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Late Pleistocene river migrations in response to thrust belt advance and sediment-flux steering — The Kura River (southern Caucasus)

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ABSTRACT

One reaction of rivers toward allogenic triggers is the large-scale river channel migration in the form of avulsions or progressive lateral migrations (combing) that are widespread phenomena around the world during the late Quaternary. Because they potentially cause significant human and economic losses and significantly change geomorphic processes in the affected regions, a deeper knowledge about causes and rates is essential and furthermore helps to identify the dominant drivers of regional landscape evolution during different periods. One possible cause for river channel migrations is sediment-flux steering, i.e. the shift of rivers in sedimentary basins against a tectonically driven trend caused by transverse sediment discharge. During the last 30 years, sediment-flux steering has been investigated by field and experimental studies in extensional half-grabens with generally small-sized transverse catchments and/or volcaniclastic sedimentation.

This study presents geomorphologic, geochronologic, and heavy mineral analyses together with complementary tectonomorphometric and earthquake data to investigate late Quaternary channel migrations of the Kura River in the southern foreland basin of the Greater Caucasus, a region where the late Quaternary landscape evolution is rather fragmentarily understood so far. Special emphasis of this study is given to the interplay between axial river flow and transverse sediment supply leading to sediment-flux steering. Large-scale migrations of the course of the Kura River during the late Quaternary reflect the interplay between tectonic processes leading to the southwestward advance of the Kura Fold-and-Thrust-Belt and climatically-triggered sediment-flux steering caused by aggradation phases of transverse rivers with comparatively large catchment areas in the Lesser Caucasus. During generally warmer periods such as the Holocene with fluvial incision and low sediment supply from the transverse rivers, the main Kura River could follow its tectonically driven trend toward the southwest. In contrast, during generally colder periods such as the upper late Pleistocene, sediment-flux steering caused by aggradation of the transverse rivers forced the main Kura River to migrate >10 km against that tectonically induced trend toward the northeast. Apart from giving information about the main drivers of the late Quaternary landscape evolution in this part of the southern Caucasus region, this study also helps to understand the cause of a permanent threat of settlements and the loss of fertile agricultural land in the intensively labored Marneuli Depression of southern Georgia.

1. Introduction

Rivers and their deposits are important recorders of landscape evolution. Their spatiotemporal evolution reflects the intricate interplay and feedback mechanisms between auto- and allogenic processes. One possible reaction of rivers toward allogenic triggers such as tectonic activity (Holbrook and Schumm, 1999; Sahu et al., 2010), climatic changes (Slingerland and Smith, 2004; Assine, 2005), or anthropogenic activity (Heyvaert et al., 2012; Kubo, 2012) are large-scale river channel migrations in the form of avulsions or progressive lateral migrations (combing). These are widespread phenomena around the world during the late Pleistocene and Holocene. Because river channel migrations have the potential to cause significant human and economic losses and to significantly change geomorphic processes in the affected regions (Slingerland and Smith, 2004; Assine, 2005), a deeper knowledge about causes for and rates of these processes is essential. Furthermore, studying the sensitivity or robustness of rivers to different external

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and internal forcings helps to identify the dominant drivers of regional landscape evolution during different periods (Whittaker, 2012; Fuchs et al., 2013). One possible cause for river channel migrations is sediment-flux steering, i.e., the shift of rivers in sedimentary basins against a tectonically driven trend caused by transverse sediment discharge either from transverse rivers or alluvial fans or caused by volcaniclastic sedimentation (Connell et al., 2012a). During the last 30 years, the consistent shift of axial rivers in asymmetric basins caused by sediment-flux steering has been investigated by field and experimental studies in extensional half-grabens with generally small-sized transverse catchments and/or volcaniclastic sedimentation (Smith, 1987; Waresback and Turbeville, 1990; Leeder and Mack, 2001; Mack et al., 2008; Kim et al., 2011; Connell et al., 2012a, 2012b). While the position of maximum subsidence in half-grabens is controlled by the geometry of the normal fault array, the location of maximum subsidence in a foreland basin depends on the propagation of the flexural wave, i.e., elastic properties of the lithosphere and the growth of the advancing orogeny (DeCelles and Giles, 1996). Burbank (1992) suggested that axial drainage dominates during tectonic loading phases, whereas erosion of the adjacent mountain chain resulting in a thinning of the crust (i.e., unloading) will feed transverse sediment input, which will push the axial trunk stream toward the foreland. It follows that the migration of the axial river toward the foreland is a function of both, the propagation of the flexural wave and the transverse sediment discharge from the mountain belt. The latter is controlled by headward erosion and associated drainage capture and by climatically modulated erosional efficiency (Kirby and Whipple, 2012).

This study presents geomorphologic, geochronologic, and heavy mineral analyses that are complemented by tectonomorphometric and earthquake data, to investigate late Quaternary channel migrations of the Kura River in the southern foreland basin of the Greater Caucasus. Special emphasis will be devoted to the interplay between axial river flow and transverse sediment supply leading to sediment-flux steering (Blair and Bilodeau, 1988). This will help to constrain the driving forces behind significant landscape changes in the southern Caucasus region that was characterized i) by the convergence between the Africa-Arabian and Eurasian plates leading to recent uplift and deformation in Greater and Lesser Caucasus (Jackson et al., 2002; Matcharishvili et al., 2013), and ii) by intensive late Quaternary palaeoenvironmental changes such as shrinking or disappearance of glaciers in Greater and Lesser Caucasus (Gobejishvili et al., 2011; Messager et al., 2013) and fundamental changes of the vegetation cover (Connor and Kvavadze, 2008). Up to now only some individual studies investigated the late Quaternary fluvial dynamics of the southern Caucasus region (Furlani et al., 2012; Ollivier et al., 2015; von Suchodoletz et al., 2015). Thus, the dominant factors of the late Quaternary landscape evolution in this region are rather fragmentarily understood so far. Finally, such an analysis shall reveal the root causes for the persistent threat to settlements and permanent loss of fertile agricultural land in the intensively laboured Marneuli region of southern Georgia.

2. Study area

The Kura River has a total length of ca. 1500 km and a catchment area of ca. 188,000 km^2. It originates from the eastern Anatolian Highland in Turkey at ca. 2740 m asl (Guluzada, 2004), and after crossing Georgia and Azerbaijan it flows into the Caspian Sea at a recent altitude of −27 m asl (Fig. 1). The upper course of the river is located in the Lesser Caucasus, an upper Cretaceous island arc that formed during north-directed subduction along the south side of the arc prior to closure of the Neotethys Ocean (Forte et al., 2010). The middle part of the Kura River approximately follows the transition from the Greater Caucasus in the north to the Lesser Caucasus in the south and thus receives tributaries from both mountain ranges (Fig. 1). The Greater Caucasus presents a doubly vergent orogen that formed by Cenozoic closure of a Mesozoic to Cenozoic back-arc basin (Forte et al., 2014). Volcanic basaltic, andesitic, trachytic, and doleritic rocks dominate the catchment of the Kura River in the Lesser Caucasus. In contrast, the catchment in the Greater Caucasus encompasses mostly strongly folded Jurassic to Neogene flysch and molasse deposits dominated by sandstones, siltstones, shales, and limestones (Gamkrelidze, 2003). East of the city of Tbilisi the Kura River bends abruptly to the SE and flows south of the Kura Fold-and-Thrust-Belt (Kura-FTB: Fig. 1). According to Gamkrelidze (2003) and Forte et al. (2010), the Kura-FTB consists of a series of south-vergent faults and thrusts paralleling the Greater Caucasus that are composed of deformed Plio-/Pleistocene flysch to molasse sediments (Fig. 1). Based on balanced cross sections in conjunction with GPS data, Forte et al. (2010) demonstrated that the western Kura-FTB accommodated a greater magnitude of shortening than the eastern part. This is concomitant with a west to east propagation of deformation in the Kura-FTB. Deformation in the western part commenced between 1.8 and 1.5 Ma (Forte et al., 2013).

Approximately 570 km from its headwaters, the Kura River enters the Marneuli/Kura Depression (denomination according to Maruashvili, 1971), i.e., the lowest part of the Kvemo Kartli Plain. This tectonic basin extends ca. 10–20 km from north to south, ca. 40 km from west to east, and shows altitudes between 280 and 350 m asl (Fig. 2). With 300–500 mm annual precipitation, the climate of the basin is semihumid to semiarid (unpublished precipitation map by W. Bagrationi, Geographic Institute Tbilisi). Here, the Kura River has a catchment of ca. 21,000 km^2 (Fig. 1), a mean annual discharge >160 m^3/s peaking during April and May (data between 1960 and 1975 for station Dzegvi ca. 55 km upstream of the study area; http://rda.ucar.edu/data/ds553.2/fsu2), and a mean slope of 0.2%. The basin is located between the Lesser Caucasus in the west (consisting of Cretaecous to Neogene volcanic and sedimentary rocks and reaching altitudes >2000 m asl) and the Kura-FTB in the east (consisting of Paleogene to Early Quaternary (Apsheronian) sedimentary rocks and reaching altitudes up to 1000 m asl: Fig. 2). The Kura River separates the remaining surface of a largely eroded Pleistocene basin fill in the western part of the basin (Marneuli Depression) with a scarp of 20 to 60 m from the lower-lying eastern part where the basin fill is eroded today (Kura Depression). In the Marneuli/Kura Depression the Kura receives several western tributary rivers originating from the Lesser Caucasus (Algeti, Khrami, Mashavera, and Debeda), showing slopes of 0.2–0.3% in their lower reaches. Their combined catchment area is ca. 9100 km^2 (Fig. 1), and their combined discharge is ca. 54 m^3/s (http://rda.ucar.edu/data/ds553.2/fsu2). The valley of the Khrami River, the receiving stream for the Mashavera and Debeda Rivers, is limited toward the Pleistocene basin fill with a scarp on the northern side of the valley. In contrast, the Algeti valley crosses the Pleistocene basin fill and is cut into these deposits as a deeply incised gorge (von Suchodoletz et al., 2015; Fig. 2). Although the catchments of the western rivers are not glaciated at all today, some minor parts in the Lesser Caucasus were glaciated during the Weichselian glacial (Gobejishvili et al., 2011; Messager et al., 2013). Caused by the small NW-SE striking Beyük Kyasin Ridge, Lake Djandari developed at the transition of the basin toward the Kura-FTB (Figs. 2, 3).

3. Material and methods

This contribution aims to provide constraints and possible mechanisms for observed river channel migrations owing to sediment-flux steering caused by large transversal rivers in a compressional setting, using the Kura River and its western tributaries in the Marneuli/Kura Depression as an example. This will be achieved by integration of field-work-derived data sets such as stratigraphical mapping, heavy mineral analyses, and numerical dating that will finally be linked with tectonomorphometric, i.e., local relief and seismicity data, to highlight areas of uplift and recent deformation.