÖP 1984), 2 – boundary between the Pleistocene loess and fluvial sediments in Transdanubia, 3 – eastern edge of the Transdanbubian loess plateau, 4 – eastern edge of the Transdanbubian Pleistocene fluvial sediments, 5 – western edge of the Pleistocene sediments (fluvial cones etc.) and Quaternary eolian sands in the Danube–Tisza interfluve, 6 – northern and western contours of the Kalocsa Depression after JASKÓ, KROLOPP (1991), 7 – trace of a geological section with its Figure number

explanation was given. Neither the followers of the fault, nor those of the depression concept realised that their respective concept could, in the best case, only explain how the Danube got from its earlier course (from Budapest towards the SE) to its present course (from Budapest towards the S); furthermore, it does not explain why, since then, the Danube migrates towards the right (west).

The *fault concept,* in its widely accepted form, started out from the idea that the present-day Danube runs along a fault, in a tectonic trough. The tectonic trough along the Danube is completely excluded by the geological section (Figure 3). This is why the current followers of this idea think that the fault was at the eastern boundary of the Danube Valley (see fault in the Figure). According to this idea the Danube primarily followed this fault but now runs along the western rim of the valley. With no trough, however, it is hardly understandable why the river follows a fault in soft sediments (and there is no sense to speak about the confirmation of this fault). It is a separate — unsolved in the frame of the fault concept — problem as to why the Danube migrated towards the west: in other words, in the direction where, according to this concept, the original (late Pleistocene) surface was gradually elevated.

A general feature of the tectonic concept is to see faults where there is apparently no logic for them: e.g. along the boundary of the Danube detrital cone and the loess plateau or along the radial channels on the slopes of the detrital cone. In the first case the trough between the two — independent from a geomorphological point of view — elevations, in the second radial slopes — on a conical surface — give sufficient explanation for the distribution of the river valley with no faults. The assumed faults are not only irrelevant to the argument but also unproven by data.

The followers of the *depression concept* are satisfied with the statement that the Danube was drawn by the Kalocsa Depression (Figure 2) from its former valley. This can be seen by the fact that the Danube follows the rim, not the axis of the depression (Figure 4); no problem is generated for them. This is the rim which, in the frame of the depression concept, should be in a higher position than the centre of the depression.

The fact cannot be ignored that on the Danube section north of the Kalocsa Depression the same problem arises as is the case with the fault concept, although in a slightly different form. At the end of the Pleistocene the first channel of the Danube should have been located in the trough along the boundary between the Danube detrital cone and the Transdanubian loess plateau (Figure 2); the trough was on the eastern boundary of the present-day Danube Valley. The Danube had to "spring" into this morphological trough due to the drawing effect of the Kalocsa Depression. From here the Danube had to cut into the surface which was elevated towards the west.

Consequently, even without getting deeper into the debate about how the Danube got into its present-day valley at the end of the Plestocene, it can be stated: neither of the two concepts can explain the evident asymmetry of the

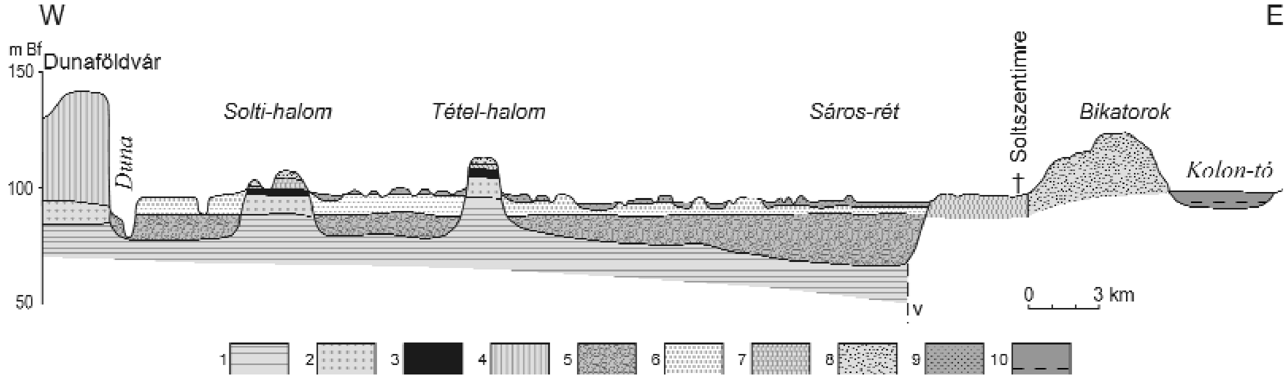

Figure 3. Cross section of the Danube Valley across the mesas on the left bank after Pécsi (1967)

Exaggeration 110:1. For location, see Figure 2. The original section was compiled by M. Pécsi using the data of M. Erdélyi and J. Sümeghy. Its simplified version is presented in Figure 60 in Mészáros, Schweitzer (2002). Most of the contractions have been accepted; the original ages and the fault limiting the Pannonian clay from the east have been restored; the new red clay layer between the Pannonian sands and clays at Dunaföldvár has been omitted; the vertical scale has been restored. Captions: 1–2 – Pannonian (Upper Miocene to Pliocene): 1 – clay, 2 – sand; 3 – Pliocene–Pleistocene boundary: red clay; 4 – Pleistocene loess (with palaeosol horizons); 5 – uppermost Pleistocene: Danube gravel; 6 – Holocene: flood sand, muddy flood sand, sandy flood mud, yellow, calcareous loess mud; in depressions and abandoned meanders meadow clay, marsh clay; in the depression of the Kolon Lake meadow soil, peat, sodic clay and meadow limestone. V = suggested fault under the Danube Valley sediments. Ny = West, K = East, m Bf = metres above the Baltic Sea, halom = small hill, rét = meadow, tó = lake

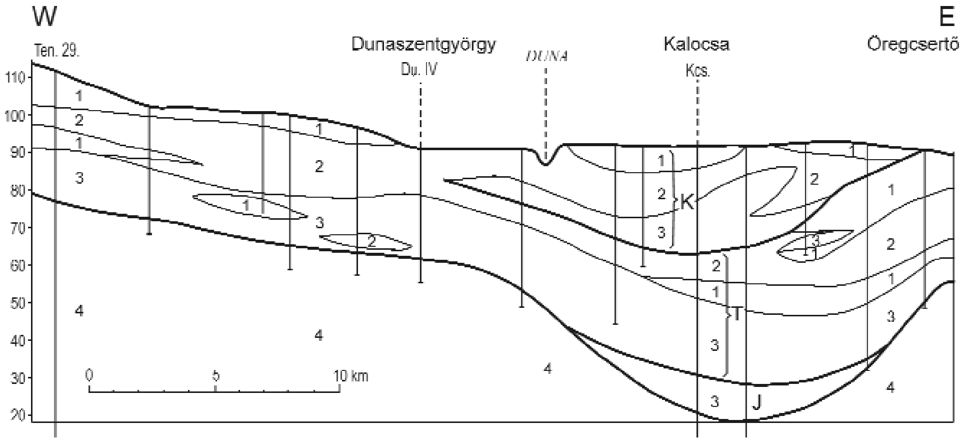

Figure 4. The cross-section of the Kalocsa Depression after Jaskó, Krolopp (1991)

Exaggeration 160:1. For location, see Figure 2. 1 – gravel, 2 – sandy gravel, sand with gravel, 3 = coarse-grained sand, 4 – sand, 5 – fine-grained sand, 6 – muddy sand, 7 – sandy mud, 8 – clay; K = Kalocsa Member (Upper Pleistocene?), T = Tolna Member (Lower Biharian = Lower Pleistocene), J = Jánoshalma Member (Lowermost Biharian – Upper Villányian = Lower Pleistocene)

Danube Valley — i.e. why the Danube migrated towards the topographical elevation (Transdanubian Plateau) during the Holocene. This obviously shows that neither of the two concept depicts the whole of the history of the Danube Valley south of Budapest, especially with respect to the origin of the slumping of the banks (which is very important from the practical point of view).

The map of the Carpathian Basin prior to the regulation of the rivers (Figure 5) clearly shows that not only the Danube, but also the Rába (Raab), Tisza (Theiss), Dráva (Drau) and Száva (Sava) were located on the right-hand rims of their flooded areas or near to it. No explanation of this fact has so far been given although the migration towards the right is clearly visible.

Summary

Hungarian science has virtually ignored the Coriolis force. Despite the fact that for more than a century there have been no doubts about the right-hand migration of the Danube and Tisza, the Earth's rotation has only been regarded as a possible cause. It is time to reconsider the explanation given by Hanusz (1890) and Halaváts (1895), which explains this phenomenon in terms of the Earth's rotation. And it is time to reject the idea that the Coriolis force is too weak to have any effect on the course of rivers, thus subordinating its influence on river migration. This rejection is in contradiction with mathematical computations and with the mapping of river asymmetry over

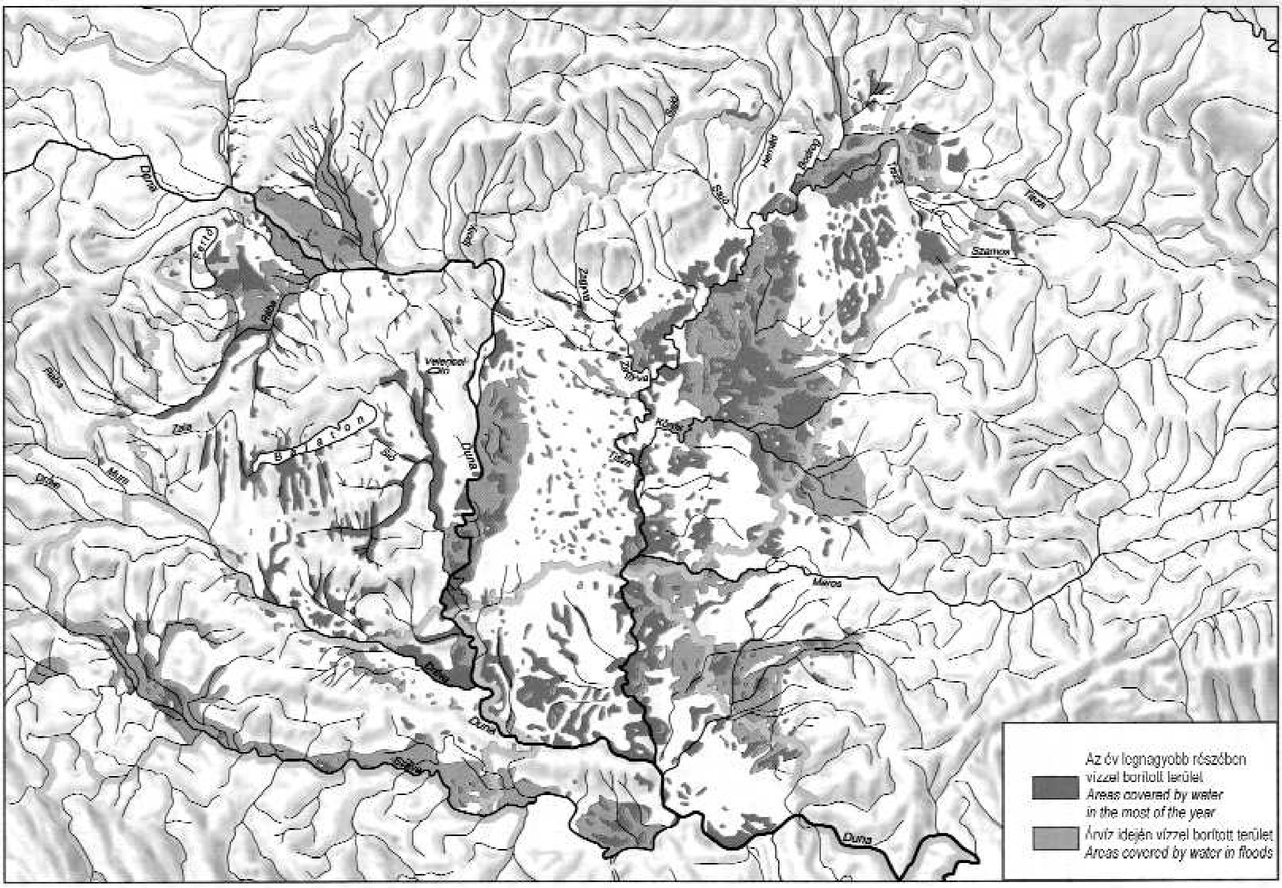

Figure 5. The Carpathian Basin prior to the regulation of rivers
Simplified from Figure 117 in MÉSZÁROS, SCHWEITZER (2002) which in turn is a simplified version of a map compiled by the Hydrographical Institute in 1938

large territories (BALLA 2009). The idea that the migration of Hungarian rivers needs a specific, local explanation should be given up since a plausible explanation only exists in terms of the Coriolis force.

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[9] In Hungarian literature upper, middle and lower sections are distinguished and these which correspond to young, maturate and old river types in American literature.

[10] Hereinafter: manuscript in English.

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[11] no date of issue given