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Paleogeographic development of the Cenozoic river systems in the central and northern Bohemia and its link to climatic changes and neotectonics

Paleogeografický vývoj kenozoických říčních systémů ve středních a severních Čechách a jejich vztah ke klimatickým změnám a neotektonice

Doctoral thesis

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Prohlášení

Prohlašuji, že jsem závěrečnou práci zpracoval samostatně a že jsem uvedl všechny použité informační zdroje a literaturu. Tato práce ani její podstatná část nebyla předložena k získání jiného nebo stejného akademického titulu.

V Praze, 31. července 2018

Declaration

I declare that this thesis was composed by myself, that the work contained herein is my own except where explicitly stated otherwise in the text, and that this work has not been submitted for any other degree or processional qualification except as specified.

In Prague, 31st July, 2018

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Paleogeographic evolution of the fluvial systems in middle and northern Bohemia and its link to climate changes and tectonic processes

Introduction

The fluvial systems in the middle and the northern Bohemia have been studied for generations of reseachers since the 19th century. The focus of this study are sedimentary accumulations (river terraces) of the Vltava, Labe and Ploučnice rivers, they have been well documented, as shown in previous overviews such as those by Balatka and Sládek (1962a,b), Šibrava (1967), Záruba et al. (1977). More recent studies are discussed by Balatka (1992), Tyráček (2001), Tyráček et al. (2004), Balatka et al. 2015 and Schaller et al. (2016a, b – *part of this study*).

According to Jaroslav Tyráček, the first supervisor of this thesis, „the dating the start of terracing and deducing the ages of the terraces is a significant problem“ with regard to two different approaches of possible solution (Tyráček et al. 2004, Tyráček and Havlíček 2009). The first view is that river-incision and formation of terrace systems is driven by climate changes (e.g. Tyráček, 1983; Bridgland, 2000; Westaway, 2002). The second view is stressing the uplift tendency known from the other parts of Europe which is an important factor in the terrace formation (e.g. Maddy, 1997; Bridgland, 2000; Westaway, 2002; Bridgland and Westaway, 2007, Tyráček and Havlíček 2009). We supposed that the fluvial systems in middle and northern Bohemia were influenced by climate changes, tectonic processes with local tectonics as well as by general uplift tendency in central Europe and the bedrock lithology. The aim of this study is to develop a new concept for the evolution of the Ploučnice River system based on the new dating of fluvial deposits.

Critical perspective

Thanks to the position of the studied area in narrow non-glaciated zone between two gigantic ice masses: the Scandinavian ice sheet in the north (e.g., Nývlt 1998) and the Alpine ice cap in the south (Suk et al., 1984), the fluvial record of the river systems in the northern and central Bohemia preserves a suitable undisturbed sedimentological record of the almost whole time span from the start of the river terrace formation to the present day.

The correlation of this fluvial record, which is preserved mainly in the river terrace infills, less fluvial fans and deltas (Štor et el. in prep.), is considered problematic

(Tyráček a Havlíček 2009) because it ignores the possible influence of the local tectonics and differences in the bedrock lithology in each individual catchments (Bull 2007).

Moreover, together with shifting of the Quaternary boundary to 2.58 Ma (e.g. Gibbard et al., 2010) and absolute dating of the fluvial terraces along the Vltava River (Schaller et al., 2016a), we have to reconsider the previous research of the river terraces of the Vltava and Ploučnice rivers (e.g. Záruba et al. 1977, Tyráček 2001, Tyráček et al. 2004, Tyráček and Havlíček 2009, Balatka et al. 2015). From previous research (summary in Balatka and Sládek 1962 a) we can define the main terrace levels with the three main terrace groups according to their relative surfaces above present-day floodplain. But we assume that the correlation with glacial and interglacial periods remains problematic. Moreover it can be difficult due to a variable bedrock lithology (e.g. Bull 2007), local tectonics (Štor et al. 2013) and differences in landscape in their surroundings. Unlike from the previous research I assume that the terrace erosional base is more relevant to determine stratigraphic position because especially in higher terrace levels the original surface could be significantly lowered by Quaternary erosion. Moreover, the erosional base is the first evidence after phase of a river incision and a whole sedimentary infill deposited during an agradation phase is younger and could be partially resedimented and eroded during the river aggradation. Therefore, possible datings of paleontological materials show as only the minimal ages of these accumulations. In addition the bedrock lithology play key role during a river incision which we can see in Vltava River and Labe River confluence (Štor et al. in prep.). The different lithologies of the bedrock can change the sedimentary environments during the river evolution because of the back curve-erosion. The fluvial sedimentation can vary from river environments to fluvial fan as far as to alluvial fan or debris fan environments.

The problem with local tectonic reactivation during Quaternary period is significant too (e.g., Špaček et al. 2006; Štěpančíková et al. 2010) and together with tectonic

predispositon of the bedrock can contribute significantly to the acceleration of the river incision (Bull 2007).

The main aims of this study

The main aim of this study is better understanding of the fluvial systems of the Ploučnice River and Vltava River in middle and northern parts of Bohemia. The development of these fluvial systems is very complex, therefore, there is a strong need of understanding the climate changes, tectonics, geology, sedimentology and the need of more accurate dating methods. Finally yet importantly, a proper choice of the geomorphologic position of the sampling area with good knowledge of the location is required.

Ploučnice River

The aim of this work is to put a new concept of the research of the Ploučnice River system evolution based on comparison of two different dating methods: isochron burial dating (^{10}Be and ^{26}Al) and optically stimulated luminescence.

First, we wanted to determine the age of the sedimentation of the river terrace infills by isochron burial and OSL datings.

Next, our focus was to compare the final results with previous works and establish the new correlation with phases of continental glaciation in Northern Bohemia.

The last aim is to focus on the youngest part of the Ploučnice River evolution: determination of the changes in the fluvial style during the transition from Pleistocene to Holocene periods.

Vltava River

The research of a Dr. Schaller´s working group was focused on determination of the denudation rates based on cosmogenic nuclides from modern river sediments and paleo-denudation rates from four Vltava River terraces with the use of isochron burial dating.

The last aim of this work is to put a new concept of the research of the Vltava River system evolution based on cosmogenic dating method.

Moreover, the focus of this work is quantifying temporal variations in Quaternary denudation over 12˚ of latitude of Vltava, Allier, Esla and Guadalquivir rivers but this topic is not part of this thesis.

Methods of the research

For the reconstruction of the paleogeographic evolution of the Ploučnice and Vltava River systems we have used multiple approaches to investigate the river systems from different points of view. The disciplines range from geology, sedimentology, geomorphology, geochemistry, over different dating methods such as isochron burial dating with in situ-produced cosmogenic nuclides, Optically Stimulated Luminescence and radiocarbon dating.

Morphotectonic analysis

This method was carried out to help to identify possible faults. The identification of faults in the studied area was essential, because of the complicated geology. We have used digital elevation model (DEM) with shaded relief maps (315º, 360º and 45º ilumination). The images provide synoptic views of the landscape surface, allowing the analysis of landforms for interpretation tectonic and geological structures (e.g. Dhont and Chorowicz 2006). Our data (Lidar 5G) allow interpretation of geological structures in second order in local scale and are suitable for verification results from geological maps 1:50 000 (www.geology.cz) in order to differentiate mapped faults from different bedrock lithology and erosional scarps. After this step, we check out real state by geomorphological field mapping and archive wells for remove anthropogenic influence (Štor et al. in prep. *– part of this study*).

Optically Stimulated Luminescence method (OSL)

This method was used for dating sand from fluvial sandy dunes with original stratification of the Ploučnice River terraces. For sampling, we used manual from USU Lab with respect to Preusser et al. (2008).

In situ-produced cosmogenic nuclides dating

The production of the cosmogenic nuclides ^{26}Al and ^{10}Be in quartz can be used to determine sediment deposition ages (e.g. Granger et al., 1997). The method makes use of the known production ratio of ^{26}Al and ^{10}Be at the Earth surface and their different half-lives (e.g., Granger and Muzikar, 2001; Granger and Schaller, 2014).

At the time of sediment deposition, the ^{26}Al/^{10}Be ratio in a clast eroding in steady-state can be inferred. Once the clast is being buried deeply enough to be shielded from further irradiation and nuclide production, the ^{26}Al/^{10}Be ratio decreases due to decay with different half-lives. The measured ^{26}Al and ^{10}Be concentrations in several samples

in the terrace reflect the sediment burial time (called “simple burial dating”) (Štor et al. in prep. – *part of this study*).

For the Vltava River and the Ploučnice River, we used the method of “isochron burial dating” which makes use of the fact that samples deposited in the same depth at the same time should lie on a slope in the ^{26}Al to ^{10}Be plot. The slope of this plot is used to determine the burial age of the clasts and hence terrace formation (see Fig. 6 in Štor et al. in prep. – *part of this study*).

Radiocarbon accelerator mass spectrometer dating

We used radiocarbon accelerator mass spectrometer dating and data from palynological analysis to date organic remains extracted from sedimentary infill within a relict meander bend of the Ploučnice River (Štor et al. 2016 – *part of this study*).

Key Findings of This Study

The Ploučnice River fluvial system

This study attempts to quantify the influence of climate changes and tectonic processes on the evolution of the Ploučnice fluvial system based on isochron burial and OSL dating.The sedimentary infill of the Ploučnice River represents an important link between the Scandinavian glaciations and the terrace systems in the Bohemian Massif. Thanks to doubled terraces with a different type of clasts in the lithology composition, it is possible to correlate them with phases of continental glaciation (Šibrava 1967). However, the resulted ages from isochron burial dating show that the fluvial accumulations (mainly river terraces and rarely alluvial fan deposits) could be older than previous authors supposed (e.g. Šibrava 1967, Záruba et al. 1977, Růžičková and Růžička 1984).

The six terrace accumulations in relative altitudes above present-day floodplain have been documented and we determined five lithofacies in their sedimentary infill: silty clay (SC), trough cross-stratified sand (St), trough cross-stratified gravel (Gt), massive gravel (Gm), massive sand (Sm). Most of the lithofacies are trough cross-stratified sand to trough cross-stratified gravel. Clay-dominated facies are very rare or even absent in the individual outcrops (Štor et al. in prep. – *part of this study*).

The fluvial style changes from high-energy braided to long-bend meandering river in the upper terrace levels (36 to 31 m above the modern river) and from high- to

medium-energy braided river in the middle terrace levels (22-16 m). In the lower terrace levels (13 to 7 m) high-energy braided to long-bend meandering river environments were identified.

Terraces found at 36 m, 31 m and 16 m above the modern floodplain were dating with cosmogenic radionuclides (in relative altitude 34, 29 and 14 m above present-day floodplain surface) while the 22 m, 13 m and 7 m terraces were dating with OSL (in relative altitude 19,11 and 6 m above present-day floodplain surface). Due to differences in age results between the two dating methods, we establish two different evolution models: The first is based on isochron burial and OSL dating method and the second model is on the OSL dating results alone. The time span represented by the river terraces remains unclear and varies from Eburonian to Eemian (1.68 to 0.056 Ma) or from Elsterian to Eemian (0.138 to 0.056 Ma), respectively. The first river evolution model is considering the tectonic activity at least since the deposition of the Mimoň terrace accumulation.

According to the morphotectonic analysis, we have recognized minimally three populations of tectonic structures (lineaments) with ESE, ENE and N-striking. The Ploučnice River channel morphology is strongly influenced by tectonics.

According to the dated terrace ages (1.153 Ma ~ 14 m) and (0.138 Ma ~ 19 m), we suppose activity of the normal fault from at least 1.153 Ma with following aggradation up to 21 m in relative altitude above recent floodplain. The second river evolution model supposes resedimentation of gravel clasts, which were dated by isochron burial dating, before their final deposition. From three OSL ages we calculated a mean erosion rate and estimated an age of the higher Bohatice step for relative altitude ~ 34 m as 248 ky (Saalian age). Resedimentation of gravel clasts in high-energy fluvial and glaciofluvial environments is very likely. The determination of the sedimentary transport history is challenging. We interpret the record as suggesting that the influence of the tectonic processes on the Ploučnice River development was overhelmed by Late Quaternary climatic changes, which have played a key role during the Ploučnice terrace system development.

Another part of the research was focused on the Ploučnice River evolution during the transition from Pleistocene period to Holocene. We used radiocarbon dating and palynological analysis to determinate age of sedimentary infill within a relict meander bend of the Ploučnice River (Abraham and Sádlo in Štor et al. 2016 – *part of this study*).

Together with geological mapping and determination of geomorphological position of sedimentary accumulations, we determinated the main phases of Ploučnice River development during the transition from Upper Pleistocene to Holocene. Four developmental phases of Ploučnice River were recognized: braided floodplain (Upper Pleistocene); anabranching river (Late Glacial/Early Holocene); abandoned anabranching river with another phase of incision (Middle Holocene) and recent meandering channel since Late Holocene.

The Vltava River fluvial system

The four terrace accumulations (or alluvial fan deposits) in relative altitudes above present-day floodplain surface have been documented. The isochron burial age constraints of four selected terrace steps are between 1.00+-0.21 to 1.99+-0.45 Ma. Results from Vltava-Labe rivers confluence indicate that the cosmogenic nuclide-based ages are generally three times older than ages based on previous work. This discrepancy could be explained by relative dating techniques or possibility of clasts resedimentation for isochron burial dating (Schaller et al. 2016a).

The data from isochron burial dating of the Vltava River acumulations arise question about possibility of alluvial fan sedimentary environments which has reversal stratigraphy than during forming the terrace fluvial system. This is supported by different bedrock lithology in Prague basin and Vltava-Labe rivers confluence.

Conclusions

Although the fluvial systems in Bohemian Massif were in general controlled by climate changes, for detailed study of Ploučnice River terrace system we also have to take into account possibility of the influence of the local tectonics or resistence of the bedrock lithology. For an interpretation of terrace age according to the relative altitude, we have to be very carefull about local tectonic predisposition with faster erosion rate. Moreover, we assume that the terrace erosional base is more relevant to determine stratigraphic position of studied fluvial accumulations because especially in higher terrace levels the original surface could be significantly lowered by Quaternary erosion.

Possibility of resedimentation of gravel clasts in high energy fluvial or glaciofluvial environments is significant. Determination of sedimentary transport history is challenging. For isochron burial dating of high energy braided fluvial system could be

statistical approach considering clast mixing more useful. Influence of tectonic processes on Ploučnice River development was partly overprinted by Late Quaternary climatic changes, which have played a key role during the Ploučnice River terrace system development.

For the future research, there is a strong need of understanding the climate changes, local tectonics, geology, sedimentology, geomorphology and the need of more accurate dating methods. Moreover, focus on the fluvial transport history of the dated samples, which includes their chronostratigraphical position, lithology, roundness, weathering and type of fluvial condition during their sedimentation, is needed.

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