Netherlands Journal of Geosciences / Geologie en Mijnbouw 81 (3-4): 407-416 (2002)

The evolution of river valleys in Lithuania from deglaciation to recent changes and data from the sediment infill of oxbow lakes

A. Gaigalas[1] & V. Dvareckas[2]

[1,2] Vilnius University, Faculty of Natural Sciences, Cziurlionio 21/27, 2009 Vilnius, Lithuania
[1] Corresponding author; e-mail: Algirdas.Gaigalas@gf.vu.lt

Manuscript received: January 2001; accepted: May 2002

Abstract

Generalized analysis of geological-geomorphological structures of river valleys in Lithuania has been carried-out. Lithuania's fluvial topography results from the retreat of the Scandinavian Nemunas (= Vistulian and/or Valdaian) Glaciation, as is shown by the study of geomorphological structures in the recent river valleys (representing the last 15,000 years), which were formed as the ice sheets progressively retreated and ice-barrier lakes were drained. Oxbows in the river valleys are most often located on the floodplain itself and on the first terrace above the floodplain. The oxbow lakes are subdivided into two groups: (1) formed in the near-river stage and (2) formed in the lake-bog stage. Separate development phases can be recognized within both groups of oxbow lakes. The more organic components of oxbow deposits provide specific information for palaeoecological reconstructions.

Anthropogenic changes to the natural landscapes of Lithuania have resulted in considerable geological transformation of rivers. Increased sediment volume, shallowing, silting and overgrowing of channels, lateral erosion of floodplains and the spread of ravine erosion on valley-side slopes are all phenomena characteristic of all the valleys in Lithuania. At present the natural components of river valleys and their ecosystems are being changed, mainly with negative consequences for humans.

Keywords: Lithuania, Last Glacial, deglaciation, Holocene, oxbow lakes, human impact

Introduction

Formation of river valleys in Lithuania resulted from the development of the Late Pleistocene Scandinavian ice sheet. River valleys in Lithuania are grouped into: (1) glacio-stadial, (2) glacio-stadial-phasial recession and (3) glacio-phasial oscillation valleys. Major river valleys were originally formed by Late Pleistocene outwash. The glacio-stadial river valleys were formed in this way during the Gruda (=Bologoe and/or Brandeburgian) and Baltija (=Vepsovo and/or Pomeranian) stadials of the Last or Nemunas (=Vistulian and/or Valdaian) Glaciation. The glacio-stadial-phasial valleys result from phased recession (fluctuation) of the Scandinavian last glacial ice sheet during the South-, Middle- and North-Lithuanian phases of the Baltija stadial Nemunas glaciation. The glacio-phasial-oscillation valleys were formed during small oscillations (fluctuations) of the ice sheet during the South-Lithuanian phase.

Ice-marginal valleys formed at the distal margins of the largest former ice sheets. An example of such a valley is found in eastern and southern Lithuania, now drained by the Rivers Zheimena, Neris, Vokê (left-bank tributary of the middle reaches of Neris river) and Merkys (Fig. 1). This is the beginning of the gigantic trans-European Shvenczioneliai-Vilnius-Warsaw-Berlin ice-marginal valley. Valleys of this type formed at the edges of stadial and phasial glaciers.

Subglacial meltwater flowing from under the lobes and tongues of ice formed a (periglacial) valley net-

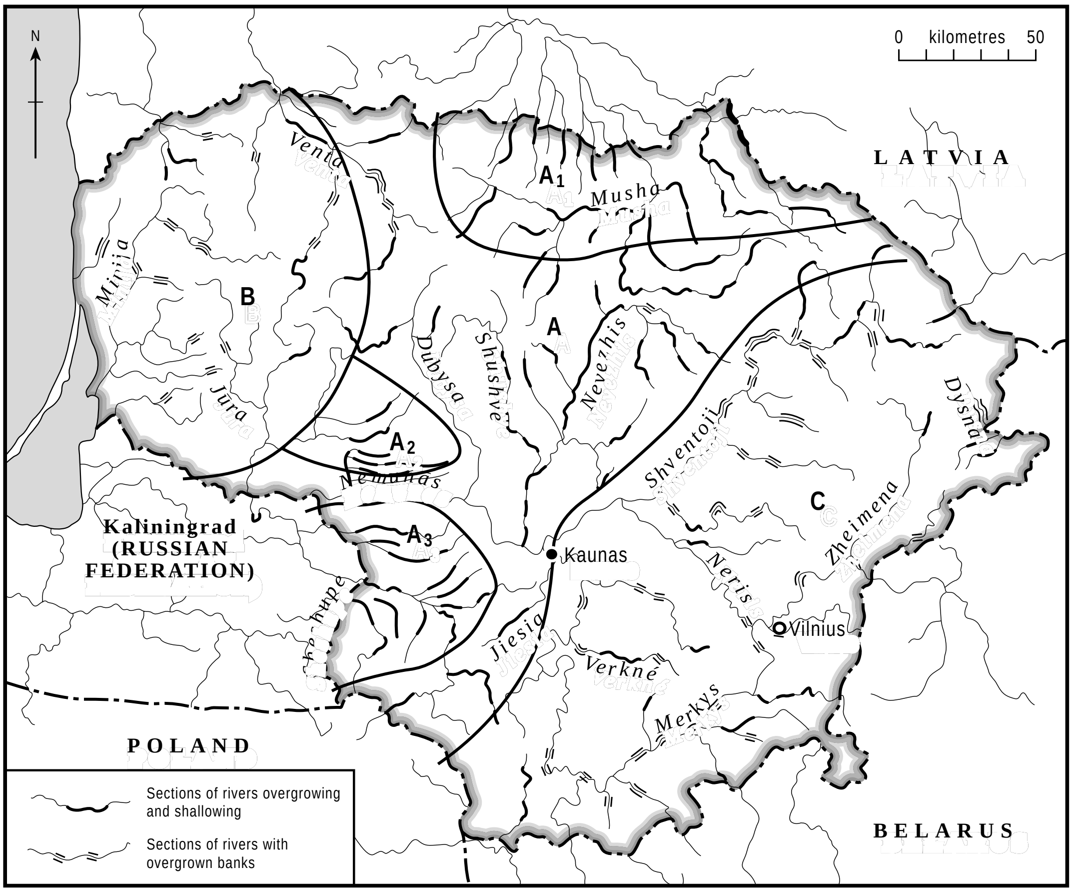
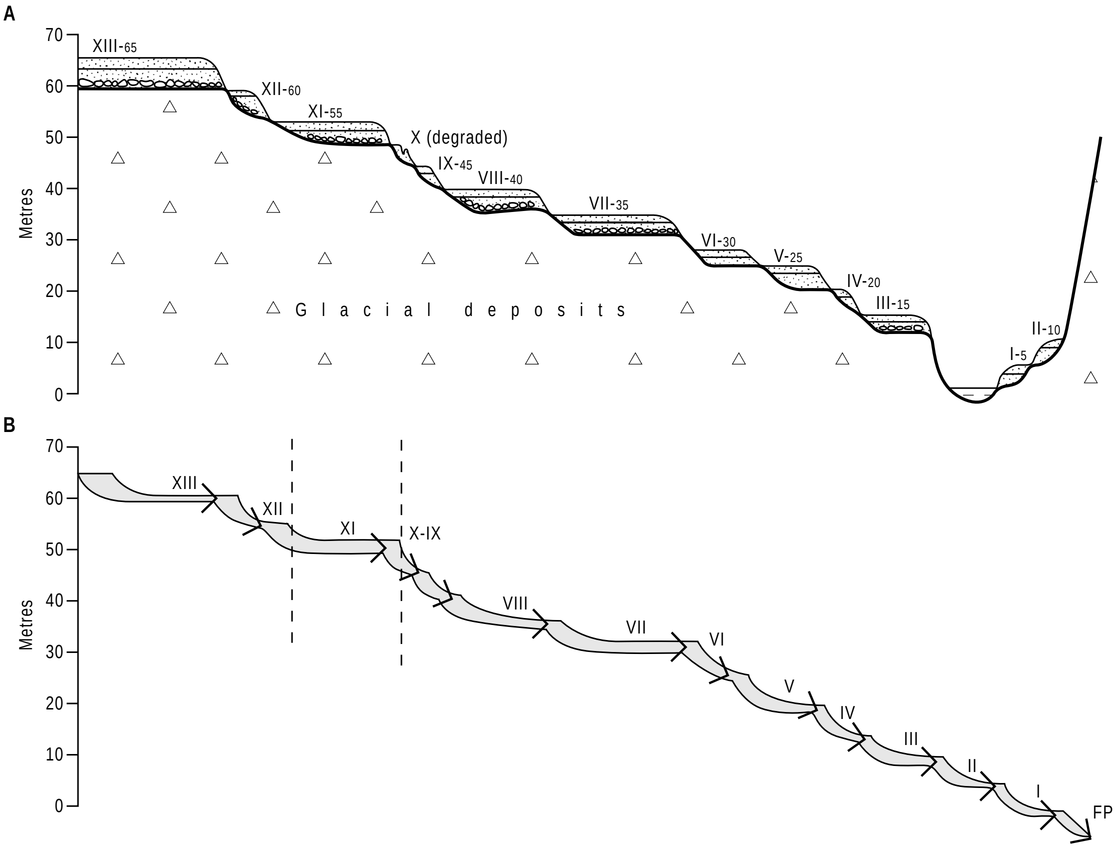


Fig. 1. The character and distribution of fluvial processes in Lithuania (according to Dvareckas & Beconis, 1987). A – plain region with spread of directed horizontal fluvial deformations and rivers under the most active human impact: A1 – Musha river, A2 – Mituva river, A3 – Sheshupe river. B – coastal region with development of periodic fluvial deformations. C – hilly region with limited evolution of horizontal and vertical fluvial deformations.

work perpendicular to the glacial margin. River valleys originating in this way are often related to the radial structure of ice sheets and radial features of glacial accumulative and erosional relief. During their formation, periglacial lakes acted as local erosional bases. When glacially overdeepened hollows became ice-free, internal radial valleys were formed.

Terrace formation

All terraces in river valleys have an erosional Pleistocene sediment base or (especially in North Lithuania) bedrock platform overlain by a single aggradational phase. Fluvial incision during deglaciation formed terrace steps with typical depths of overlying alluvium of 3-5 m. In the area of Lithuania the formation of the river network was determined by the conditions of the last ice sheet during deglaciation (Gaigalas & Dvareckas, 1987). It should be noted that the most ancient river valleys with the maximum number of terraces are located in SE Lithuania and were formed by the prefrontal and frontal parts of the Gruda (= Bolagoe and/or Brandenburgian) and Baltic (= Vepsovo and/or Pomeranian) ice sheets of the Nemunas Glaciation. The presence of 7-13 terraces above the floodplain is therefore characteristic of river valleys in southern Lithuania (Fig. 2). To the north and west, following ice-sheet retreat, the number of terraces in the river valleys decreases to 3 or 4. So the number of terraces provides an approximate indication of the age of river valleys. It should also be noted that the height of terrace bases increases northwards, with a corresponding decrease in their depth of sediments from 5 to 1 m. This is related to many factors, including the dynamics of deglaciation, stages and phases of ice-sheet degradation, climatic conditions, hydrology, distribution and drainage of periglacial lakes, neotectonic movements, fluctuations in water level of the Baltic Sea, lithological substratum and vegetation cover. To differentiate the socle (base) from alluvium, authors have used terrace spectrogrammes (Gaigalas & Dvareckas, 1987). Having implemented more detailed investigations of terrace spectrogrammas we can assert that: (1) the thickness of the alluvium layer of Lithuanian river terraces is normally about 3-5 m and not over 20 m as has so far



C

XIII	XII	XI	X - IX	VIII	VII	VI	V	IV	III	II	I	FLOOD PLAIN
Erosional - 'socle', single suite terraces												
Alluvium												
Glacial-fed					Saturated with loam particles		Saturated with clay particles		Limonite horizon		Humic	
Tundra vegetation (XIIc pollen zone)							*Betula - Pinus* (XIIb - XIIa pollen subzones)		*Pinus - Betula* (XI - X pollen zones)		Quercetum mixtum (X - I pollen zones)	
Full Glacial Oldest Dryas							Bölling-Older Dryas		Alleröd-Younger Dryas		Holocene	
Average particle size of alluvium in mm							5.291		4.133		3.431	
Sorting coefficient							0.678		0.694		0.723	
16000 years							13000		12000		10500	3000

Fig. 2. Schematic transverse section showing (A) the idealized structure of a typical Lithuanian valley, with terrace numbers and heights in metres, (B) curve showing palaeodynamic phases and (C) tabulated explanation.

been the common opinion; (2) 'socle' (erosional, with a Pleistocene base or a bedrock platform) and not accumulative terraces predominate; (3) terraces developed during dynamic phases of either vertical erosion (incision) followed by deposition of coarse but thin channel deposits (instrative) or of lateral erosion and associated deposition of both coarse-grained and fine-grained (perstrative) alluvium.

All terraces of fluvial valleys in Lithuania can be classified into five main groups (related to position within the staircase): (1) upper glacio-fluvial terraces and rudimental levels of periglacial lakes or outwash plains, (2) terraces (XIII-VI) of overspill valleys connecting lakes, (3) middle glacio-fluvial terraces (V-IV), (4) lower terraces (III-II), and (5) first terrace and floodplain.

Prior to the Holocene up to 11 fluvial terraces were formed, now preserved above the modern floodplain (Fig. 2). During the Holocene only the first terrace (3-5 m above the floodplain) and the floodplain itself were formed and the rudimental floodplain began to widen in some places. The first terrace, which is one of the most widely distributed (Dvareckas & Beconis, 1987), comprises mainly floodplain alluvium with loamy, highly humified sand. Channel alluvium (gravel) belonging to this terrace is well washed and sorted. The mean size of detrital material in the alluvium of the first terrace is 3.431 mm and its sorting coefficient is 0.723. The distribution of this terrace reveals numerous oxbow lakes, for example, along the rivers Shventoji, Zheimena and Minija (Fig. 1).

The various changes that took place during the Late Glacial and Holocene climatic cycle are reflected in the sediments and morphology of Terraces XIII-I and the floodplain. Processes of natural evolution in river valleys during the Late Glacial and Holocene are shown in Figure 3. The formation of periglacial alluvium, accumulation of the deposits of various dynamic phases and suspension currents took place in the cold arid climate of the glacial stage, when the periglacial terraces were formed. This is known as the glacial-fluvial or glacial cycle.

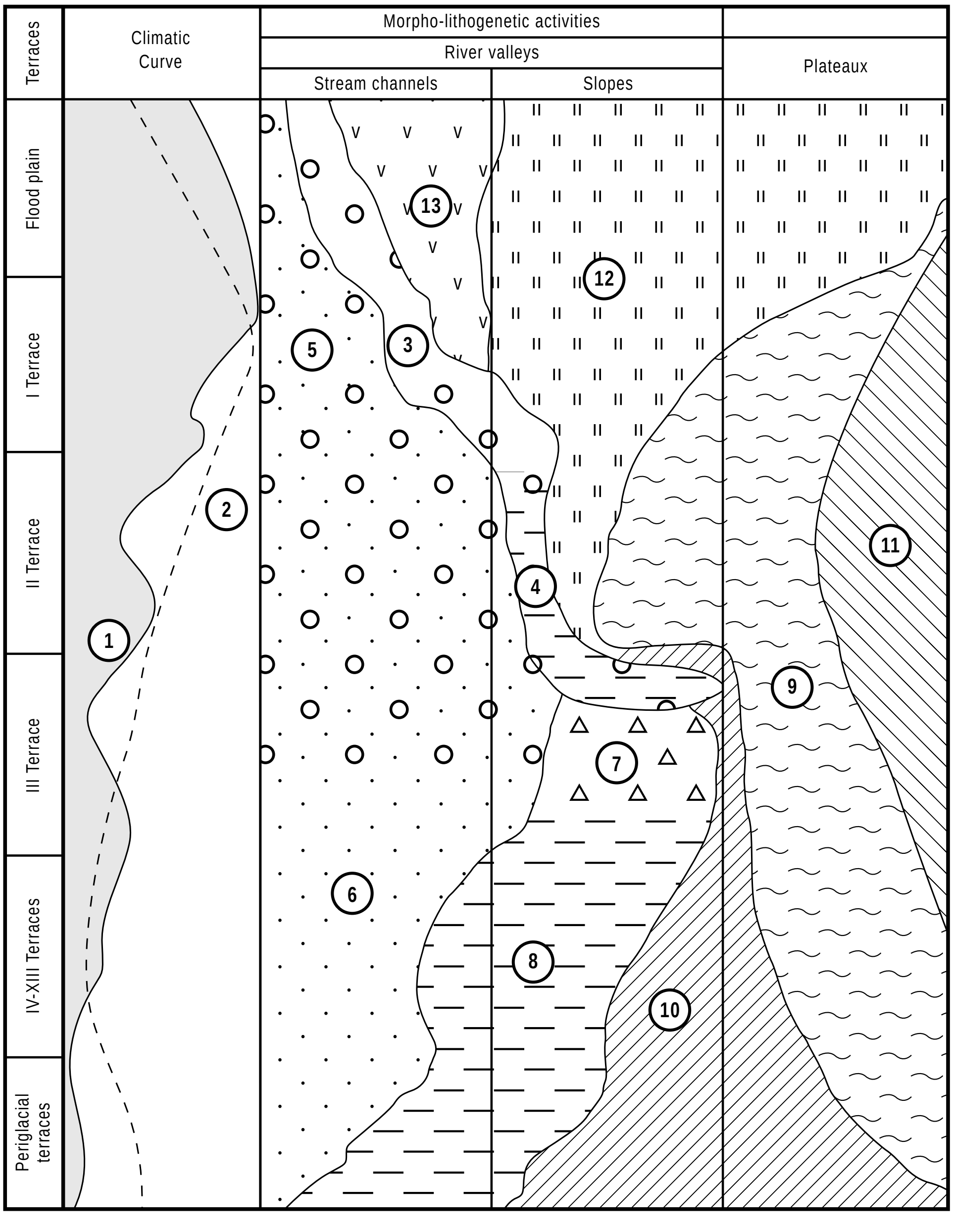


Fig. 3. Morphogenetic evolution of Lithuania in the Late Glacial and Holocene (After Gaigalas et al., 2001). 1 – temperature curve, 2 – curve of dampness, 3 – erosion of river valleys, 4 – erosion of slopes, 5 – aggradation of humid alluvium, 6 – aggradation of periglacial alluvium, 7 – solifluction, 8 – slopewash, 9 – aeolian processes, 10 – glacio-karst, 11 – superficial flow, 12 – soil genesis, 13 – bogging of oxbow lakes.

Accumulation from glacial outwash and avalanches, glaciolimnic sedimentation, aeolian processes, water erosion pebble and boulder pavement formation (basal horizon), suspension current and glacio-fluvial accumulation were typical for Terraces XIII-IV, formed in the cold semi-humid climate of the Oldest Dryas. These terraces (XIII-IV) are partly glacio-fluvial in origin. Activities related to permafrost, frost action, glacio-karst and thermo-karst, solifluction, slope processes, ravine formation, suspension current, episodic humification, aeolian processes and aggradation of humid (damp) climate alluvium and alluvial fan deposits were more important for Terrace III, which was formed in the Older Dryas – Bölling cold humid climate (cryohumid fluvial geomorphologic cycle).

The succeeding Alleröd –Younger Dryas warm humid climatic episode, when Terrace II was formed, resulted in solifluction, down-cutting and lateral erosion, aeolian processes, limonitization, episodic humification, and further aggradation of alluvium and alluvial fan deposits, representing the alluvial geomorphologic cycle.

The Holocene saw the increase of down-cutting and lateral erosion, aeolian processes, humification, soil formation, normal alluviation and 'balk-relief' (ravine and gully) formation. Terrace I was formed at this time in the normal alluvial geomorphologic cycle of temperate climate. The present river channel erosion and accumulation processes are closely connected with erosion of soils and ravines on the watershed area. The balance between these erosion processes stabilized in postglacial times.

Data from oxbow lakes

Special attention was paid to the fossil oxbow lakes in the river valleys of Lithuania and to the lake-bog deposits filling them. The more organic components of these deposits provide specific information for palaeoecological reconstruction, using palynological analyses and radiocarbon dating (Table 1). Oxbows in the river valleys are most often located on the floodplain itself and on the first terrace above the floodplain; Only rarely have they been observed on the higher terraces. They are usually crescent-shaped, but other configurations are also possible (Dvareckas, 1960).

Using studies of geomorphological processes, lithological composition of alluvium, vegetation, pollen analysis and radiocarbon dating, it has been possible to reconstruct the development of oxbow lakes in the valleys of the rivers Shventoji, Minija, Nevezhis, Zheimena, Neris and others of the Nemunas catchment and beyond (Gaigalas et al., 1987). These valleys have numerous oxbows, differing in both shape and origin, although most attention has been paid to those filled with alluvium and peat deposits. The oxbows are subdivided into two main groups based on sedimentation conditions (Fig. 4):

(1) those formed in the near-river stage; (2) those formed in the lake-bog stage.

Group 2 is further subdivided:

(2a) those in which the river channel moves away from the oxbow lake;

(2b) those in which the river channel moves towards the oxbow lake.

Both groups of oxbows show the following phases of development (Fig. 4):

(1) erosion; (2) transition from erosion to accumulation; (3) lacustrine;

(4) transitional from lake to bog; (5) bog;

Deposits formed during these phases have been identified from their structure and stratigraphy.

Group 1 oxbow lakes are characterized by sand and loamy sand deposits and, in particular, mineralized peat deposits without detrital sapropel. During the first phase of development (Fig. 4), both ends of the oxbow lake depression were still open. During the second phase only the lower end of the lake remained open, whereas the higher end was being filled with sand, i.e. it was gradually being cut off. During the third phase the higher end was completely closed with sand and loamy sand, whereas the lower end remained open. During the fourth phase the lower part of the oxbow lake depression was finally separated from the river channel and the lake was being filled with stagnant-water facies. During the fifth phase of development, the oxbow lake depression was finally filled completely with peat and its surface overgrown with trees, including alders and willows, and grass. Oxbow lakes of the first group are those retaining a good hydrological connection with the river, especially during spring floods.

Group 2 oxbow lakes are notable for their rapid development. They differ greatly from the oxbows of the first group. In the course of development, they were more isolated and had a hydrological connection with the river only during high floods. In their lowest deposits, which usually contain detrital sapropel, the shells of the following molluscs are common: *Bithynia tentaculata*, *Valvata piscinalis*, and *Sphaerium corneum*. Other species such as *Planorbis planorbis*, *Valvata cristata*, *Segmantina nitida*, *Anisus contortus*, *Gyraulus* sp. and *Limnaea stagnalis* are markedly less numerous. These shells reveal warmer climatic conditions. Such oxbow lakes are cut into bedrock or higher terraces and are especially common in SE Lithuania. Their de-

Table 1. Dating of the sediments of alluvial terraces.

Site	Material	Radiocarbon dates
I. floodplain terrace (0.5-3 m)		
Manczagire	peat (upper layer sediments of oxbow lake of Ula river – left-bank tributary of Merkys river)	1520 ± 225 (Vs-1)
Manczagire	wood (lower layer sediments of floodplain of Ula river)	2895 ± 225 (Vs-2)
Smorgonys	wood (lower layer, floodplain of Neris river)	2270 ± 60 (Vs-53)
Petrashiunai	wood (oxbow lake of Disna river)	2810 ± 70 (Vs-51)
Giraitishkes	wood (oxbow lake of Nemunas river)	2170 ± 180 (Vs-59)
Pikelionys	wood (floodplain of Nemunas river)	2640 ± 160 (Vs-120)
Vilnius	wood (floodplain of Neris river)	1980 ± 120 (Vs-264)
II. First terrace above the floodplain (3-5 m)		
Pavariai	wood (terrace of Shventoji river)	4740 ± 90 (Vs-52A)
		5030 ± 100 (Vs-52B)
Valakampiai	wood (terrace of Neris river)	5800 ± 140 (Vs-162)
Valakampiai	wood (terrace of Neris river)	4900 ± 130 (Vs-163)
Valakampiai	wood (terrace of Neris river)	5690 ± 160 (Vs-164)
III. Second terrace above the floodplain (6-13m)		
Zervynos	wood (terrace of Ula river)	11310 ± 110 (Vs-42)
		11930 ± 110 (TA-124)
Zervynos	peat (oxbow lake sediments of Ula river)	13080 ± 250 (Vs-58)
		12160 ± 120 (TA-125)
		12650 ± 130 (TA-191)
Pamerkes	wood (lower layer sediments of oxbow lake of Merkys river)	11920 ± 160 (Vs-45)
		11730 ± 110 (TA-192A)
		11820 ± 110 (TA-192B)
		12200 ± 160 (Mo-340)
Pamerkes	peat (upper layer sediments of oxbow lake of Merkys river)	11500 ± 430 (Mo-341)
Manczagire	wood (upper layer sediments of oxbow lake of river Ula)	12100 ± 100 (Vs-46)
		11630 ± 120 (TA-138)
Manczagire	peat (upper layer sediments of oxbow lake of Ula river)	11930 ± 110 (TA-24)
Rudnia	wood (upper layer sediments of oxbow lake of river Ula)	11530 ± 110 (Vs-43)
		11530 ± 110 (TA-190)
		11970 ± 180 (U-675)
		12080 ± 460 (U-2107)
Rudnia	peat (upper layer sediments of oxbow lake of Ula river)	12715 ± 315 (Mo-339)
Vilnius	wood (from oxbow lake sediments of Neris river)	8070 ± 906 (Vs-223)
Pauosupe	wood (from alluvium of Uosupe river – right-bank tributary of Ula river)	8790 ± 90 (TA-189)
Gozha	wood and cone (upper layer sediments of oxbow lake of Nemunas river)	8500 ± 300 (Mo-34)
Gozha	detritus of vegetation from the oxbow lake sediments of Nemunas river	11050 ± 100 (Vib-41A)
		11080 ± 100 (Vib-41B)
		11060 ± 100 (Vib-41)
		10870 ± 100 (Tln-137)

velopment may relate to climatic fluctuations at 7, 12 and 21 years rhythms.

More complex oxbow lakes have been observed, especially in rivers draining glacigenic hollows. A very interesting process of carbonate formation has occurred in these hollows, as found, for example, in the valleys of the rivers Skroblas (left-bank tributary of the lower Merkys river), Ula (another left-bank tributary of the lower Merkys), Shventupis (tributary of the Jiesia river) and in the upper reaches of the Zheimena (Fig. 1). These carbonate beds share certain characteristics: a chemical origin and pelitomorphic (pelitic) texture. The subglacially excavated valleys were partitioned by end-moraine ridges: from as few as 3-5 to as many as 10 barriers. Between morainic barriers there are small local lake basins, filled with carbonates, sand and peat. For instance, such carbonate deposits lie above the Pleistocene sediment base surface of the 3rd terrace, with its relative height reaching 13.0 m. There are three carbonate horizons with numerous freshwater molluscs.

Radiocarbon dating and palynology

Radiocarbon dating of oxbow lake deposits makes it possible to trace the main geochronological bound-

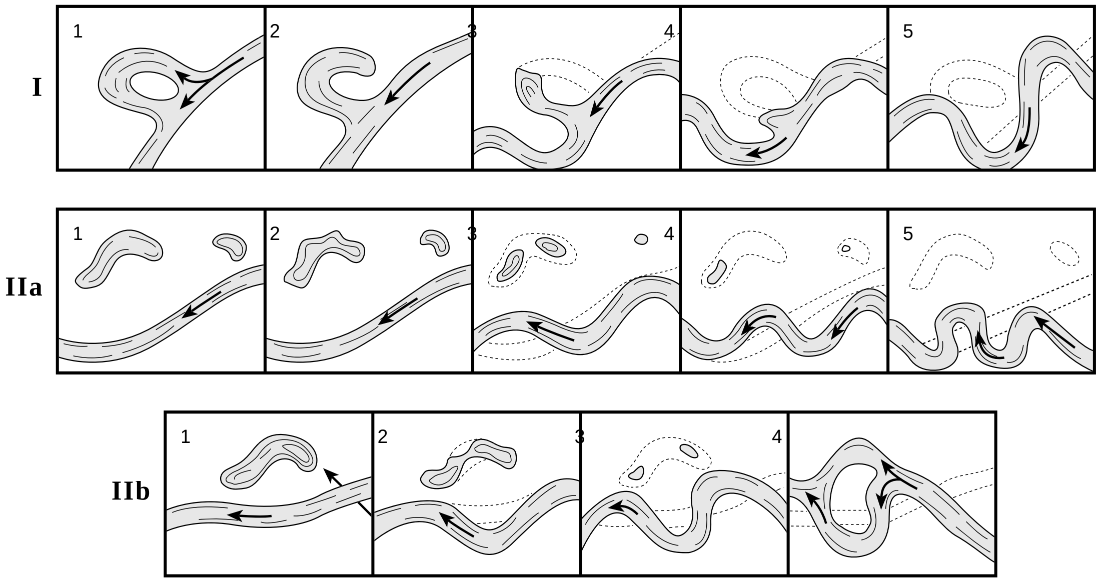


Fig. 4. Development phases for most oxbow lakes in the river valleys of the Nemunas catchment: I – the first group of oxbow lakes (formed in the near–river stage), II – the second group of oxbow lakes (formed in the lake-bog stage): first subgroup (a) – the river channel moves away from the oxbow lake, second subgroup (b) – the river channel moves towards oxbow lake; 1-5 – separate phases.

aries of the sedimentation in the lakes situated on the terraces and flood plains of river valleys (Table 1).

Pollen analyses and radiocarbon dating enabled us to distinguish three complexes of Holocene oxbow lake-bog deposits: the lower (pollen zones IX – VII) – 10,000-8,000 BP, the middle (pollen zones VI – IV) – 8,000-4,300 BP and the upper (pollen zones III – I) – 4,300 BP to present (Table 2).

Table 2. Stratigraphic subdivision of Lithuanian Late Glacial and Holocene oxbow lake deposits according to Gaigalas & Dvareckas, 2001 (using Kabailienė, 1998).

Date of boundaries 10^3 y ^{BP}	Stage		Chronozone	Pollen assemblage zone (PAZ)	Pollen zones (L. von Post)	Oxbow lake sediments
	HOLOCENE		SUBATLANTIC	*Pinus-Betula-*Cerealea	I	Peat
1				*Picea 2* (second max.)	II	
2,5				*Picea-Alnus*		
			SUBBOREAL	*Betula-Pinus 2*	III	Loamly sand and peat
4				*Picea 1* (first max.)	IV	
5				*Alnus-Picea*		
6,7			ATLANTIC	*Tilia-Ulmus-*Quercus	V	Sapropel
8				*Alnus-Ulmus*	VI	
8,1			BOREAL	*Pinus-Corylus*	VII	Loamly sand, silt and sand
9				*Pinus 2*	VIII	
10			PREBOREAL	*Betula*	IX	Loamly sand
10,9	PLEISTOCENE	LATE GLACIAL	YOUNGER DRYAS	*Artemisia-Betula*	X	Varved clay, silt and sand
			ALLERÖD	*Pinus 1*	XI	Peat, varved loamly sand
11,9				*Betula-Pinus 1*		
12,3			OLDER DRYAS	Poaceae-*Artemisia-Betula*	XII	Varved clay, silt and sand
			BÖLLING	*Betula-Pinus* – Poaceae		Peat, varved clay, silt, sand

Deposits of the lower complex were formed mainly in Group I oxbow lakes, with a good connection with the river retained (see above). Such deposits consist of sand and loamy sand and, in particular, mineralized peat. There is no detrital sapropel here. The climate was still cool.

Deposits of the middle complex were formed in oxbows that were mainly fed by unconfined groundwater and formed during the climatic optimum, when broad-leaved tree species (oak, hornbean, hazel, lime, alder etc.) prevailed (Table 2). Dark oak-wood remains are found in the alluvium of oxbow lakes situated on the first terrace above the flood plain of the River Shventoji. High discharge and rich vegetation led to increased formation of meanders, controlled mainly by the interactions of gradient, discharge and sediment load.

During the Atlantic period the development of river channels and the formation of alluvial deposits were considerably influenced by vegetation. This gave rise to free meandering of rivers. Due to the resultant lateral migration of channels, valley bottoms were considerably widened. From this time until the intensification of human influences on the natural landscapes, which extended over several millennia, there were no noticeable changes in the valleys**,** except in the river channels themselves, the development of which took place under the conditions of equilibrium between sediment discharge and transport capacity. Due to extensive woodland development, sediment run-off was insignificant and processes of subsurface erosion prevailed.

The analysis of seven spore-pollen diagrams from the ancient riverbeds of the Shventoji and other valleys revealed certain common features. Tree pollen predominates in all diagrams, especially pine (*Pinus*) and alder (*Alnus*). Fir (*Picea*) was widespread in the initial phases of accumulation and is represented by a curve with two maxima, which correspond to the 4th and 2nd zones of forest development according to L. von Post. The first fir (*Picea*) peak (4th zone) corresponds to the beginning of the Subboreal period, the second to the early Subatlantic. Deciduous trees are represented mainly by lime (*Tilia*), followed by evenly distributed elm (*Ulmus*) and oak (*Quercus*), which gradually decrease with time, as well as birch (*Betula*) and hazel (*Corylus)*. Some differences between spore-pollen diagrams relate to river meandering, lithological composition and other edaphic factors rather than to climatic fluctuations.

The analysis of the alluvium of the Shventoji and other rivers shows that sand and sandy soil of the near-river stage and detrital sapropel of the lake stage were formed in the Atlantic and Subboreal periods. Grey coloured oak trunks characterize the Atlantic period. The peats of the bog stage were formed in the late Subboreal and Subatlantic periods.

At the end of the Subatlantic period, due to the mass devastation of the forest, the hydrological processes of the rivers had changed. Spring floods had become more sudden, so that the deposits of old riverbeds were covered with floodplain sands.

Oxbow lakes with deposits of the upper complex (pollen zones III – I) are filled with slightly mineralized peat and loamy sand. The deposits of these groundwater-fed oxbows have been investigated in detail in the environs of Vilnius City (Gaigalas, 1998). On the first terrace above the floodplain of the Neris River, oxbow lake deposits were formed during the second half of the Boreal; there are numerous radiocarbon dates (from 6,000 to 3,760 BP) obtained from sites in Vilnius. Oxbow lake deposits in the floodplains of Lithuanian rivers are considerably younger (from 3,000 to 270 BP) than those forming parts of terraces. Sometimes, in the lake-bog deposits, archaeological remains are found, which can be of considerable value when interpreting the results of palynological analysis and radiocarbon dating. At the confluence of the Vilnia (left-bank tributary of the Neris river) and the Neris (at the Lower Castle of Old Vilnius), about 60 radiocarbon dates (from several hundred years to 6,140 ± 210 BP) have been obtained, enabling reconstruction of the main development stages of the fossil lake. These complexes of lake-bog deposits have been found under the former armoury of the Lower Castle. The lower complex, represented by humic sand, lies beneath a peat bed. Wood remnants found in the lower complex are dated c. 4,000 BP. The middle complex comprises peat, which was formed, according to radiocarbon dating, at 3,000-2,000 BP. Radiocarbon ages of tree remains range from 4,840 ± 100 to 3,760 ± 90 BP. The upper complex of deposits can be traced over the peat bed with clearly differentiated archaeological layers. The earliest possible signals of an anthropogenic effect are dated to 5,410-4,895 BP (3rd millennium BC), with increasing activity and cereal cultivation at 5,000 BP (4th – 3rd millennia BC).

Human impact

Human impact on the environment is traced from 5,700 to 4,000 ^{14}C years BP (Middle Neolithic time) and during historical times (Kabailienė, 1999; Table 3). The signal from human activities about 5,500 BP was still weak. Although pre-agrarian human impact on the environment generally proves to be insignificant, local oxbow sediment disturbances and higher

Table 3. Correlation of farming history stages with chronozones and archeological periods (according to Seibutis & Savukynienê, 1998).

Chronozones	**Archaeological periods**	**Farming phases**
Subatlantic	Iron Age	Fallow agriculture (6) Flourishing rye cultivation (5) Subatlantic farming decline (4) Subboreal draught farming (3)
Subboreal	Bronze Age	
	Neolithic	Meadow pasture cattle rearing (2)
Atlantic	Mesolithic	Forest pasture cattle rearing (1)

nutrient concentration can be traced near old settlements. A three-phase development of agricultural activity in the Stone Age settlements of Lithuania is proposed by Rimantienė (1999): (1) cultivation of hemp by hunter-gatherers of the Middle Neolithic, (2) import of domesticated animals and cereals as an indication of difference and status, and (3) economic dependence on cereal cultivation and cattle breeding. Fluctuations in human influence on fluvial processes relate to agricultural land-use. An enormous increase in charcoal particles in oxbow sediments of the Usupys river (right-bank tributary of the Verknė river; Pikelionys section) between 1640 and 300 BC suggests that fire was used to clear forest for agriculture. Generally 6 phases of human impact may be distinguished (Table 3): (1) forest pasture cattle rearing, (2) meadow pasture cattle rearing, (3) Subboreal draught farming, (4) Subatlantic farming decline, (5) flourishing rye cultivation and (6) fallow agriculture.

An intensification of fluvial erosion-accumulation processes at the end of the first millennium AD is related to the expansion of agriculture. Felling and devastation of forests and land tillage caused widespread gully erosion and denudation of slopes. Erosion products considerably increased sediment run-off and promoted the rapid formation of various shallows in river channels. The dynamic state of many river beds shows a slight tendency towards aggradation with weak downcutting. Vertical and horizontal migration in the beds was restricted by the deposition of boulders and pebbles on the beds and by trees and shrubs growing on the banks of all the rivers. Mobile forms of bed-load prevailed; accumulation on the floodplain occurred mainly as a very low increase in the level of natural levees and scrolls (Beconis & Dvareckas, 1991). Against a background of anthropogenization of natural landscapes in Lithuania, transformation of morpholithogenetic processes thus took place.

Recent river networks in Lithuania are divided into several regional groups (Fig. 1), according to differences in sediment input and transportation, as well as the development of channel migrations. The rivers most affected by human impact are located on the plains, where silting, choking with vegetation and channel degradation are severe now and are expected to worsen in the future, e.g. the horizontal migration rate is increasing from 0.1 to 1.5 m/ year (Gaigalas et al., 1991).

With increasing human impacts during the last few decades, the character and trend of bed processes have changed greatly. Due to increased sediment input from the catchment, river channel depths have declined and the formation of stable sand ridges, shoals and shallows has begun. Characteristic outcomes are an increase in channel sedimentation and, even more seriously, of gully erosion on slopes. In areas of intensive agriculture, the silting up of rivers has accelerated, causing the spread of wetland vegetation and also nutrients. As river beds become shallower and overgrown, lateral erosion leads to the increase in their sinuosity. During recent years, the extent of bank erosion along many rivers (the Shventoji, Nevezhis, Zheimena, Sheshupe, Minija and others) has increased by 30-35 % from the time of Soviet agri-collectivization (from c.1953, after the death of Stalin). In the future, further complications are expected to appear in fluvial load transportation and related phenomena.

Conclusions

Fluvial forms within Lithuanian's topography are closely related to deglaciation, melting and retreat of the last (Scandinavian) ice cover. The first terrace of Holocene age is widespread and composed mainly of floodplain alluvium with loamy highly humified sand. Channel alluvium (gravel) belonging to this terrace is well washed and sorted. Valuable information comes from oxbow lakes, which are usually located on the floodplain or on the first terrace, and only in rare cases they are observed on the higher terraces. The oxbow lakes are subdivided into two groups, differing in sedimentation conditions, the first formed in the near-river stage and the second formed in the lake-bog stage. Further distinction within the second group depends upon whether the river channel migrated away from the oxbow lake or towards it. Separate development phases can be recognized within both groups of oxbow lakes. It has been found that the deposits in the lower part of oxbow lake infills (detrital sapropel) correspond to the Atlantic and Subboreal periods. In the warm climate of the Atlantic period the river beds were richly covered with plants which caused intense meandering of rivers.

Lithuania has recently experienced anthropogenic transformation of river beds. Shallowing and overgrowing of river channels is a process that cannot be prevented. Further complications are expected to appear in load transport of rivers and related spreading of lateral migration. Nowadays the natural components of the river valleys and their ecosystem are being changed thereby producing effects adverse to humanity.

Acknowledgements

We thank David Bridgland, Vicky Innes and the reviewers for improving our paper and the cartographers of Durham University for drafting electronic versions of the diagrams.

This research was partly supported by the Lithuanian State Science and Studies Foundation.

This paper contributes to IGCP 449 (Global Correlation of Late Cenozoic fluvial deposits)

References

Beconis, M. & Dvareckas, V., 1991. Geomorphological investigations of the bed and flood plain processes in the rivers of Lithuania. The geographical yearbook 27, Natural processes. Vilnius: 34-49 (in Lithuanian).

Dvareckas, V., 1960. Morphogenesis of the oxbow lakes in recent physycogeographical conditions. The geographical yearbook 3, Vilnius: 177-191 (in Lithuanian).

Dvareckas, V. & Beconis, M., 1987. Morphogenesis of river valleys in the Southern Peribaltic area and human impact on recent processes. Palaeohydrology of the temperate zone, I, Rivers and Lakes. Tallinn, "Valgus": 111-119.

Gaigalas, A., 1998. The evolution of the geological environment of the Castles Vilnius. PACT 54: 111-130.

Gaigalas, A., Dvareckas, V., Florek, V. & Beconis, M., 1991. Geomorphodynamic processes in the river valleys of Lithuania and Poland. The geographical yearbook 27, Natural processes. Vilnius: 34-43 (in Lithuanian).

Gaigalas, A. & Dvareckas, V., 1987. Geomorphological structure and development of river valleys during last Glaciation and Holocene in the South Peribaltic area. Palaeohydrology of the temperate zone, I, Rivers and Lakes. Tallinn, "Valgus": 99-110.

Gaigalas, A., Dvareckas, V. & Banys, J., 1987. Reconstruction of sedimentation conditions in the oxbow lakes of Lithuanian river valleys. Methods for the investigation of lake deposits: palaeoecological and palaeoclimatological aspects. Vilnius: 228-234.

Gaigalas, A., Dvareckas, V. & Karmaza, B., 2001. Surfacial flow. Stone age in South Lithuania. Vilnius: 114-122 (in Lithuanian).

Kabailienė, M., 1998. Vegetation history and climate changes in Lithuania during the Late Glacial and Holocene, according to Pollen and Diatom data. Pact 54. I-1, Belgium. Rixensart: 13-30.

Kabailienė, M., 1999. Geological development of, and human impact on the coastal area of the Southern Baltic, interpreted from Pollen and Diatom evidence. Pact 57. I-3. Belgium. Rixensart: 71-87.

Rimantiennė., R. 1999. Traces of agricultural activity in the Stone age settlements of Lithuania. Pact 57. III-1b. Belgium, Rixensart: 275-290.

Seibutis, A. & Savukynienė, N., 1998. A review of major turning points in the agricultural history of the area inhabited by the Baltic peoples, based on palynological, historical and linguistic data. Pact 54, I-4. Belgium, Rixensart: 50-59.