Geomorphology 232 (2015) 193–208

Contents lists available at ScienceDirect

Geomorphology

journal homepage: www.elsevier.com/locate/geomorph

Response of fluvial, aeolian, and lacustrine systems to late Pleistocene to Holocene climate change, Lower Moravian Basin, Czech Republic

Jaroslav Kadlec [a,*], Gary Kocurek [b], David Mohrig [b], Dattatreya P. Shinde [c], Madhav K. Murari [c], Vaidehi Varma [c], Filip Stehlík [d,e], Vojtěch Beneš [f], Ashok K. Singhvi [c]

[a] Institute of Geophysics AS CR, v.v.i., Boční II/1401, 141 31 Prague 4, Czech Republic
[b] Department of Geosciences, Jackson School, University of TX, Austin, USA
[c] Geosciences Division, Physical Research Laboratory, Ahmedabad 380 009, India
[d] GeoTec-GS, JSC, Prague, Czech Republic
[e] Institute of Geology and Palaeontology, Charles University in Prague, Czech Republic
[f] G-Impuls Praha Ltd., Prague, Czech Republic

ARTICLE INFO

Article history:
Received 15 July 2014
Received in revised form 16 December 2014
Accepted 17 December 2014
Available online 24 December 2014

Keywords:
Quaternary
Czech Republic
Fluvio-aeolian
Lake
Turbidites
Climate change

ABSTRACT

Late Pleistocene to Holocene Morava River valley-fill of the eastern Czech Republic reflects the geomorphic evolution of the valley as forced by climate change. Valley-fill stratigraphy was studied through measured sections, optically stimulated luminescence (OSL) and radiocarbon dating, ground-penetrating radar surveys of relict sand dunes, archived drill-hole data, and a comparison of elevations and ages of stratigraphic units. Fluvial systems evolved from meandering with floodplains to braided during MIS 3. Braided fluvio-aeolian systems dominated through MIS 2 and the Last Glacial Maximum (LGM). Valley aggradation occurred during arid glacial times of a low water-to-sediment discharge ratio. Most valley-fill was removed at 13 ka with incision by a large-bend meandering river with an estimated bankful paleodischarge 3× larger than the modern Morava River. The Holocene Morava River has varied from meandering to anabranching with low rates of floodplain aggradation. The Bzenec sand body, up to 36 m thick, represents an erosional remnant bypassed during late Pleistocene incision and consists of interpreted lacustrine turbidites overlain by braided stream and aeolian dune strata. The turbidites consist of laterally continuous, thin, normally graded beds of rounded and frosted sand grains of aeolian origin. Dates and elevation data argue that the valley lake formed during the LGM through downstream damming by a braided terminal fan and sand dune complex. The turbidites are interpreted to have formed through fluvial undercutting and slumping of dune accumulations as lake level rose. This process forced an erosional unroofing of aeolian accumulations, reflected in inverted OSL dates for the turbidites.

1. Introduction

Central Europe underwent pronounced climatic change during the late Pleistocene to Holocene. Using marine isotope stages (MIS) with ages from Lisiecki and Raymo (2005), alternating relatively temperate interstadial and cold stadial periods of MIS 3 (57–29 ka) across much of Europe (Coope, 2002) yielded to glacial MIS 2 (29–14 ka) and the Last Glacial Maximum (LGM), taken as between 26.5 and 20–19 ka (Clark et al., 2009). The Scandinavian Ice Sheet extended across eastern Germany and into Poland (Svendsen et al., 2004), with an arid periglacial corridor (Tyráček, 1995; Hubberten et al., 2004) between the ice sheet and alpine glaciation in the Eastern Alps (Starnberger et al., 2011), Western Carpathians (Makos et al., 2013), Krkonoše (Engel et al., 2011), and Bohemian Forest mountains (Mentlík et al., 2013). Regional warming began about 15 ka (Walker, 1995; Hubberten et al., 2004), but with a return to glacial conditions during the Younger Dryas between 12.8 and 11.5 ka (Berger, 1990; Alley, 1993, 2000). The end of the Younger Dryas was marked by an abrupt transition to the warmer and wetter climate of the Holocene (Taylor et al., 1997).

These late Pleistocene to Holocene climatic changes impacted surface parameters – such as vegetation, evapotranspiration, sediment availability, and fluvial discharge – which, in turn, profoundly altered the regional geomorphology. In addition to the development of glacial and periglacial landscapes during the LGM, drainage patterns were altered (e.g., Mangerud et al., 2004); fluvial systems changed between braided, meandering, and anastomosing (Vandenberghe, 1995, 2003; Mol et al., 2000); widespread sand sheets and dune fields formed (Kasse, 2002); and loess was widely deposited (Frechen et al., 2003).

The Morava River drainage network of the eastern Czech Republic consists of tributaries issuing from orogenic uplands into a trunk stream housed within a tectonic basin. Morava valley-fill has been shown to consist of a complex mosaic of alluvial fan, fluvial, aeolian sand, and

* Corresponding author. Tel.: +420 267103334.
E-mail address: kadlec@ig.cas.cz (J. Kadlec).

http://dx.doi.org/10.1016/j.geomorph.2014.12.030
0169-555X/

loess accumulations deposited since the Pliocene (Kukla, 1975; Havlíček, 1991; Havlíček et al., 1994, 1996, 1997, 2007; Frechen et al., 1999; Tyráček and Havlíček, 2009). The purpose of this paper is to explore the stratigraphic and chronologic relationships of interpreted fluvial, aeolian, and lacustrine strata within a segment of the Morava River valley in which the strata records the response of these depositional environments to climatic change from MIS 3 to the Holocene. Previous work in this area has largely been regional in nature and without a detailed study of the valley-fill stratigraphic architecture and its chronology. This study demonstrates a climate-driven complex history of valley aggradation and incision caused by braided and meandering rivers, respectively. An LGM lake system is identified in which dated facies relationships argue that the lake formed with downstream damming by a braided terminal fan and aeolian dune complex and that lake sedimentation was largely by turbidity currents originating with fluvial undercutting of aeolian dune strata. Results from this study highlight the potential for extracting the climatic record from basins extending from the lower Morava River to its confluence with the Danube River.

2. Geomorphic and geological settings of the study area

The Morava River and its tributaries drain the eastern Czech Republic and adjacent areas of Austria and Slovakia before merging and flowing southward to join the Danube River in Slovakia (Fig. 1). The catchment area of the Morava River (26,658 km^2) includes (i) the Upper Moravian Basin that drains highlands composed of Proterozoic crystalline rock and upper Paleozoic marine and continental strata, and (ii) the Lower Moravian Basin that drains Paleogene *flysch* nappes of the Western Carpathian Mountains (Figs. 1–2). The Dyje River and its tributaries issue from the eastern margin of the Bohemian Massif, which consists largely of Proterozoic crystalline rock. The Dyje River crosses the Carpathian nappes to merge with the Morava River at the southern border of the Lower Moravian Basin. The southern extent of the Morava River is through the broad lowlands of the Záhorská Basin. The Lower Moravian and the Záhorská basins are floored by Miocene marine strata contiguous with the Vienna Basin to the southwest. Bedrock within the Upper and Lower Moravian Basins and the Záhorská Basin are overlain by Quaternary deposits (Fig. 2).

The primary focus of this study is the Bzenec area in the Lower Moravian Basin (Fig. 2). As seen in Fig. 3, the modern Morava River valley is defined to the northwest by incised relict meander bends. These meander bends truncate a Quaternary sand body (hereafter, the *Bzenec sand body*) that is up to 36 m thick and that has been interpreted as aeolian accumulations (e.g., Vitásek, 1936; Havlíček et al., 2007). Stabilized dune forms are apparent in the digital elevation model (DEM), especially south of Bzenec (Fig. 3). Up to 5 m of Holocene meandering channel and floodplain deposits occur within the modern incised valley and overlie Pleistocene fluvial deposits (Kadlec et al., 2009). In order to place the accumulations in the Bzenec area within the context of the Morava River valley, Quaternary exposures were also investigated southward in the Záhorská Basin, upstream in the Lower Moravian Basin, and in the Dyje River valley (Fig. 2).

3. Methodology

Outcrops are scarce within this heavily vegetated and cultivated area, and most exposures occur within active or abandoned sand quarries. In addition to the sections shown in Fig. 2, numerous other abandoned quarries were explored and new excavations were made. Sections were measured and characterized by lithology, sedimentary structures, and grain size and surface texture. Drill-hole data for the Bzenec sand body, housed at the Czech Geological Survey, were used

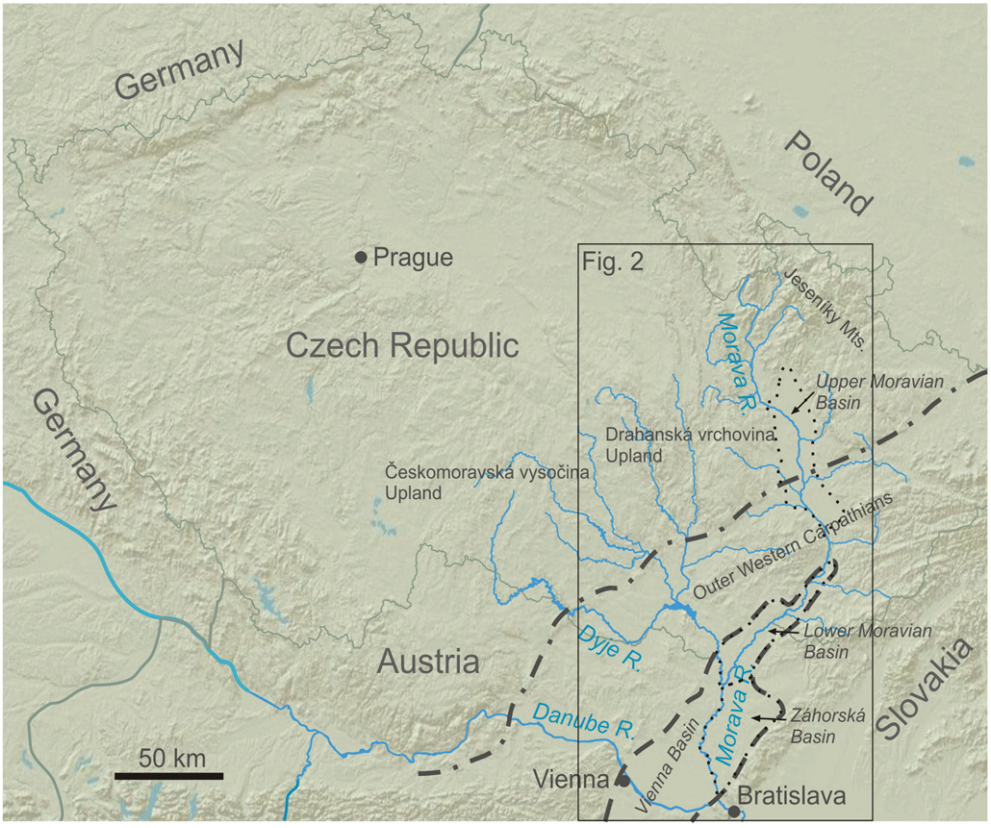

Fig. 1. Drainage network of the Morava River and its tributaries, including the Dyje River, before joining the Danube River in Slovakia. The dash-dot line generally separates uplands of the Bohemian Massif to the west from the Western Carpathian Mountains to the east. Note the Upper Moravian, Lower Moravian, and Záhorská basins, which house Pliocene to Holocene strata. The dashed line outlines the extension of the Miocene Vienna Basin into the Lower Moravian and Záhorská basins. Box denotes location of Fig. 2.