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TIMESCALE FOR CLIMATIC EVENTS OF SUBBOREAL/SUBATLANTIC TRANSITION RECORDED AT THE VALAKUPIAI SITE, LITHUANIA

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ABSTRACT. Oxbow lake deposits of the Neris River at the Valakupiai site in Vilnius (Lithuania) have been studied by different methods including radiocarbon dating. A timescale was attained for the development of the oxbow lake and climatic events recorded in the sediments. ^{14}C dates obtained for 24 samples cover the range 990–6500 BP (AD 580 to 5600 BC). Medieval human activity was found in the upper part of the sediments. Mollusk fauna found in the basal part of the terrace indicate contact between people living in the Baltic and the Black Sea basins. Mean rates were calculated for erosion of the river and for accumulation during the formation of the first terrace.

INTRODUCTION

This work presents the results of radiocarbon dating of samples collected at the Valakupiai site, near Vilnius in eastern Lithuania (54°43′58″N, 25°18′33″E; 98.5 m asl) (Figure 1). Special attention was paid to the remnant oxbow lake in the Neris River valley and to the lake-bog deposits filling it. Detailed study of the deposits delivered specific information that enabled paleoecological reconstruction of the site, as well as a description of the geochronological evolution of the oxbow lake and accompanying climatic events. One can recognize separate dynamic phases formed during the course of development of the oxbow lake. At the beginning (first phase), both ends of the oxbow lake ravine were open. During the second phase, only the lower end of the lake remained open while the higher end was gradually being filled with sand, i.e. it was gradually being cut off. During the third phase (end of development), the oxbow lake was completely enclosed with sand and silt. It was isolated from the river channel and had a hydrologic connection with the river only during high floods. The oxbow lake sequences are characterized by sand, loamy sand, and organic material, in particular, mineralized peat deposits. Oxbow lake sediments are located on the first terrace above the floodplain in the Valakupiai meander of the Neris River. Peat, wood remains, and other organic remains were recovered, some of which were used for ^{14}C dating. From the wood remains, 9 ^{14}C dates ranging from 5800 ± 140 to 4040 ± 65 BP (Gaigalas 2004) were obtained previously. The terrace itself was formed on Middle Pleistocene glacial till, on which lays a basal conglomerate comprising brown gravel. Above the floodplain and oxbow lake, sediments relatively rich in organics and plant remains were formed. The oxbow lake sediments were covered by thin, intercalated layers of humus and eolian sand, with soil on the top of terrace. Fossil mollusk shells were found on the basal conglomerate at depths of 3.9–4.1 m. They occurred in rare lenses of fine sand filling kettle-formed depressions in red-brown till loam. The basement of the terrace is formed of brown till loam, which is calcareous, hard, and monolithic, with pebble and gravel up to 15%. It resembles a natural optimal mixture of various-sized particles ranging from pelites to large psephites. A macroscopic view of the till clay shows that it resembles the Middle Pleistocene Medininkai glaciation till.

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Figure 1 Location of the Valakupiai site

INVESTIGATED SITE AND METHODS

The Valakupiai site oxbow sediments were investigated by different methods and dated by ^{14}C. Samples were collected from the first terrace above the floodplain of the Neris River. *Ancylus fluviatilis* dominates the identified molluskan fauna. The most common species are *Unio* sp., which favor stream water conditions. These, together with the forest species *Acicula polita* and *Arianta arbustorum*, indicate warmer climatic conditions during the Atlantic period. In general, the mollusk fauna is characteristic of the Baltic Sea drainage area. *Theodoxus fluviatilis* is an exotic mollusk and belongs to a typical Black Sea (Ponto-Caspian) drainage basin fauna. At the beginning of the Holocene and during the Eemian (Merkinė, Muravian) interglacial, *Th. fluviatilis* crossed the division line between the Black and Baltic seas (Sanko 1999). Hence, in the Holocene this species spread to Lithuania, as well as to the rivers of northern Europe, mainly due to migration of humans along river systems. The first appearance of *Th. fluviatilis* in the Baltic drainage area is therefore geochronologically significant. Samples of *Unio* sp. were collected because they are probably the most reliable material for ^{14}C dating. One ^{14}C date we obtained (6540 ± 55 BP) corresponds with calibrated ranges of 5610–5590 BC (0.8%) and 5560–5470 BC (67.4%).

The till loam of the Medininkai glaciation at the bottom of the first terrace above the floodplain currently lies above the Neris River water level, but in the river channel it lies below the water at about 3.5 m. In the Holocene, the Neris River incised into this till about 3–4 m, and an alluvial cover of about 4 m was formed. Mean rates of erosion of this river (about 6 cm per 100 yr) and the formation of the first terrace above the floodplain (to 6 cm per 100 yr) were of the same magnitude. This similarity shows the neotectonic stability of the investigated area. Sand particles washed away by the river during floods settled together with other fine particles from the floodplain and formed floodplain alluvium layers in the oxbow lake alluvium. The lower part of the fluvial sediments is rich in dark oak-wood remains.

The oxbow lake sediments in the Valakupiai section were formed in the near-river stage at the beginning of their evolution and in the lake-bog stage in the upper part of the section (Gaigalas and Dvareckas 2002). In the lower part of the section, we found an admixture of channel alluvium in the interlayers of floodplain alluvium. This admixture was brought in when there was a connection between the oxbow lake and the river. The upper part of the floodplain alluvium interlayers also contains eolian sand admixture. During spring floods in the closed oxbow lake, floodplain alluvium settled, while during the drier summer periods, wind-driven sand was brought in from the forming terrace surface, especially from the near-channel part of the terrace and river levels.

The Valakupiai section at the Neris River thus reflects the typical stages in oxbow lake development: 1) the near-channel stage, when a connection existed with the river; and 2) the lake development stage, when the lake basin separated from the channel was periodically flooded. The first-stage oxbow lake sediments in the Valakupiai outcrop are sandy. Sand deposits are white-washed and contain wood remains. Texture features are expressed by horizontal layering. Wood remains in the oxbow facies were brought in by the river stream through the junction channel.

The second (lake) stage of the oxbow is reflected in the studied Valakupiai section by rhythmic alternation of oxbow and floodplain alluvium lamina. The oxbow alluvium lamina contains humus and is dark in color, while the floodplain alluvium periodically deposited by floods is of a gray-yellowish color and has a different mineralogical composition. It also contains an admixture of eolian sand originating from wind erosion of the floodplain alluvium and brought in during summer droughts.

^{14}C dates were obtained on organic material collected in sections from the floodplain and oxbow lake sediments. Samples were collected from the outcrop. Twenty-four samples were dated (Table 1). All were carefully checked for the presence of contaminating material, and all the contaminants (e.g. younger rootlets) were removed prior to sample pretreatment. We used the standard acid-alkali-acid (AAA) pretreatment for all samples except the mollusks. The sample carbon was converted into CO_2, and all but 5 of the ^{14}C ages were obtained using gas proportional counter (GPC) systems operated in the Gliwice Radiocarbon Laboratory (Pazdur et al. 2000, 2003). Samples with different carbon contents were dated using different counters. Each ^{14}C date was calibrated using OxCal v 3.10 software (Bronk Ramsey 1995, 2001) and the IntCal04 calibration curve (Reimer et al. 2004) (Table 1, Figure 2). We did not apply any reservoir correction for the mollusk date; therefore, it may be treated as a maximum age.

RADIOCARBON DATING RESULTS

^{14}C dating results were used to build timescales for some of the climatic events recorded in the oxbow lake sediments. The dating of oxbow lake and floodplain sediments is a problematic subject, mainly due to the complexity of the dated material (Figure 3). These sediments comprise various components of different ages. Some of the problems in the ^{14}C dating of soil samples include the contamination by roots penetrating upper layers, the infiltration of organic matter dissolved in water, and the influence of microorganisms and soil fauna. All of these factors can result in younger than expected obtained ages (Nowaczyk and Pazdur 1990; Pessenda et al. 2001).

Different fractions of soil were dated separately. ^{14}C ages of organics (ORG) and residuum (NaOH RES) were significantly younger than the ages of humic fraction obtained by solution of the samples in NaOH. The humic fraction (NaOH SOL) is significantly older than the total sample materials. The data used in the construction of an age-depth model comprised calibrated ^{14}C ages (Figures 2 and 3). These cover the period from 3770 BC to AD 1260 (Table 1, Figures 2 and 3). This means that the accumulated terrace was formed over about 5000 yr.

To build the age-depth model for the Valakupiai sediments, we rejected all dates obtained for the NaOH SOL fraction and some samples that we think were redeposited (Figure 3). In Figure 3, each sample is represented by 4 perpendicular ticks. Two horizontal ticks represent sample thickness,

Table 1 ^{14}C dating results.

Depth (m)	Material	Dated fraction[a]	Lab nr[b]	Age ^{14}C (BP)	Calibrated age range (68.2%)	
0.65–0.60	Humus	NaOH SOL	Gd-12734 R	1170 ± 40	AD 770–900 AD 920–940	62.6% 5.6%
1.60–1.65	Organics with charcoal	ORG	Gd-17343	990 ± 240	AD 810–1260	68.2%
1.83–1.86	Humus	NaOH RES	Gd-16338	1350 ± 100	AD 580–780	68.2%
2.50–2.55	Organics with wood	ORG	Gd-12770 R	3570 ± 95	2040–1770 BC	68.2%
2.97–3.00	Organics and humus	ORG	Gd-15832	3220 ± 90	1610–1410 BC	68.2%
2.97–3.00	Organics and humus	NaOH SOL	Gd-12732 R	4660 ± 70	3620–3600 BC 3520–3360 BC	2.8% 65.4%
3.11–3.13	Organics and humus	ORG	Gd-30093	4780 ± 100	3660–3490 BC 3440–3370 BC	53.4% 14.8%
3.24–3.26	Wood remains	WR	Gd-15531	2845 ± 80	1130–900 BC	68,2%
3.31–3.33	Organics and humus	NaOH RES	Gd-12736 R	4610 ± 55	3520–3420 BC 3390–3330 BC 3210–3190 BC 3150–3140 BC	40.8% 22.2% 3.4% 1.8%
3.38–3.41	Wood remains	ORG	Gd-15529	3460 ± 65	1880–1730 BC 1720–1690 BC	58.7% 9.5%
3.38–3.41	Organics with wood	ORG	Gd-12739	3840 ± 60	2460–2370 BC 2350–2200 BC	15.7% 52.5%
3.47–3.48	Organics and humus	ORG	Gd-15835	3500 ± 90	1950–1730 BC 1720–1690 BC	63.1% 5.1%
3.47–3.48	Organics and humus	NaOH SOL	Gd-15776 R	4880 ± 75	3770–3630 BC 3560–3530 BC	61.3% 6.9%
3.56–3.58	Clay with organics and humus	ORG	Gd-12769	4190 ± 60	2890–2830 BC 2820–2670 BC	17.1% 51.1%
3.60–3.62	Organics and humus	NaOH RES	Gd-12773	3190 ± 60	1520–1400 BC	68.2%
3.60–3.62	Organics and humus	NaOH SOL	Gd-15779 R	4590 ± 90	3520–3420 BC 3390–3310 BC 3300–3260 BC 3240–3100 BC	20.1% 17.4% 2.9% 27.9%
3.63–3.68	Oak timber	W	Hv-2663	4040 ± 40	2620–2480 BC	68.2%
3.63–3.68	Oak timber	W	Gd-12538	4040 ± 65	2840–2810 BC 2670–2470 BC	4.4% 63.8%
3.63–3.68	Oak timber	W	Lu-5069 R	4190 ± 60	2890–2830 BC 2820–2670 BC	17.1% 51.1%
3.63–3.68	Oak timber	W	Gd-11720 R	4210 ± 50	2900–2850 BC 2820–2740 BC 2730–2690 BC	21.8% 34.4% 12.0%
3.95–4.01	Oak timber	W	Vs-164 R	5690 ± 160	4710–4360 BC	68.2%
3.95–4.01	Oak timber	W	Vs-163	4900 ± 130	3930–3870 BC 3810–3620 BC 3600–3520 BC	8.5% 46.3% 13.4%
3.95–4.01	Oak timber	W	Vs-162 R	5800 ± 140	4830–4810 BC 4800–4480 BC	1.6% 66.6%
3.95–4.01	Mollusk (*Unio*)	CARB	Gd-12818 R	6540 ± 55	5610–5590 BC 5560–5470 BC	0.8% 67.4%

[a]NaOH SOL – dated fraction soluble in NaOH; NaOH RES – dated residuals after NaOH treatment; ORG – dated organic material; WR – dated wood remains; W – dated wood; CARB – dated shell carbonate.
[b]R following the lab number means that this result was rejected for age-depth model construction (see text).

while distance between 2 vertical ticks delimits the probability distribution of the calibrated ^{14}C date for the sample (at ~68% confidence level). The age of the bottom part of the sediment should be rep-

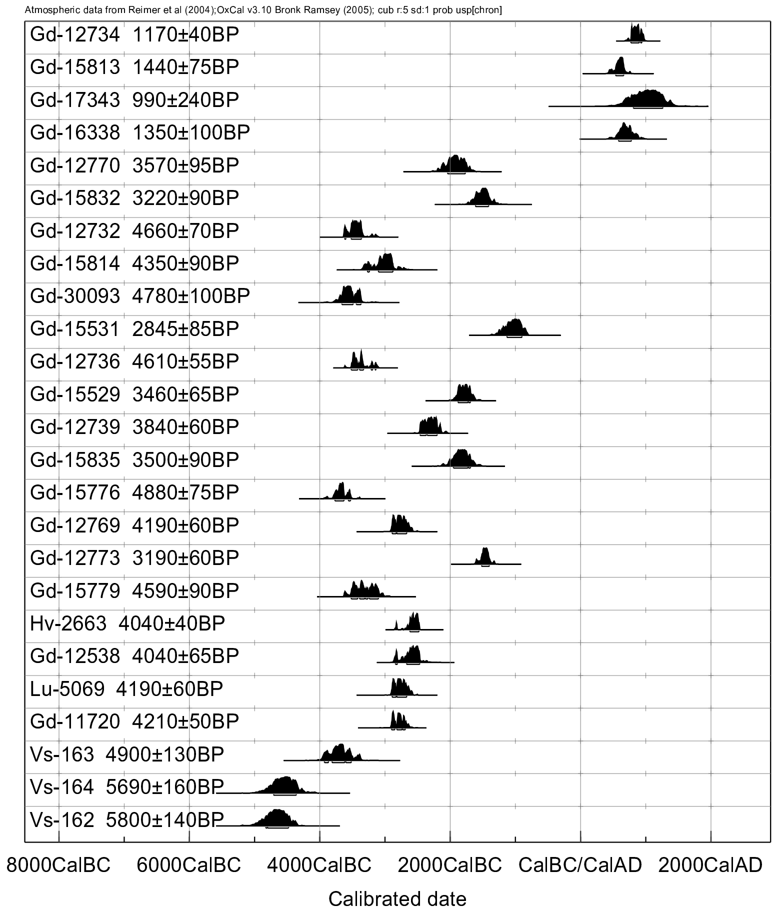

Figure 2 Calibrated ^{14}C dates obtained for organic samples. Probability density functions were obtained using OxCal v 3.10 software (Bronk Ramsey 1995, 2001) and the IntCal04 calibration curve (Reimer et al. 2004).

resented by the youngest date obtained for all oak timbers, given the uncertainties regarding inbuilt age; therefore, the older dates of oaks were not considered. After rejection, midpoint estimators of each calibrated date and corresponding sample depth were used for fitting a 3rd-order polynomial, building an approximate age-depth model. Because of the relatively large spread of data and the shapes of the obtained probability distributions of calibrated dates, there was no need to use a more sophisticated method to build the age-depth model in this case.

The approximate age-depth model enabled us to place climatic events that occurred in the Atlantic/Subboreal and Subboreal/Subatlantic transition zones on the timescale, based on the sediments that were archived in the Neris River oxbow lake (Table 2). The spread of calibrated ^{14}C dates (Figures 2 and 3) in the vertical section of the Valakupiai site above the first floodplain terrace reflects specific events in the development of the oxbow lake. The reverse chronology of the upper- and lower-occurring deposits (Figure 3) is related to the redeposition of older organic remains, mainly decaying wooden matter washout somewhere upstream, and then transported by water and introduced to the oxbow lake.

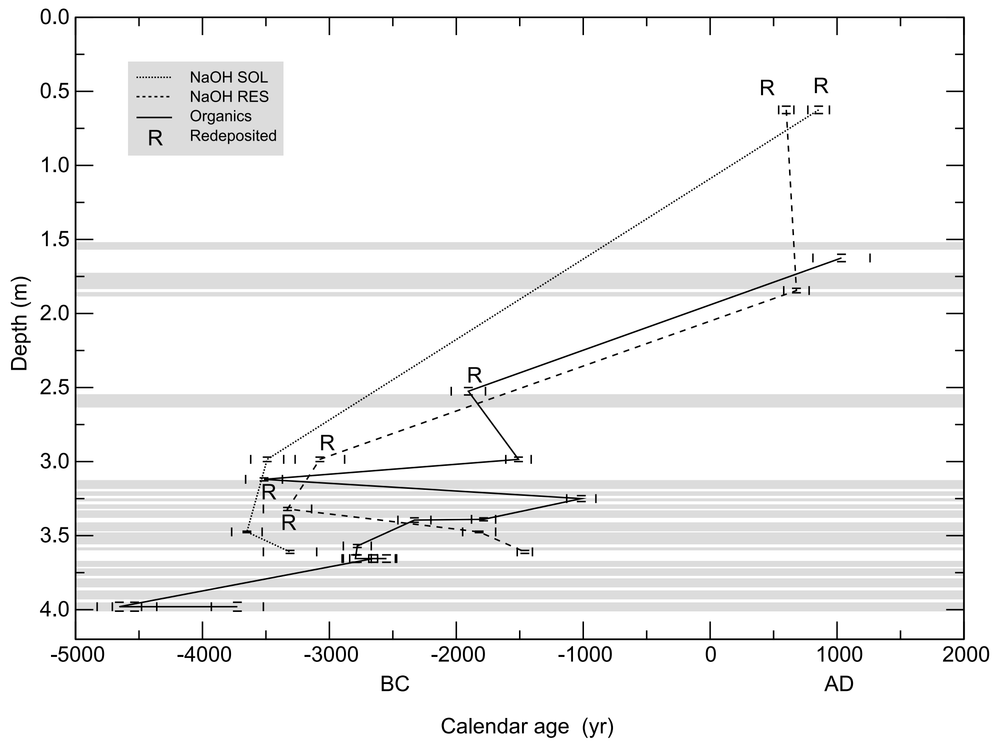

Figure 3 Age-depth graph for all ^{14}C-dated organic samples. Levels of 18 flood events are marked as gray bars. For each sample, the thickness of the dated layer is represented by the distance between horizontal ticks, and the 68% probability range of the calibrated dates is represented by the distance between vertical ticks (NaOH SOL = humic fraction; NaOH RES = humin fraction).

Organic matter from the deeper layer (1.60–1.65 m) containing charcoal shows a younger age than the upper humus material (Table 1, Figure 3). Particles of charcoal were probably transported from more shallow layers by human activity and/or by the soil fauna. Dark oak-wood trunks of the Atlantic climatic period were found at the bottom of the alluvial sequence. The oaks belong to the second part of the Atlantic period, and they were buried in the Subboreal as indicated by the ^{14}C dates (Table 1). The flood and oxbow lake deposits, which covered the buried oaks, were formed in the Subboreal and Subatlantic periods.

At the end of the warm Atlantic period and the transition to the Subboreal, the climate was getting cooler and unfavorable for broad-leaved trees, including oaks, which grew in the environs of Valakupiai. The thermophilic forests degraded and their fallen trunks were covered by the alluvium of the floodplain terrace and the oxbow lake sediments. The oak trunks were probably brought in by stream whirls and trapped in the oxbow lake. The connection with the river was cut off. The oxbow deposits settled unevenly in time (Figure 4). The section shows 18 identified flood events (Figures 3 and 4, Table 2), which were separated by oxbow lake sedimentation.

CHRONOLOGY OF CLIMATIC EVENTS

During the Atlantic period (about 3600 BC), thermophilic tree forests grew with a high population of oaks (Gaigalas et al. 1976, 1987). Boulder-pebble-gravel deposits were cemented by iron hydrox-

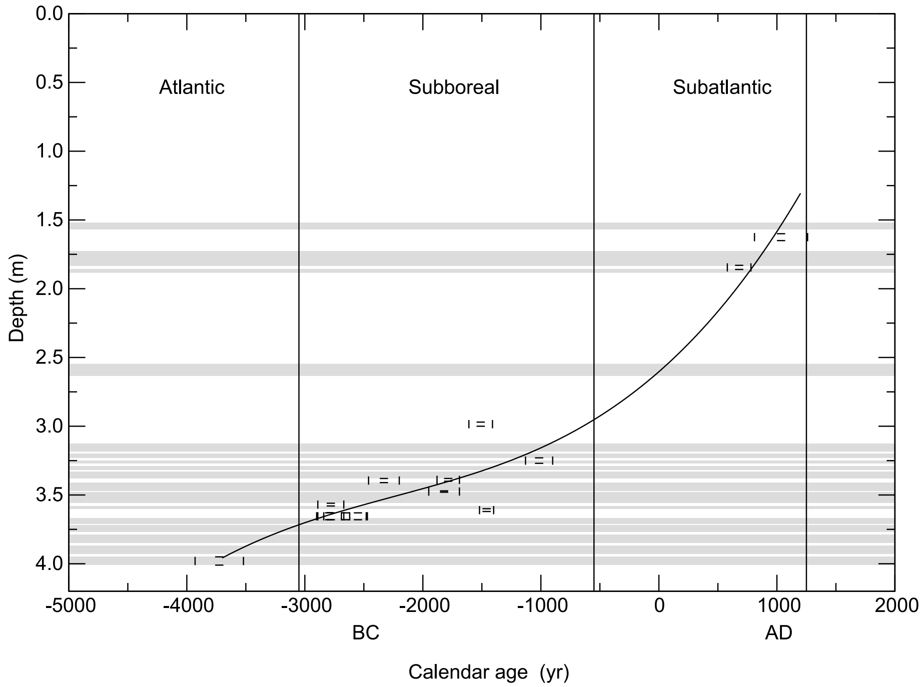

Figure 4 Age-depth model built using calibrated ^{14}C dates for the non-redeposited organic samples and interpolating numeric values by the 3rd-order polynomial. The age of the lowest level was determined by the youngest oak tree date. Levels of 18 identified flood events are marked as gray bars. For each sample, the thickness of the dated layer is represented by the distance between horizontal ticks, and the 68% probability range of the calibrated dates is represented by the distance between vertical ticks.

Table 2 Estimation of flood event chronology. Estimation is based on the age-depth model presented in Figure 4. Age ranges correspond to the depth range of the layer.

Depth of flood layers (m)	Estimated calendar age of flood
1.52–1.57	AD 1050–1010
1.73–1.83	AD 890–800
1.86–1.88	AD 780–760
2.55–2.63	AD 70–40 BC
3.13–3.18	930–1060 BC
3.20–3.23	1110–1200 BC
3.25–3.27	1260–1320 BC
3.29–3.31	1380–1450 BC
3.31–3.32	1450–1480 BC
3.33–3.38	1520–1700 BC
3.41–3.47	1820–2070 BC
3.48–3.56	2110–2450 BC
3.58–3.60	2540–2620 BC
3.67–3.71	2890–3030 BC
3.72–3.77	3060–3220 BC
3.79–3.85	3280–3440 BC
3.87–3.93	3490–3640 BC
3.95–4.01	3680–3810 BC

ide in the Neris River channel. Under warm climatic conditions, the mollusk fauna prospered (before ~3000 BC). During this period, there was contact between people inhabiting the Black and Baltic sea basins. Evidence of human presence has been found in the Neris River in above-floodplain terrace deposits formed in the period between AD 810–1260. At the end of the Atlantic and the beginning of the Subboreal period (~3000 BC), the climate cooled. Trunks of decaying oaks were trapped in an oxbow (3350–2640 BC) that had a connection with the Neris River channel (2640–1890 BC). The oxbow lake separated from the river at the end of the drier Subboreal (after 1890 BC). The drier climate conditions are also reflected by the reduction of spruce (2000–1000 BC), while its expansion is observed in 2 periods—between 2600–2000 BC and 1000 BC–AD 700 (T Rylova, personal communication 2005)—related to increasing humidity. However, according to the approximate age-depth model, most of the floods occurred at the end of the Atlantic and in the first period of the Subboreal. The boundary between the Subboreal and Subatlantic is drawn at 550 BC (Figure 4). This corresponds to a change in the sediment accumulation rate. The Subatlantic/Subboreal boundary at 550 BC also finds support in ^{14}C dates from the site of the Vilnius castles (the castle was redesigned and rebuilt many times) (Gaigalas 1998) as well as from Bebrukas Lake (Šulija et al. 1967).

CONCLUSIONS

Dating of the Valakupiai oxbow lake deposits by ^{14}C enables us to state the following:

1. The age of deposits in the Valakupiai section of the Neris River meander suggests that the river changed course towards the right bank before 3000 BC.
2. The oxbow lake was linked with the main river channel between ~2640 and 1890 BC.
3. At ~1890 BC, the link was interrupted and the lake development stage began.
4. The alluvium on the first terrace above the floodplain of the Neris River contains oak remnants from the end of the Atlantic climatic period, buried about 3000 BC. According to dendrochronological studies, the climate was becoming cooler in the period from the Atlantic to the Subboreal, with a wetter period at the beginning.
5. Traces of human activities found in the first terrace above the floodplain were dated to the period AD 810–1260.
6. Accumulation of the oxbow lake sediment lasted ~2670 yr.
7. Before 5600 BP, mollusk fauna contained an exotic species (*Theodoxus fluviatilis*) from rivers of the Black Sea basins, indicating contact between peoples inhabiting the Baltic and Black sea basins.
8. The rates of fluvial erosion and accumulation confirm the possibility of neotectonic stability of the studied area.

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