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A systematic overview of the coincidences of river sinuosity changes and tectonically active structures in the Pannonian Basin

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ABSTRACT

As tectonic movements change the valley slope (low-gradient reaches of valleys, in sedimentary basins), the alluvial rivers, as sensitive indicators, respond to these changes, by varying their courses to accommodate this forcing. In our study sinuosity values, a commonly used characteristic parameter to detect river pattern changes, were studied for the major rivers in the Pannonian Basin in order to reveal neotectonic influence on their planform shape.
Our study area comprises the entire Pannonian Basin (330,000 km^2) located in eastern Central-Europe, bounded by the Alps, Carpathians and Dinarides. The studied rivers were mostly in their natural meandering state before the main river regulations of the 19th century. The last quasi-natural, non-regulated river planforms were surveyed somewhat earlier, during the Second Military Survey of the Habsburg Empire. Using the digitized river sections of that survey, the sinuosities of the rivers were calculated with different sample section sizes ranging from 5 km to 80 km. Depending on the bank-full discharge, also a 'most representative' section size is given, which can be connected to the neotectonic activity.
In total, the meandering reaches of 28 rivers were studied; their combined length is 7406 km. The places where the river sinuosity changed were compared to the structural lines of the "Atlas of the present-day geodynamics of the Pannonian Basin" (Horváth et al., 2006). 36 junctions along 26 structural lines were identified where the fault lines of this neotectonic map crossed the rivers. Across these points the mean sinuosity changed. Depending on the direction of the relative vertical movements, the sinuosity values increased or decreased. There were some points, where the sinuosity changed in an opposite way. Along these sections, the rivers belong to the range of unorganized meandering or there are lithological margins.
Assuming that the rivers indicate on-going faulting accurately, some places were found, where positioning of the faults of the neotectonic map could be improved according to the sinuosity jumps. However, some significant sinuosity changes cannot be correlated to known faults. In these cases other factors may play a role (e.g., hydrological changes, increase of sediment discharge also can modify sinuosity). In order to clarify the origin of these changes seismic sections and other geodynamical information should be analyzed to prove or disprove tectonic relationship if hydrological reasons can be excluded.

1. Introduction

In the last decade fluvial geomorphological analysis is increasingly used in order to detect youngest neotectonic activity across fault zones. Over time river geomorphology is sensitive to changes in hydrological and sediment transport conditions (e.g. due to climate change and humans), but in space the rivers can respond spectacularly to changes in valley gradient, topography and substrate which are affected by neotectonics. If a fault causes a displacement that has a vertical component, the rivers of the area tend to change their courses and their style, often good indication of fault activity. According to Schumm (1972, 1977), Schumm and Khan (1972) and Schumm et al. (1972), stream patterns are sensitive indicators of valley slope change. The reduction of valley slope will lead to a reduction of sinuosity, the ratio of channel length to valley length or valley slope to channel slope.

This response is assumed to be detectable, if the fault is a completely new fault, or if the fault reactivated recently, after a long period of inactivity (Holbrook and Schumm, 1999). If the tectonics has been persistent for long time, but there are other, much stronger processes, the channel response may remain unclear (Holbrook and Schumm, 1999).

The hydrology of the river system (baseflow vs. peakflow, floodwave propagation through valley and floodplain) interacts with the associated groundwater system of the tectonic basin fill and the flatter topography allows for wider floodplains. The geometric and substrate differences are also controls on vegetation on river bank and floodplain, which co-control fluvial style.

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Taking the valley-slope reducing effects as given (as implicitly done by Schumm in most of his papers), it is useful to look at the sinuosity variations along these systems and, where systems of the same age are compared and observed differences are not explainable as the growth of discharge due to joining tributaries, and there one can interpret sinuosity change as neotectonic response-signal in the fluvial geomorphology.

This work aims to analyze the geomorphological response of rivers to active deformations within our study area which is the Pannonian Basin where the aforementioned complexity of the phenomenon is also observable. The basin is located in eastern Central Europe, bounded by the Alps, Carpathians and Dinarides, and it is unique in some geomorphic and tectonic senses. The inner part of the basin is characterized by a mosaic of hilly landforms (typically uplifting) and two major areas of prevailing subsidence that form conspicuously flat alluvial plains: the Little Hungarian Plain and the Great Hungarian Plain (GHP). During the Pliocene, tectonic reactivation interrupted the previously widespread subsidence and the filling up of the Pannonian basin (e.g., Bada et al., 2007). This recent activity has manifested itself in the uplift of the western and eastern flanks, and continuing subsidence of the central part of the basin creating a patchwork pattern of differential crustal uplift. In the Late Pliocene, extensional basin formation came to an end, and compressional inversion of the Pannonian basin is in progress since (Horváth and Cloething, 1996). In response to the filling up and restructuring of sediment supply paths, a river system also formed in that time (Nádor et al., 2003; Gábris and Nádor, 2007).

During the Quaternary, the subsidence rate increased in the deepest part of the basin (Horváth and Cloething, 1996). Within the basin the rate of subsidence changed often, so that the rivers often changed their channels (Franyó, 1992; Joó, 1992; Székely, 2009). In the modern situation, differential subsidence is still on-going, but the subsiding areas with fastest subsidence rates nowadays coincide with areas of considerable hydrocarbon and water extraction (Franyó, 1992; Joó, 1992). The tectonically subsiding areas of the Pannonian Basin are characterized by the alluvial rivers with low or very low gradient settings; the prevailing process is aggradation. Alluvial terraces, if they exist at all, have very low relief as well. Their deformation by the tectonic forcing is considered to be below the detection limits.

Based on industrial seismic sections and earlier studies numerous faults were identified and presented in the integrative neotectonic map of Horváth et al. (2006). The noisy upper 50–100 m of the seismic sections, however, typically cannot be evaluated and in most cases the neotectonic activity of these faults could not be assessed. In order to be able to classify them in the alluvial, low-relief area, we have carried out the classic analysis of river channel pattern (more specifically the sinuosity analysis) with some methodological extensions.

The classic experimental studies were performed by, among others, Ouchi (1985) to study the effects of substrate warping on channels through alluvial basins (Fig. 1). Any deformation that changes the slope of a river valley resulted in a corresponding counteractive change in sinuosity, back to equilibrium channel slope. Where the sinuosity changes downstream along a river the rates of meander migration and floodplain reworking accelerate accordingly.

Assuming this model being valid, the increasing slope is a very important property in this consideration. The river has to stay in a given channel–slope range to do the self-organized meandering. Schumm and Khan (1972) in their classic paper studying the phenomenon in flume experiments found that the sinuosity increases only to a critical dip (at a given discharge). If the slope increases above this threshold, the river sinuosity decreases. Considering the varying discharge, Leopold and Wolman (1957) and Ackers and Charlton (1971) studied how the channel pattern changes with the changing slope and bankfull-discharge. Fig. 2 summarizes these threshold dependencies together with the calculated and measured values of the rivers studied in this work. Most of the river reaches belong to the self-organized meandering domain.

The discharge (bankfull, average or mean-annual) determines to a large extent channel dimensions (width, depth, meander amplitude, meander wavelength), but the quantity of water moving through a channel does not affect the basic pattern (Schumm, 1977). The type of sediment load transported by the river also plays a role: channels that carry decent amounts of fines (slit, clay) as suspended load is more likely to be sinuous (Schumm, 1977), whether they also carry significant amounts of bed load or not (Kleinhans and van den Berg, 2011).

Besides geomorphological response to along-river differences in hydrology, sediment load and active tectonics, alluvial channels have been reacting to human activities since prehistoric times, and direct and lagging responses to climatic variations such as the Pleistocene–Holocene transition 15,000–10,000 years ago (e.g. Vandenberghe, 1995) also play a role. Consequently, it may be difficult to separate the causes of the river course modification, especially if reaches are considered individually only. Observing a downstream change in natural channel pattern on its own is an insufficient indication to infer active tectonics. Nevertheless, if there is an independent indication for the presence of fault zones e.g., based on geological or geophysical reasons, identification of anomalous reaches that were neither affected by in regulation/engineering construction, nor have tributary influences may reasonably be assumed to be the result of active tectonics (Schumm, 1986).

Nowadays, as the low plains of the Pannonian Basin are highly flood-endangered, most of the rivers are regulated. The main river control works were carried out in the second half of the 19th century. During these works, the lengths of the rivers decreased, consequently the channel slope increased, and the shape of the rivers became straighter. The confinement of their course by the regulating earthworks influences or reshapes their original free meandering course, thus, if a fault is recently active, the rivers cannot change their sinuosity in the natural way to react to the valley slope changes.

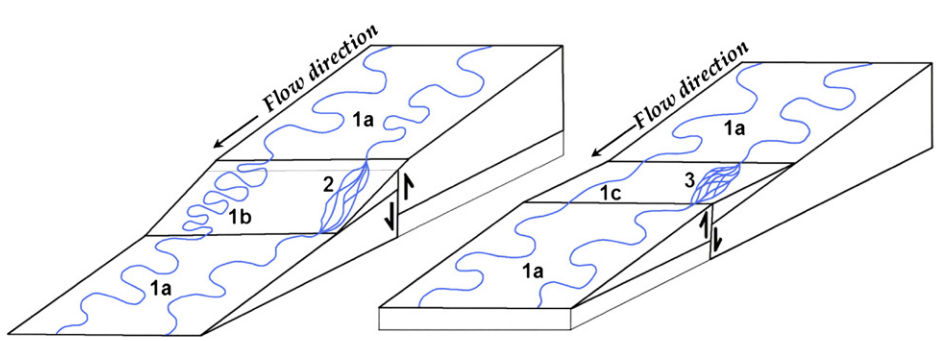

Fig. 1. The illustration of the river responses to the active vertical movements based on the flume experiments of Ouchi (1985) and the theories of Holbrook and Schumm (1999). 1a: Meandering pattern with normal sinuosity, 1b: meandering pattern with high sinuosity, 1c: meandering pattern with low sinuosity (even including straight pattern), 2:wandering or braided pattern, 3: anastomosing pattern.