RADIOCARBON DATING OF HOLOCENE SEDIMENTS: FLOOD EVENTS AND EVOLUTION OF THE LABE (ELBE) RIVER IN CENTRAL BOHEMIA (CZECH REPUBLIC)

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ABSTRACT. We studied the structure and development of the Holocene floodplain of the Labe (Elbe) River by radiocarbon dating sections of the upper and middle courses of the river. We focused on geomorphological and sedimentological conditions, mineralogy and the chemical composition of sediments. We established the stratigraphy of the Holocene deposits of the floodplain. The results of our investigation of fluvial sediments imply that several abrupt changes in temperature and precipitation occurred during the Holocene. These changes led to intervals of hydrological disequilibrium, which caused the formation of two Holocene terraces and a contemporaneous floodplain. The lower terrace was flooded and covered with sediments upon which the recent floodplain formed. During the Holocene, there were four periods during which large tree trunks were deposited in the fluvial sediments, indicating periods of extensive flooding. The supposition that these events were of more global scale is supported by the results of investigations made on the Holocene floodplains of other regions.

INTRODUCTION

We studied the structure and development of the Holocene floodplain of the Labe River in selected sections of the upper and middle courses of the river in the territory of the Czech Republic (Fig. 1). We focused on the sedimentology and stratigraphy of the Holocene deposits of this floodplain and determined the sedimentary chronology in archaeological studies using radiocarbon dating. We found that the terrace structure of the Holocene floodplain formed by repeated erosion and aggradation. At intervals during the periods of sedimentation, tree trunks were deposited, indicating periods of increased flooding. Human settlement also affected the evolution of the Holocene floodplain. Wood samples were taken from carbonized oak trunks that were found in fluvial sediments of the Labe River under the water level.

METHODS

Radiocarbon Dating

We dated wood samples in the Radiocarbon Laboratory of the Department of Hydrogeology and Engineering Geology, Charles University, Prague. The dating methods used in this laboratory were described previously (Šilar and Tykva 1991). The samples received the standard acid-base-acid (ABA) treatment and were ^{14}C-measured by CO_2 proportional counting. Table 1 summarizes the measurements of 23 samples collected over a period of several years.

Results are reported in ^{14}C years before present (BP) with 1-σ standard deviation and calculated using the convention of Stuiver and Polach (1977). The ^{14}C ages were also dendrochronologically corrected using the CALIB 3.0 program (Stuiver and Reimer 1993). The standard deviations of the corrected ages result from those of the ^{14}C ages and of the calibration curve. The corrected ages are reported in 1- and 2-σ standard deviations.

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TABLE I. Results of Radiocarbon Dating Wood Samples from Holocene Sediments of the Labe River

Sample locations	Sample no.	^{14}C age (yr BP)	Range of calibrated ages (yr BP) 1 σ	2 σ	References
Špindlerův Mlýn	CU-1043	370 ± 120	517 (460, 340) 291	631 (460, 340) 0*	Stuiver and Pearson (1993); Růžičková, Šilar and Zeman (1993)
	CU-1044	180 ± 120	310 (270, 180, 150, 10, 0) 0*	499 (270, 180, 150, 10, 0) 0*	Stuiver and Pearson (1993); Růžičková, Šilar and Zeman (1993)
Sandberg	CU-1155	6170 ± 150	7214 (7142, 7135, 7079, 7078, 7021) 6861	7382 (7142, 7135, 7079, 7078, 7021) 6677	Stuiver and Pearson (1993)
	CU-1154	8940 ± 190	10039 (9944) 9658	10302 (9944) 9490	Kromer and Becker (1993)
	CU-1151	4800 ± 140	5656 (5581, 5501, 5498) 5324	5890 (5581, 5501, 5498) 5074	Stuiver and Pearson (1993)
Lžovice	CU-1156	540 ± 110	646 (541) 502	672 (541) 316	Stuiver and Pearson (1993)
Hradištko	CU-1010	3040 ± 150	3380 (3240, 3220) 2986	3561 (3240, 3220) 2808	Pearson and Stuiver (1993)
	CU-1023	1160 ± 120	1228 (1060) 937	1296 (1060) 789	Stuiver and Pearson (1993)
	CU-1026	3670 ± 140	4220 (3980, 3940) 3738	4410 (3980, 3940) 3780	Pearson and Stuiver (1993)
	CU-1022	3870 ± 140	4502 (4270) 4001	4809 (4270) 3867	Pearson and Stuiver (1993)
Kluk	CU-986	4410 ± 160	5298 (4980) 4834	5562 (4980) 4561	Stuiver and Pearson (1993); Růžičková, Šilar and Zeman (1993)
	CU-987	1700 ± 140	1734 (1570) 1412	1922 (1570) 1305	Stuiver and Pearson (1993); Růžičková, Šilar and Zeman (1993)
	CU-1040	3800 ± 150	4412 (4150) 3931	4566 (4150) 3726	Pearson and Stuiver (1993); Růžičková, Šilar and Zeman (1993)
	CU-1041	1620 ± 130	1692 (1520) 1349	1824 (1520) 1284	Stuiver and Pearson (1993); Růžičková, Šilar and Zeman (1993)
	CU-1070	2240 ± 140	2353 (2310, 2230, 2210) 2053	2716 (2310, 2230, 2210) 1884	Stuiver and Pearson (1993); Růžičková, Šilar and Zeman (1993)
	CU-1074	3520 ± 150	3982 (3830, 3790, 3770, 3750, 3740) 3624	4228 (3830, 3790, 3770, 3750, 3740) 3410	Pearson and Stuiver (1993); Růžičková, Šilar and Zeman (1993)
	CU-1075	3580 ± 150	4083 (3860) 3650	4282 (3860) 3472	Pearson and Stuiver (1993); Růžičková, Šilar and Zeman (1993)
Ostrá	CU-988	9390 ± 240	10,890 (10,370) 10,042	11,000 (10,370) 9914	Kromer and Becker (1993)
	CU-1042	8530 ± 220	9821 (9490) 9267	9969 (9490) 8987	Pearson, Becker and Qua (1993); Linick *et al.* (1986)
Borek	CU-1079	1670 ± 130	1712 (1540) 1404	1872 (1540) 1297	Stuiver and Pearson (1993)
Tišice	CU-1153	7510 ± 170	8414 (8319) 8123	8567 (8319) 7937	Pearson, Becker and Qua (1993); Linick *et al.* (1986)
	CU-1152	5920 ± 150	6895 (6739) 6548	7163 (6739) 6407	Stuiver and Pearson (1993)

*0 represents a "negative" age BP.

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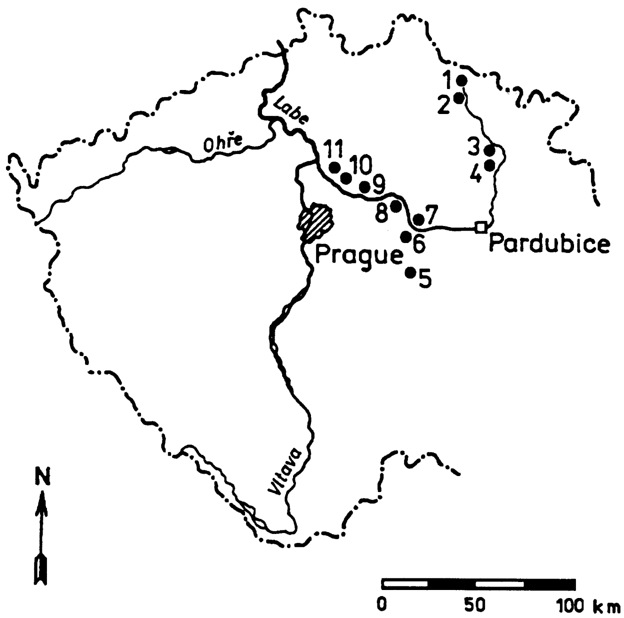

Fig. 1. Site locations: 1. Špindlerův Mlýn; 2. Vrchlabí; 3. Hostinné; 4. Debrné; 5. Bylany; 6. Sandberg and Lžovice; 7. Hradištko; 8. Kluk; 9. Ostrá; 10. Borek; 11. Tišice

Sedimentological Research

Three natural levels can be distinguished in the Holocene floodplain of the upper and middle courses of the Labe River: two floodplain terraces (higher and lower) and the recent floodplain (Fig. 2). The two floodplain terraces are not consistently developed along the whole course because of local conditions (*e.g.,* there is an antecedent valley at Kuks). The three levels provide evidence for the existence of three periods when the river reached a graded profile, *i.e.,* the sediments were neither eroding nor accumulating. Changes were usually sudden and resulted in a considerable increase of sedimentary discharge.

The recent floodplain level developed during sweeping floods in the Little Ice Age, at their highest frequency during the Middle Ages, connected with cooling and increased precipitation during cold climatic fluctuations. The higher floodplain terrace lies 4 m above the present river level and is a remnant of an early Holocene floodplain. It consists of early Holocene fluvial gravel and sand, and wind-blown sands. Remnants of river meanders are preserved on its surface. Underlying Pleistocene fluvial sandy gravels, characterized by pine woods occur in cores taken from these meanders.

The surface of this higher floodplain terrace is covered with layers of sand and silt. At Ostrá, we discovered a 40-cm-thick silt intercalation, but we have not determined its origin; it may represent weathered pyroclastic material. Findings of high concentrations of Nb (13–15 ppm), Y (28–46 ppm) and Zr (121–267 ppm) seem to support this assumption. These elements and their contents suggest low-alkali to alkali volcanism. Underlying Cretaceous marlstones (Nb <7 ppm, Y 9 ppm, Zr 92 ppm), and Quaternary fluvial sediments (Nb <7 ppm, Y <7 ppm, Zr 21 ppm) show considerably lower concentrations of these elements.

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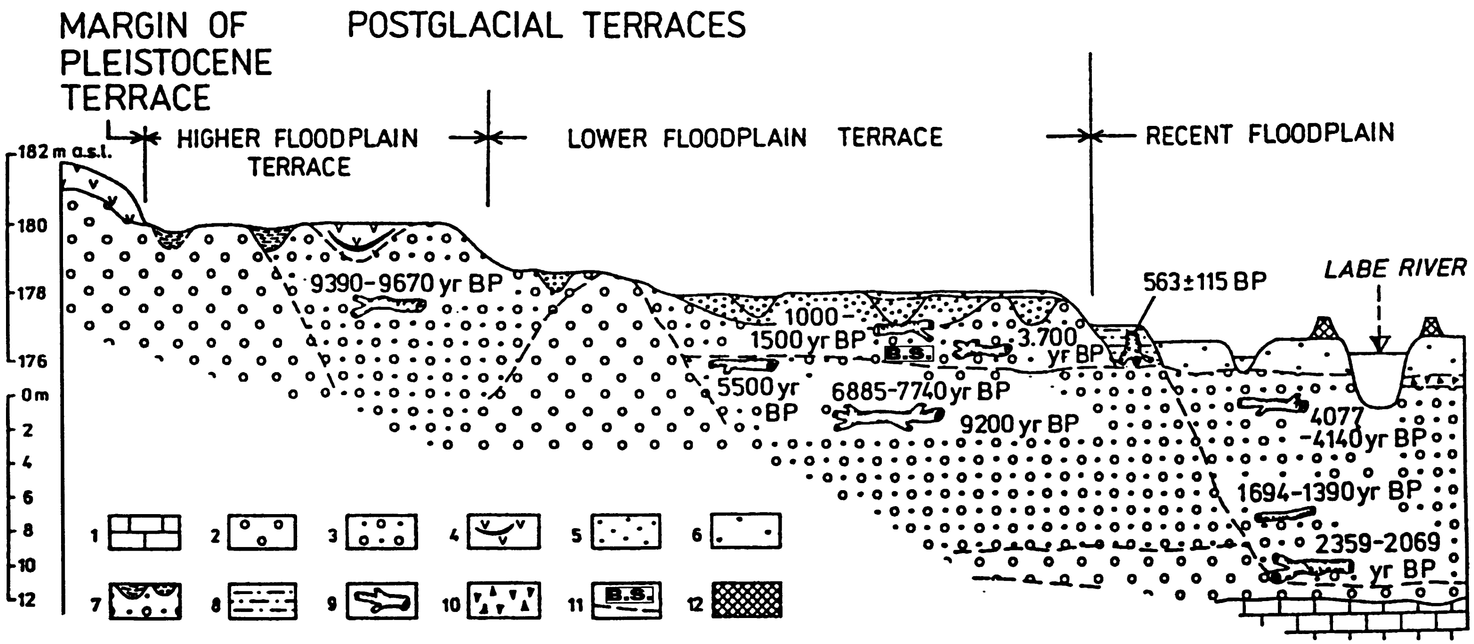

Fig. 2. Schematic geological section of the floodplain in the middle course of the Labe River. Key to symbols: 1. Upper Cretaceous marlstone; 2. fluvial sandy gravel of the Upper Pleistocene; 3. Holocene fluvial sand with admixture of gravel; 4. wind-blown sand, locally with an interlayer of volcanic (?) material (marked at Ostrá with a black crescent); 5. fluvial loams with brown soils on the surface; 6. fluvial loams ("flood loams"); 7. deposits filling up oxbow lakes (loams and sands); 8. medium-grained fluvial sand with admixture of gravel; 9. trunks; 10. admixture of fragments of bricks; 11. presumed geological boundary, B.S. = buried surface; 12. flood dikes. (To emphasize the vertical differences in surface morphology, the scale above the mean Labe River water level is doubled in comparison to the geological section below water level.)

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The lower Labe River floodplain terrace represents a remnant terrace from the end of the archaeological "fortified settlement" age. The surface of this terrace lies 2.5–3.0 m above the present river level. It consists of fluvial sands with an admixture of gravel and fluvial sandy loams that cover the majority of this terrace and that fill depressions of abandoned meanders. This level was studied at Sandberg and Hradištko (Fig. 1). Archaeological findings are known on the remnant terrace at Hradištko.

The recent floodplain is the narrowest, compared to the others, reaching only 0.2–0.25 the width of the lower floodplain terrace. This annually flooded area is covered with fluvial "flood loams" and numerous oxbow lakes connected with the river. The present Labe River valley has been made navigable mostly at the level of the recent floodplain by straightening the river course, thereby cutting off numerous meanders from the river system. The new riverbed can be described as a navigable canal with perfectly paved river banks. The origin of this recent floodplain is linked with an abrupt climate change at the onset of the Little Ice Age.

Results

We summarize below the main stages of the development of the Holocene Labe River floodplain (the chronology is indicated in calibrated years BP for the period prior to AD 0 as usual in Quaternary geology, and in calibrated years AD for the subsequent period, as usual in archaeology).

10,000–9500 cal BP

Erosion of the Pleistocene sandy gravels from the last glacial; accumulation of sediments of the upper floodplain level; occurrence of oak forests on the surface of the floodplain.

9500–9000 cal BP

Successively: sedimentation of a layer containing tree trunks (see Table 1, Ostrá samples); isolated occurrence of Pleistocene fluvial sediments in meander cores, occasionally with Mesolithic settlements; eolian activity; deposition of volcanogenic material; wind-blown sands.

~8000 cal BP

Disruption of the graded profile; fluvial erosion, formation of the upper floodplain terrace as a morphological level; formation of the base of deposits of the lower floodplain terrace.

7700–6900 cal BP

Second layer with trunks; redeposition of older sediments including subfossil trunks from the upper floodplain terrace and deposition of younger trunks, accumulation of fluvial sands and gravels of the lower floodplain terrace.

~5500 cal BP

Third layer with trunks; the river system reaches an equilibrium and begins to meander; deposition of organic material in oxbow lakes; onset of Neolithic settlement continuing to the Bronze Age (Dreslerová 1994); trunks with traces of cutting at the Kluk site (Fig. 1).

~3700 cal BP

Fourth layer with trunks; destruction of river equilibrium; sudden renewal of sedimentation of gravels and sands; fluvial sands and gravels overlie the previous surface.

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3500–3200 cal BP

Equilibrium is re-established; further river meandering; deposition of fluvial loams; brown soils develop on the surface of the floodplain in areas covered with floodplain forest.

~ AD 0

A new wave of settlement in the first centuries (the Roman period), and in the early Middle Ages.

AD 1150

Destruction of equilibrium; floods; settlements are abandoned again during the early Middle Ages; *ca.* 2-m erosion in some parts of the floodplain; the floodplain forest reappears.

AD 1250

Extensive floods and aggradation; floodplain forest partially buried by overbank deposits.

AD 1550–1700

Extensive floods caused by considerable cooling and humidification of climate; formation of the space for the recent floodplain; redeposition; sedimentation.

AD 1800–1900

Deposition of fluvial loams and sands; the river reaches equilibrium and meanders; in the late 19th century, the floodplain is resettled; large-scale construction on the surface of the recent floodplain; regulation of the river flow; bank protection; construction of locks and weirs; opening of new large sand pits.

CONCLUSION

Our investigation of the Holocene fluvial sediments of the Labe River suggests that several abrupt changes in temperature and precipitation occurred during the Holocene. These changes caused periods of hydrological disequilibrium that resulted in the formation of two Holocene terraces, and are marked by four intervals of tree-trunk deposition in the fluvial sediments. In central Europe, these intervals represent climatic catastrophes, and they may correlate with global events, as suggested by studies of Holocene floodplains in other regions (Schirmer 1980, 1983).

Our present knowledge thus indicates that the current Labe River valley is the result of abrupt, irregularly repeated climatic events that occurred over the past 10,000 yr. Will similar climatic changes take place in the future? It seems likely, but our present knowledge about the processes causing these changes does not allow us to predict them. In particular, we do not know how to separate the recent anthropogenic impacts from the climate-controlled hydrological changes.

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