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RECONSTRUCTION OF GEODYNAMIC PROCESSES ON THE VISTULA RIVERBANK IN MEDIEVAL TORUŃ (POLAND)

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Abstract

During roadworks on Bulwar Filadelfijski in Toruń, the foundations of a Benedictine monastery and the Holy Spirit Church were uncovered. Geoarchaeological research analyzed fluvial, denudational, and anthropogenic layers in the Vistula riverbank. The aim was to determine the spatial and stratigraphic relationships between fluvial and denudational sediments and anthropogenic embankments in the Vistula riverbank zone. Key findings: (1) Early medieval fluvial and denudational processes shaped sediments, with Bronze Age and Roman artifacts redeposited by medieval floods. (2) Late medieval construction (monastery, perimeter wall) led to anthropogenic embankments dominating the area. (3) After the monastery's mid-17th-century destruction, major floods deposited overbank alluvium. The study clarifies the site's stratigraphic evolution under natural and human influence.

Keywords

geoarchaeological reconstruction • fluvial and denudational processes • anthropogenic embankments deposits • medieval town • Vistuli River valley

Introduction

Since the dawn of history, river valleys have been one of the main areas for the development of human settlements. The distribution of towns in river valleys represents considerable variability. Regarding topographical conditions, Kiełczewska-Zalewska (1977) distinguished five types of city locations in river valleys: (i) on an island – the city lies between the channels; (ii) in a bend – the city lies in the bend of a meandering river; (iii) on a scarp – the city lies on a high riverbank; (iv) in the valley bottom – the city is located in the valley bottom, directly by the river; and (v) on two banks when the city lies on both sides of the river. The prehistory settlement of river valleys has been determined by natural and cultural factors. The importance of both cannot be overstated, but this article considers only the former. These include: (i) geomorphological factors – landforms, especially the width of the valley floor, the height of valley slopes and valley floor formations, and the course and layout of river channels; (ii) hydrological factors – water conditions, including river runoff and hydrological regime; (iii) geological factors – lithology and the occurrence of rock materials; and (iv) soil factors – primarily soil characteristics affecting fertility and cultivation.

Due to the variety of geodynamic processes occurring in the river valley, the city's location relative to the riverbed (channels), valley floor forms, and valley slopes are significant factors. The course of fluvial processes shaping river valleys is primarily related to the flow of water in the riverbed and in the valley bottom (Teisseyre, 1991; Szmańda 2011). As Macklin and Lewin (2015) noted, one of the most significant natural factors influencing the dynamic of the settlement development in river valleys in the past was the variability in the hydrological regime. This was manifested in the emergence of periods characterized by a greater frequency of large floods due to climate change. Hydroclimatic factors, which are responsible for the development of river valley bottoms, had a decisive influence on geomorphological features, including: (i) the size, pattern, and activity of river channels and (ii) the relief and lithology of the flood plain. Macklin and Lewin (2015) also distinguished five types of settlement locations considering the geomorphological variation and activity of river channels and floodplain forms: (i) alluvial fans and aprons; (ii) laterally mobile rivers; (iii) rivers with well-developed levees and flood basins; (iv) river systems characterized by avulsions and flood-outs; and (v) extensive wetlands fed by rivers.

In addition to fluvial processes, the important morphogenetic processes in river valleys are mass movements and surface runoff, which occur mainly on the slopes of the river valleys (Banach et al., 2013; Tyszkowski, 2014; Weidner et al., 2019; Grabowski et al., 2022). The interrelationships between fluvial and denudation processes also influence how river valleys are populated and how humans manage the river channel (Dolbunova et al. 2020; Kittel et al., 2021). Analyzing these relationships has significant implications for the validity of geoarchaeological interpretations and, ultimately, for understanding the human-environment relationships occurring in river valleys (Howard & Macklin, 1999).

In consideration of these observations, we can say that human-environment relations in river valleys, particularly the development of settlements adjacent to river channels, are primarily influenced by landforms and the dynamics of processes shaping channels, floodplains, and valley slopes. Alluvia resulting from the dynamics of fluvial processes is an important environmental archive suitable for geoarchaeological research (Macklin et al., 2014). As a result of this assumption, the authors conducted a geomorphological and sedimentological study to determine the nature and dynamics of the processes shaping the bank of the Vistula River (Poland) along which the Toruń's Medieval Old Town complex extends. A comprehensive analysis of the observed forms and sediments acilitateed the reconstruction of geodynamic processes, predominantly fluvial and denudation, within the Vistula bank zone at the location of the former Benedictine nunnery complex

Figure 1. Copperplate by Christian Daniel (1656-1712), E – The Church of the Holy Spirit and the Benedictine nunnery complex

Source: Public domain: https://polona.pl/item-view/6ccdd2b4-f538-402a-bdae-c2223fb95d09?page=0

and Holy Spirit Church in Toruń (Fig. 1). The aim of the research was to determine the significance of fluvial and denudational processes shaping the Vistula bank zone on the functioning of the monastery complex. In a broader sense, the results of this study also contributed to understanding the influence of environmental conditions and needs? son the development of a medieval town situated on the banks of a big lowland river.

Study area and methods

Characteristic of the study area

The field research was carried out as part of an rescue archaeological survey related to a road project on Philadelphia Boulevard in Toruń. Archaeological excavation has revealed a significant number of fragments of the perimeter wall and outbuildings foundations belonging to the former religious complex of the Benedictine Order and the Holy Spirit Church. These buildings are located near the Monastery Gate, which is a part of the defensive walls of the Medieval Old Town Complex in Toruń (Fig. 2). In the central area of the excavation, a well-preserved granite mooring pole is situated on a 19th century foundation. It is a significant orientation point in the excavation under study (Fig. 3). The sacred complex is dated to the period between the 2nd half of the 13th century and the 2nd half of the 17th century (Tandecki, 1995). Following its demolition by Swedisch Army in 1656, residential buildings and inns were built on the site. Moreover, after their dismantling in 1809, the fortification structures of the 19th century Toruń Fortress were erected in this place (Jasinski, 1982; Tandecki, 1995).

The Medieval Old Town Complex in Toruń was inscribed on the UNESCO World Heritage List in 1993. The settlement is situated on the right bank of the Vistula River in the Toruń Basin mesoregion, as defined by Kondracki (1968) and Solon et al. (2018). The relief of the land surface and the thickness of anthropogenic berms in Toruń and their surroundings were studied in detail by Molewski and Juśkiewicz (2018) and Molewski (2015). Floodplain of the Vistula River is the study area. It is situated approximately 40 m a.s.l.

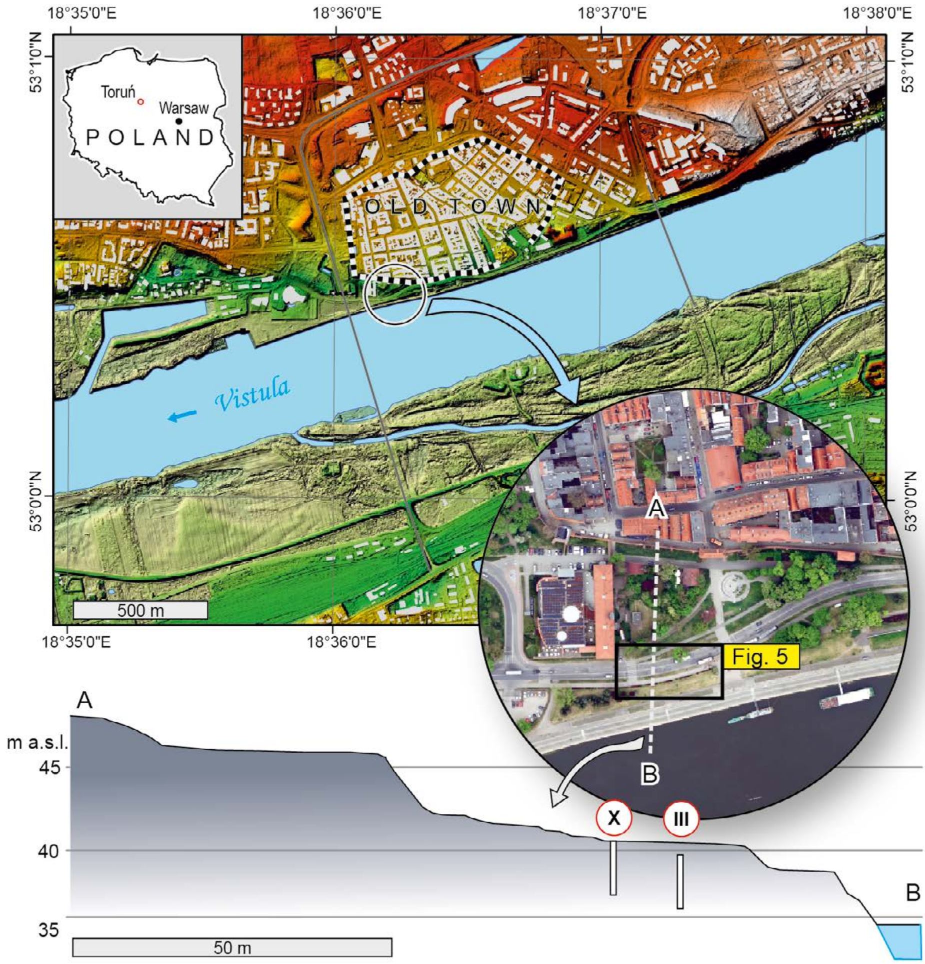

Figure 2. Location of archaeological excavation and documentary sites (sediment cores and lithofacial profiles) on Philadelphia Boulevard in Toruń

(Fig. 4). This floodplain transitions by a long slope to the level of the river terrace, which is located approximately 8 m higher. The Holy Spirit Church was situated halfway up the hillside, and the monastery buildings were at the foot of the slope on the floodplain. The area on which the church and monastery complex of the Holy Spirit was built, was bounded on the western side by a valley drained by an unnamed watercourse flowing into the Vistula River. The lower section, approximately 500 m long, was transformed into a city moat (Tomczak, 1971). One of the oldest mills in Torun – the so-called Frog Mill – operated at the mouth of this watercourse to the Vistula River. Due to insufficient water resources, it was inefficient, and therefore, its use was discontinued in the 16th century (Mikulski, 2019).

The location of the Vistula riverbed in the Toruń section was relatively stable. According to Tomczak (1971), the position of the riverbed hasn't significantly changed from the Middle Ages to the beginning of the 19th century. At that time, the Vistula had an anastomosing channel pattern. The main river channel was characterized by a braided pattern with river

Figure 3. The granite mooring pole

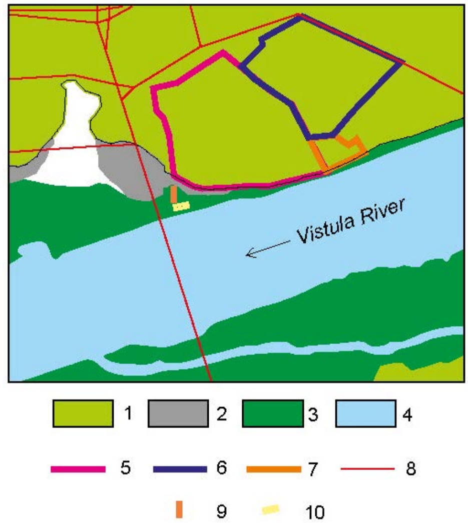

Figure 4. The geomorphological sketch of the surroundings of the Medieval Old Town Complex in Toruń

Source: Based on Molewski (2015).

islands, while side channels showed a sinuous pattern. The narrowing of the river channel, which occurred between 1830 and 1915, resulted from river regulation. The width of the river channel near Toruń decreased from 2-3 km to 400 m.

The bedrock in the study area includes anthropogenic berms (Molewski, 2015) and Quaternary alluvia overlying Neogene clay (Tomczak, 1982). The position of the clay floor in the Torun Basin is highly variable and influenced by erosional and glaciotectonic processes (Wilczyński, 1969). One of the clay outcrops was found along the line of the defensive wall of the Old Town in its southwestern part, i.e., in the zone directly adjacent to the study area (Molewski & Juśkiewicz, 2018). Previous geological research in the Lower Vistula Valley indicates that strongly deformed and glaciotectonically disturbed Neogene formations are usually exposed in the lower and middle parts of valley slopes. The glaciotectonically uplifted series of Poznań clays with layers of sandy sediments are often intermixed with older Pleistocene sediments. Discontinuous surfaces present within the Neogene sedimentary sequence are potential slip surfaces. Younger formations lying on the clay can move along these surfaces. This occurs under conditions of intense hydration by infiltrating water from the overlying clay sediments. The result is a change in their persistence parameters. This causes some of the highly hydrated sediments to detach and move along the top of the plasticized clays. This natural process, determined by the geological structure, are intensified by the lateral erosion of the river and the infiltration of the river water into the underlying alluvia during floods. The presence of clays in the base surface can be considered one of the reasons for the increased geodynamic activity of the slope of the river terrace on which the Old Town of Toruń is located (Fig. 4). The inclination of the tower in the city walls, the so-called the "Leaning Tower" is, among other things, the manifestation of this activity (Molewski, 2015). The presence of a side valley used by a watercourse flowing directly into the Vistula River could affect groundwater flow conditions at the edge of Vistula's elevated floodplain. The specific water conditions in direct contact with the surface of the Vistula channel and its tributary, combined with the shallow clay deposits, could have caused landslides at this location. Increased activity of the banks of the lower Vistula River in places with similar geomorphic and geological features has been found in many other sections of the river (e.g., Tyszkowski, 2012). The influence of the river on the stability of the right bank of the river is also evident after the regulation of its channel. The landslide on the riverbank in the eastern part of Philadelphia Boulevard created in 2012 is an example of his. This process was associated with slope drainage during prolonged low water levels in the Vistula River.

Field research methods

The geoarchaeological survey was conducted at the archaeological site in October and November 2023. This included: (i) seven mechanical drillings with the use of a kit to sample sediments with an undisturbed structure, from which lithofacial profiles I-VII were obtained; (ii) an outcrop at a depth of 1.9 m near the wall of the monastery complex, which was deepened to a depth of 3 m by hand drilling. Based on the data from this outcrop and hand drilling, a lithofacial profile VIII was prepared; (iii) three outcrops, located in the southern (IX) and northern (X and XI) parts of the archaeological site (Fig. 5). Drillings were placed in two profiles: (i) longitudinal NS (I-V); and (ii) latitudinal WE (VI-VIII). From the drillings and outcrops, 172 sediment samples were obtained for grain size analysis, and four wood samples were collected for radiocarbon dating. The lithofacial characterization of the sediments using the methods of the study described below in this article was carried out during the field survey. Macroscopic evaluation of sediment texture was verified by the results of grain size analyses.

Sedimentological analytical methods

The sediment samples were analyzed at the Laboratory of Sedimentology and Soil Science, Department of Geoenvironmental Research, Institute of Geography and Spatial Organization, Polish Academy of Sciences, Krakow. A total of 213 grain size analyses were performed, including 41 samples of sands and gravels above 1 mm by the sieving method on Fritsch sieves with 1 phi mesh spacing and 172 samples of sediments of less than 1 mm in diameter (fine sands, silts, and clays) by the laser method using a the Malvern Mastersizer 3000 Laser Particle Sizer. The results of the analyses were converted to fractional intervals of 1 phi (according to the Krumbein scale, 1934). The sediment types were determined based on the modified sediment classification proposed by Szmańda (2011). Based on the results of the grain size analyses, the values of the statistical parameters were determined in phi units. The Gradistat software was used to calculate the statistical indices used to determine the values of two graphical grain size indices: (i) mean grain size (Mz), sorting (σ_1), and (ii) skewness (Sk) (Blott & Pye, 2001).

Absolute dating methods

Radiocarbon dating was performed at the Laboratory of Absolute Dating in Cianowice (Poland). For age determination, four wood samples were taken from three profiles. The LSC (Liquid Scintillation Counter) technique was used to date three samples: (i) III – 292-294 cm deep (MKL-6540); (ii) 336-339 cm deep (MKL-6541), and (iii) VII – 270-300 cm deep (MKL-6539). The AMS (Accelerator Mass Spectrometry) technique was used to date the wood from profile I at a depth of 405 cm (MKL-A6583). Calibrated radiocarbon ages (cal. yr BP) were generated using the IntCal20 radiocarbon calibration dataset and OxCal 4.4 calibration software (Bronk Ramsey, 2009).

Methods for recording data in sediment lithofacial profiles

Lithofacial profiles were developed following the lithofacial coding methods described

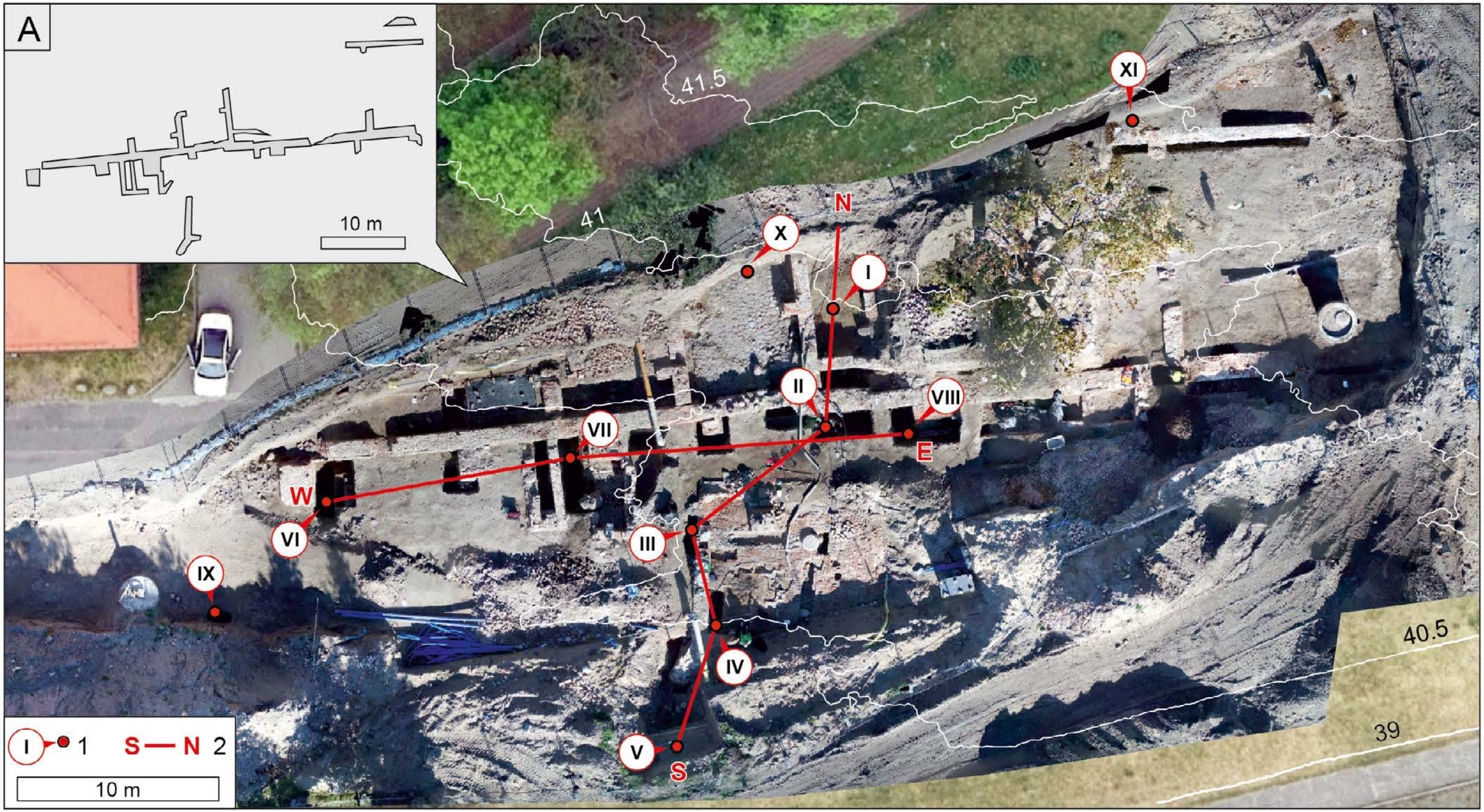

Figure 5. Distribution of drillings (I-VIII) and outcrops (IX-XI), A – the perimeter wall and foundations of outbuildings

by Zielinski and Pisarska-Jamroży (2012), while in the case of overbank alluvia, the coding proposed by Szmańda (2011) was used. This coding involves applying letter symbols to textual (uppercase) and structural (lowercase) features. In addition, coding of organic remains and artifact data was proposed for this study: (i) names of organic remains: C (Carbon) – amorphous organic matter and charcoal; Wo (Wood) – wood fragments; Br (Branch) – branch or trunk fragments; Bo (Bone) – bone or bone fragments; (ii) artifact designations: Po (pottery) – pottery fragments; pottery age designations: Po(1) – Bronze Age; Po(2) – Roman Period; Po(3) – Medieval Period; Po(4) – Modern Period; Bk (Brick) – brick fragments; Pu (Pug) – pugging fragment; Ti (Tile) – tile fragments; Ca (Carbonates) – carbonates, carbonate mortar.

Results

Results of grain size composition analyses

The analyzed sediments of the excavation floor and walls are not homogeneous in terms of grain size distribution (Tabs. 1, 2). Based on the results of the grain size analysis of the investigated samples, eleven types of sediment were identified in the excavation floor, and nine in the excavation wall.

Two out of eleven types of sediments identified in the excavation floor are dominant: sandy silt (39.4%) and silty sand (32.4%). Approximately 10% of the sediments are multifractional, with a predominance of the silty fraction and an admixture of 10% to 40% sands and/or clays. The share of clayey silt is

Table 1. Grain size distribution of sediments in the basement of the archaeological outcrop (profiles I-VIII)

Sediment Type	Fraction share % average (range)				Grain size parameter			Percentage
	gravel	sand	silt	clay	*Mz*	σ_I	Sk_I	
DFS	0.0	38.5	38.0	23.5	6.54	4.05	0.34	0.7
GS	69.7	19.7	4.0	0.2	-3.28	3.01	0.75	0.7
S	2.2 (0.0-14.7)	88.0 (75.9-86.2)	9.6 (6.2-13.5)	0.2 (0.0-0.7)	-0.01-2.83	0.92-1.71	0.01-0.42	4.9
SF	0.1 (0.0-0.7)	59.1 (42.6-79.2)	39.1 (20.2-56.0)	1.8 (0.1-7.3)	2.50-4.85	1.45-3.41	-0.23-0.69	32.4
FS	0.1 (0.0-1.5)	36.2 (16.0-49.3)	59.9 (47.4-76.8)	3.8 (0.5-17.0)	4.11-6.30	1.61-3.22	-0.26-0.35	39.4
FSF(c)	0.0	23.1 (12.4-39.4)	63.5 (49.5-79.1)	13.5 (8.5-21.2)	5.33-6.70	2.05-3.52	-0.32-0.24	6.3
F	0.0	0.0	92.3 (91.0-93.5)	7.7 (6.5-9.0)	6.85-6.97	1.26-1.53	0.06-0.14	1.4
FF(c)S	0.0	11.5 (7.9-14.8)	65.9 (57.1-76.7)	22.6 (13.0-35.0)	6.63-8.46	2.32-2.89	-0.12-0.07	4.2
FF(c)	0.0	5.0 (0.0-8.8)	65.8 (52.0-77.1)	29.1 (14.1-43.9)	6.64-9.07	1.51-3.29	0.00-0.33	7.7
F(c)S	0.0	13.7 (10.4-16.9)	42.3 (40.2-44.4)	42.7- (40.2-45.2)	7.90-8.26	3.04-3.53	-0.21-(-0.22)	1.4
F(c)F	0.0	12.2	39.9	47.8	8.86	3.26	-0.17	0.7

DFS – silty sandy diamicton, GS – sandy gravel, S – sand, SG, gravelly sand, SF – silty sand, F –silt, F(c) – silt – with an admixture of more than 10% of clay fraction, FS – sandy silt, FSF(c) – sandy clayey silt – with an admixture of more than 10% of clay fraction, F – silt, FF(c)S – clayey sandy silt, F(c)S – sandy clay, F(c)F – silty clay.

Table 2. Grain size distribution of sediments in the excavation walls of the archaeological outcrop (profiles IX-XI)

Sediment Type	Fraction share % average (range)				Grain size parameter			Percentage
	gravel	sand	silt	clay	*Mz*	σ_I	Sk_I	
G	76.7	11.1	6.4	5.8	-2.1	3.6	0.6	3.3
GSF	48.3	35.1	11.9	4.7	-0.9	3.8	0.4	3.3
SG	21.1	65.3	9.7	3.9	1.1	3.0	0.2	3.3
SGF	30.5 (27.2-33.8)	43.7 (38.0-49.4)	22.2 (20.9-23.4)	3.6 (0.0-7.3)	1.4 (1.1-1.8)	3.7 (3.0-4.4)	0.0 (-0.3-0.3)	6.7
S	0.5 (0.0-1.9)	89.9 (84.0-95.3)	9.3 (4.4-14.3)	0.4 (0.2-0.7)	1.8 (1.8-2.0)	1.4 (0.9-2.0)	0.3 (0.1-0.5)	13.3
SF	1.1 (0.0-9.8)	64.4 (53.9-84.7)	31.9 (13.9-44.2)	2.6 (0.0-9.1)	3.2 (1.7-4.1)	2.3 (1.3-3.4)	0.3 (0.2-0.6)	53.3
FSG	19.5	34.3	43.6	2.5	2.1	3.6	-0.1	3.3
FS	0.0	44.1 (41.5-46.5)	53.2 (51.0-55.2)	2.7 (0.0-4.7)	4.2 (3.7-4.6)	2.0 (1.6-2.2)	0.2 (0.1-0.3)	10.0
FSF(c)	0.0	42.3	34.5	23.2	5.8	4.8	0.5	3.3

G – gravel, GSF – sandy silty gravel, S – sand, SG, gravelly sand, SF – silty snad, FGS – gravelly sandy silt, FS – sandy silt, FSF(c) – sandy clayey silt

7.7%, and that of sands is 4.9%. The proportions of the other five sediment types did not exceed 1%.

Among the basic fractions, the silt one dominates (47% on average), with a slightly smaller proportion of the sandy one (44% on average). The clay fraction averages 6.7% (with a maximum of 47.8% in silty clays), and the gravel one is the smallest, averaging 2%, with a maximum of 70% in the gravel and sand sediment samples. The clay and gravel fractions should be considered additional. Due to the high fractional variability of the sampled sediments, they are either poorly or very poorly sorted. The skewness of the grain size distributions of the studied sediments are predominantly positive.

In the sediments taken from the excavation, more than 50% are silty sands. Sands and sandy silts contribute more than 10%. The grains of the sand fraction predominate (60% on average). The proportion of silt grains is also significant (29% on average). The additional fractions are gravel (average 8%) and clay (average 3%). As in the bedrock of the quarry, the sediments in its walls are also poorly sorted.

Results of the lithofacial analyses

The results of the lithofacial analyses in profiles I-XI, whose field textural observations were corrected by the results of the grain size analyses (except for the sediments of profile VIII from a depth of 190 cm, which were determined macroscopically), are shown in Figure 6. The horizontal axis displays the individual profiles: (i) Graph of the average grain diameter (Mz); (ii) Macroscopically marked diamicton (anthropogenic berm) on profiles IV, V, VI, VIII; (iii) Macroscopic determination of the sediment texture in profile VIII below a depth of 190 cm. Figure 6 shows the results of the analyses of profiles I-V ranked by altitude in the longitudinal (NS) direction. While figure 7 presents the results of the lithofacial analyses of profiles V-VIII, which are arranged in the latitudinal direction (WE). In both cross-sections, the approximate level of the Neogene clay deposits is marked with

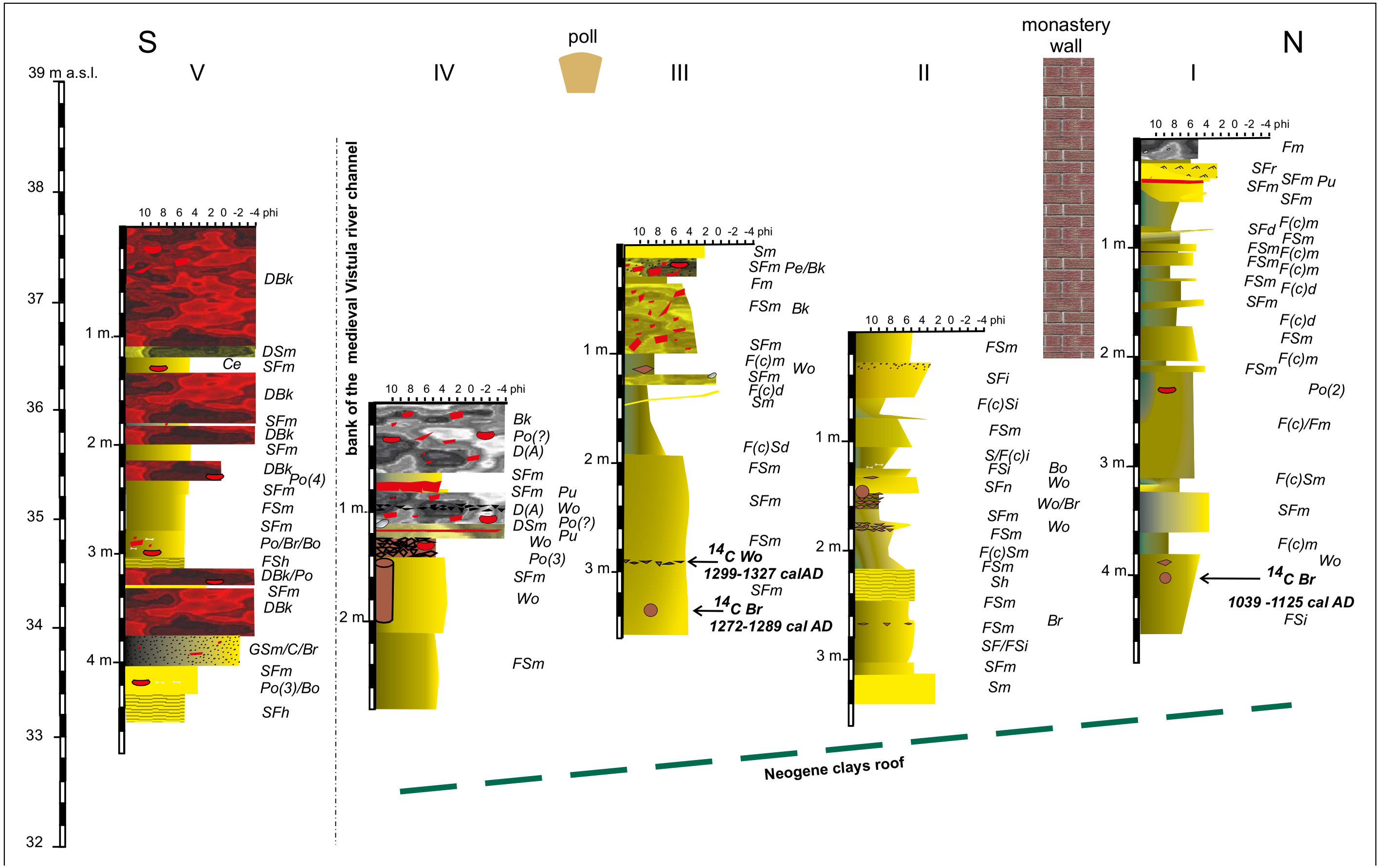

Figure 6. Cross-section of sediments in the base surface of an archaeological excavation in a longitudinal sequence on Philadelphia Boulevard in Toruń

Explanation of symbols: **Sediment texture:** G – gravel, GSF – sandy silty gravel, S – sand, SG – gravelly sand, SF – silty sand, F – silt, F(c) – silt with an admixture of more than 10% of clay fraction, FGS – gravelly sandy silt, FS – sandy silt, F(c)S – sandy silt with an admixture of more than 10% of clay fraction, D – diamicton, DS – sandy diamicton, D(A) – anthropogenic diamicton with pottery fragments, DBk – brick diamicton. **Sediment structure:** m – massive, n – normal grading, i – inverse grading, h – horizontally laminated, r – ripple cross lamination. **Organic remains:** C (carbon) – amorphous organic matter and charcoal, Br (branch) – fragments of a branch and trunk, Wo (wood) – fragments of cut wood, piles, Bo (bone) – bones or their fragments. **Artifacts:** Po (pottery) – fragments of pottery; Age designation Po(1) – Bronze Age, Po(2) – Roman period, Po(3) – Middle Ages, Po(4) – modern period, Bk (brick) – fragments of brick, Pu (pug) – fragments of pugs, Ti (tile) – fragment of a roof tile, Ca (carbonates) – carbonates, carbonate mortar

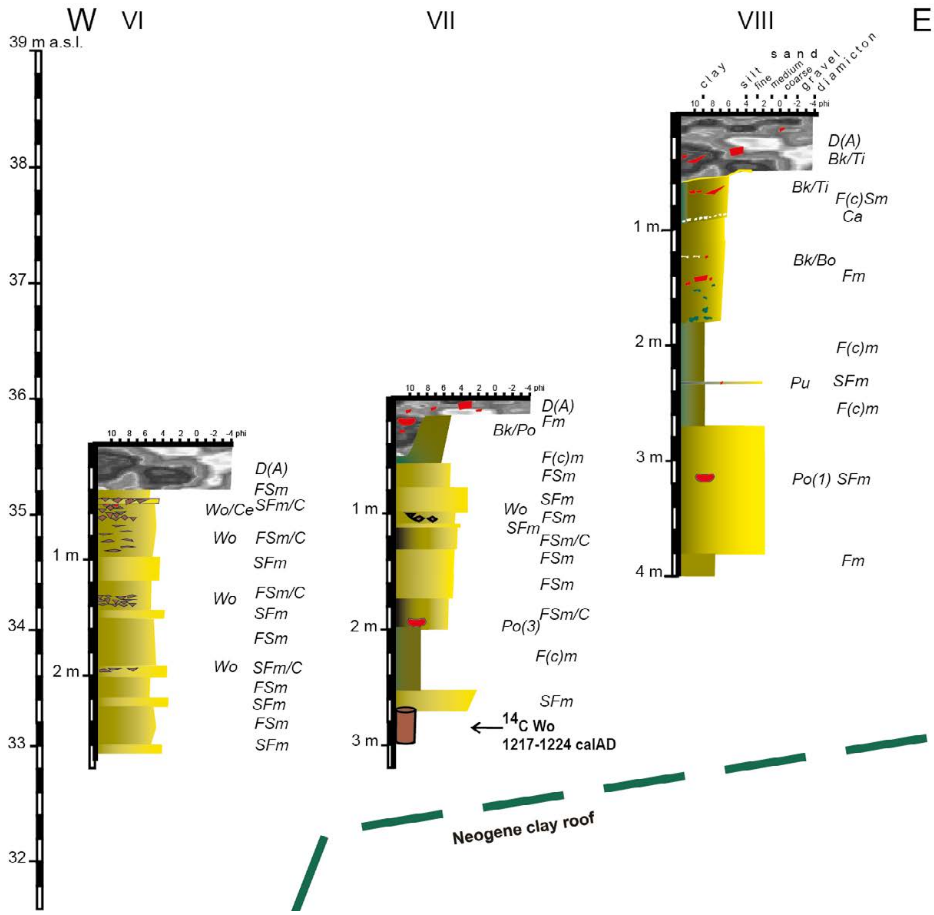

Figure 7. Cross-section of sediments in the base surface of an archaeological excavation in a latitudinal sequence on Philadelphia Boulevard in Toruń. Explanation of symbols in Figure 6

a dashed green line. The results of the calibrated radiocarbon dating were obtained for profiles I, III (Fig. 6), and VII (Fig. 7). The age of the pottery was marked in the consultation with archaeologists: K. Kuczara-Alagierska (for profile VIII), J. Bojarski and R. Kaźmierczak (for profiles I, IV, and VII), and P. Kittel (for profile V). Moreover, the results of the lithofacial exposures in the southern (IX) and northern (X and XI) walls of the trench are presented on Figure 8. A lithofacial profile of IX was made based on the analysis of the outcrop, which contains two levels of paving. The second level from the top is from the period of construction of the so-called "coal wharf", which occurred in 1880. Profile X was created from the outcrop of sediments above the brick rubble created during the demolition of the monastery buildings in 1656. Profile XI, on the other hand, is above the wall that is a remnant of the 19th century buildings of the Toruń Fortress.

Radiocarbon analysis results

The age of four wood samples was determined. A sample of a branch taken from a depth of 405 cm was dated from profile I. Wooden wharfs were taken from profile III from a depth of 292-294 cm, while a branch

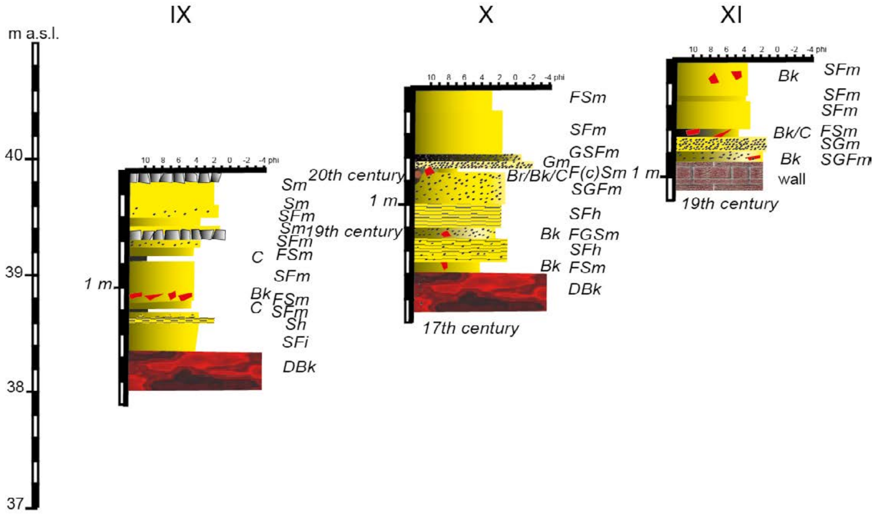

Figure 8. Lithofacial profiles of sediments from the southern (IX) and northern edge of the archaeological excavation on Philadelphia Boulevard in Toruń. Explanation of symbols in Figure 6

fragment was taken from a depth of 336-339 cm. A fragment of a wooden pile was taken from profile VII from a depth of 270-300 cm. The location of the collection of these samples is marked in Figures 6 and 7. The species of dated wood was not marked. The results of the radiocarbon dating of samples are presented in Table 3.

Discussion

Following the typology of Kielczewska-Zalewska (1977), in terms of topography, the location of the medium-sized city of Torun can be classified into two types: type iii – on a scarp – the city lies on a high riverbank; and type iv – in the valley bottom – the city is located in the valley bottom, directly by the river. The type iii location is determined by the town square neighbourhood, together with the layout of streets and buildings located on the third terrace of the Vistula River valley. This terrace was formed in the Late Glacial (Tomczak, 1982) and is located a few meters above the Holocene floodplain. In its bedrock there are Quaternary glacial tills and Neogene clays, which determined the activation of mass movements. They were important in the development of geodynamic processes in the area where the former Benedictine nunnery complex and the Holy Spirit Church were located. While the classification of Torun's

Table 3. The results of radiocarbon dating of the drillings form the archaeological excavation on Philadelphia Boulevard in Toruń

Dated material	Profile number	Depth b.g.l. [cm]	^{14}C Age yr BP	Laboratory code	Calibrated Age AD (prob. 68.2%)	Calibrated Age AD (prob. 94.5%)
Wodden branch	I	405	921±21	MKL-A6583	1046 -1164	1039-1125
Wooden wharfs	III	292-294	770±80	MKL-6540	1176-1299	1045-1395
Wodden branch	III	336-339	820±60	MKL-6541	1176-1272	1045-1289
Wooden pile	VII	270-300	890±35	(MKL-6539	1176-1272	1045-1289

location as type iv (in the valley bottom) is determined by its proximity to the Vistula River, the bank of which was located at the former Benedictine nunnery complex.

Geomorphological factors among the natural ones favouring the location of mid-century Toruń were as following: (i) the high bank of the terrace above the floodplain, which limited the extent of floods; (ii) the proximity of the riverbed, allowing easy access to water; (iii) the layout of the riverbed separated by islands favoured the river crossing. On the contrary, hydrological factors can be considered unfavourable due to the floods that have been occurring since the Middle Ages (including particularly dangerous ice jam floods). The floods were the reason for the translocation of the city from its previous location on a flood plain several kilometres downstream to the current urban layout of the Old Town (Fig. 4). Geological structure is also among the unfavourable elements, due to the shallow subsurface of the area, with the deposition of tils and clays causing landslides.

Sedimentological studies have been helpful in determining the relationship between geodynamic processes (floods and mass movements). The presence of additional fractions in sediments is critical for the correct interpretation of these processes. Grain size analyses showed that, in the case of the studied sediments, the additional fractions included the gravel and the clay ones. The share of the clay fraction is mainly related to the underlying Neogene clays, which are the source of this fraction. Eight samples in profile II (28%), three samples in profiles III (17%), VII (21%), and VIII (50%), and fourteen samples in profile I (which make up 40% of the samples in this profile) all showed significant contributions of more than 10% of the clay component. The sediments in which the share of clay fractions exceeds 10% are marked in the lithofacial profiles with the symbol F(c) in Figures 8 and 9. This leads to the conclusion that the north-eastern part of the investigated archaeological outcrop also contains clayey sediments other than Neogene clay. Their proportion decreases toward the south and west. The presence of the clay component in the sediments was not observed west of drillings VII (Fig. 7) or south of the mooring pool (Fig. 6).

The high variability in the proportion of clay fractions in the different types of sediments, highest in clayey silts or silty-sandy silts and lowest in silty clays or silty-sandy clays, is related to the redeposition of Neogene clays underlying the studied sediments. These are primarily deformed clays (Fd) with admixtures of silty and sandy fractions. This redeposition may have occurred as a result of mass movements, mainly by landslides of the clays present on the slope. Furthermore, the clay particles are of a different origin than the Neogene clays, whose 23% share was found in profile X, in the layer of clay-sandy sediments – F(c)Sm, at a depth of 70-80 cm (Fig. 8). In this case, the source of the clay fraction is probably glacial clays washed out in the Vistula riverbed. The remnants of moraine cobbles were found in many places along the riverbed in the section from Włocławek to Toruń (Habel, 2013).

Only eighteen sediment samples, or 10% of all analyzed samples, contained gravel grains. The greatest number, up to six samples, was found in the profile X, i.e. in the outcrop made in the north wall of the investigated excavation. Gravel sediments with a gravel fraction of more than 10% were found in: (i) at the foot of profile III (15%), at a depth of 144 cm; (ii) at the foot of profile V (70%), at a depth of 400 cm; and (iii) in the outcrops in the northern part of the investigated excavation in five samples in profile X (which represents 50% of the samples taken from this outcrop); and two samples from profile XI (which represents 33% of the taken samples). The source of the gravel is mainly glacial till present in the riverbed (Babiński, 1992; Habel, 2013). The gravel eroded from the bed and then accumulated on the floodplain. Its fraction originating from the Vistula riverbed has been documented in many places in the overbank alluvia (Szmańda, 2011). The proportion of the gravel fraction in the studied sediments is, therefore, a good indicator of the magnitude of the Vistula flow and the dynamics of erosion-accumulation processes in the channel and on the floodplain.

An important grain size indicator used in interpreting water flow dynamics is skewness (McLaren, 1981; McLaren & Bowles, 1985). The skewness of grain size distributions of most sediments, regardless of type is positive, meaning that the size of the modal fraction is greater than the median. The sediments with positive skewness distributions are dominated by grains coarser than the mean grain size in the sample. Such a sediment distribution can arise in a fluvial environment in sandy or sandy-silty sediments in two cases: (i) as a result of erosion by flushing fine clastic particles out of the sediment during the rise of a flood wave, or (ii) as a result of a rapid decrease in the flow energy of water during the fall of a flood wave and the deposition of larger grains (McLaren, 1981). On this basis, it can be assumed that most of the studied natural sediments are a result of sedimentation during floods.

The negative skewness of clay sediments is usually due to a greater proportion of fractions finer than the median. Such sediments are formed in an environment of slowly decreasing water energy (McLaren, 1981). This mode of accumulation is typical of a deep-water lake environment. This confirms the reservoir origin of Neogene clays, which subsequently redeposited from the bedrock and incorporated into the structure of younger alluvia. Dispositional conditions, similar to the lake environment, take place during the slow drawdown phase of the flood wave, when subaqueous sediment accumulation occurs on the floodplain, mainly in the distal part of the floodplains and in the flood basins (Teisseyre, 1988). Such an interpretation can explain the presence of sandy clays in profile X (Fig. 8).

The accumulation chronology of the examined sediments was established using radiocarbon dating data and the determination of the age of the pottery. The oldest radiocarbon date, 1039-1125 years, was determined in profile I from a fragment of wood (a branch) buried in sandy silts (probably overbank alluvia) at a depth of 405 cm (34.5 m a.s.l., Fig. 6). In this profile, a fragment of pottery dating to the Roman period was also found in a layer of deluvial clayey silts at a depth of 230 cm (36.2 m a.s.l.). The oldest ceramic fragment from the Bronze Age was discovered in profile VIII (in the vicinity of profile I) at a depth of 320 cm (35.4 m a.s.l.) in a layer of sandy silts with organic matter content, which was deposited during floods (Fig. 7). The age of the pottery may indicate that the deposition of the overbank alluvia analyzed above took place in the Bronze Age and that the activation of deluvial processes on the valley slope occurred at the beginning of our era. The radiocarbon dating of the wood taken from the alluvia below the layers with the Bronze Age and Roman period pottery, indicates that the beginning of flood accumulation at the excavation site occurred not earlier than 1000 years ago. Based on the results of luminescence dating of the overbank alluvia on Kępa Bazarowa, the island opposite the research site, it should be concluded that river overbank alluvia also began to form on this island approximately 1000 years ago (Szmańda et al., 2004). If we assume that the beginning of a more intensive accumulation of river overbank alluvia occurred during the period of deforestation of the valley bottom in the 10th and 11th centuries, then the accumulation of overbank alluvia in the Toruń Basin began in the early Middle Ages. This means that the fragments of Bronze Age and Roman potteries found in the alluvia were redeposited elsewhere. Traces of the Bronze Age settlement in Toruń were discovered at the site from the present ruins of the Teutonic Castle (Chudziakowa & Kola, 1974; Chudziakowa, 1983), located a few hundred meters east of the studied monastery complex. This suggests that the ceramic fragments discovered in the alluvia may have originated at this location. Evidence for the continuity of settlement in the area of the Old Town of Toruń from the Bronze Age to the Middle Ages includes the remains of a settlement dating from the 10th to the 11th century that existed on the castle hill in the pre-Teutonic period (Chudziak & Bojarski 2016).

The results of radiocarbon dating of a sample taken from a wooden pile discovered at a depth of 270-300 cm (33 m a.s.l.) in the silty sands in profile VII (Fig. 7) indicate that it was rammed or buried here at the beginning of the 13th century (Toruń foundation period). The silty sands sediments above the wooden pile were deposited after the city was founded. The edge of a valley drained by a watercourse flowing into the Vistula west of the archaeological excavation probably ran through this site. The presence of a valley edge in this region is evidenced by a sharp change in the depth of the Neogene clays between profiles VI and VII (Fig. 7). In profile VII, they are deposited above the alluvium at a ground ordinate of 33.5-34 m a.s.l. This is the lowest and westernmost clay layer found in outcrops and drillings. The extent of clay colluvia deposition can thus be estimated to be between profiles VI and VII. In the organic sandy silts overlying these clays, a fragment of medieval pottery was found at a depth of 200 cm (34 m a.s.l.). As their age is synchronous with that of the disbursed timber pile, it should be assumed that this pottery was in situ.

Two additional radiocarbon dates were made of wood taken from branches at a depth of 330-340 cm (34.2 m a.s.l.) and wood shavings at a depth of 290 cm (34.6 m a.s.l.) found in silty-sandy sediments in profile III (Fig. 6). Their age was established at the turn of the 13th and 14th centuries, i.e., the period of the establishment of the monastery buildings and the adjacent wooden Vistula harbor-wharf (Tandecki, 1995; Superczyński, 2018). The wooden wharf buildings still reached a few meters to the south, as in profile IV, and fragments of a wooden structure were found at a depth corresponding to the level of silty-sandy sediments with wood fragments in profile III (Fig. 6). The Vistula channel was then placed between profiles IV and V. Several pieces of evidence support this conclusion: (i) at a depth corresponding to the wooden structure in profile IV (34-35 m a.s.l.) and profile V, there is a brick rubble with fragments of late medieval pottery, and at 35.5 m a.s.l., there are fragments of modern pottery; (ii) between the levels of brick rubble with medieval and modern pottery are sand and silt deposits, which may have accumulated in the Vistula channel during low-energy flows or in its immediate vicinity during floods; and (iii) fragments of early medieval pottery were found in the lower part of profile V in silty sands overlying horizontally laminated sands that were deposited in the river channel. This sequence of sediments indicates that the site of profile V during the period of construction of the monastery complex was a river channel, which, from the late medieval period onward, was successively backfilled with brick rubble and river alluvia.

Three outcrops were made in the walls of the archaeological excavation. Sandy and sandy-silty sediments are visible in the outcrop on the southern wall of the excavation (profile IX). Due to textural features such as the positive skewness of sediment grain size and structural characteristics such as primarily horizontal lamination and flood rhythmite, these sediments can be interpreted as flood alluvia. The coal layers found here (38.7 m a.s.l. and 39.15 m a.s.l.) may indicate the accumulation of these sediments since the mid-19th century. During this period coal dust appeared on the alluvia overbank in various places in Poland, including the area around Kraków. This was associated with the beginning of industrial coal mining in Upper Silesia (Rutkowski, 1984). The remaining granite cobblestones above these layers are from the 19th and 20th centuries.

In two outcrops located in the northern part of the archaeological excavation, a total of several flood cyclothems or rhythmites were found, the presence of which in the alluvia was described by Szmańda (2006, 2018). These alluvia contain fragments of building pottery (bricks and roof tiles), layers of coal dust, pieces of charcoal, and animal bones. These were deposited synchronously during the flood, along with the mineral material. Four sets of layers from different floods can be distinguished in profile X at the level of debris, probably dating from the demolition of the monastery by the Swedish Army in the 17th century (Fig. 8): (i) a cyclothem comprising three layers of FSm/SFh/FGSm at an ordinate of 39.0-39.4 m a.s.l.; (ii) a three-layer cyclothem of SFm/SGFm/F(c)Sm – an ordinate of 39.4-39.9 m a.s.l.; (iii) a cyclothem of SFm/SGFm/F(c)Sm – an ordinate of 39.4-39.9 m a.s.l.; (iv) rhythmite Gm/GSFm – ordinate of 39.9-40.1 m a.s.l.; and (v) rhythmite SFm/FSm – ordinate of 40.1-40.7 m a.s.l. In profile XI, which is located several meters to the northeast of profile X and made over the remains of the 19th century fortifications of the Toruń Fortress, there are two sets of layers originating from two different floods (Fig. 8): (i) cyclothem SGFm/SGm/FSm at a ground ordinate of 40-40.15 m a.s.l.; (ii) rhythmite SFm/SFm differing slightly in grain size characteristics. The SFm layer (Mz – 3 phi) located at an ordinate of 4.15-4.5 m a.s.l. is coarser grained than the adjacent SFm layer (Mz – 4.1 phi) located at an ordinate of 4.5-4.6 m a.s.l. The differences in grain size indicate that the former was deposited during the rising phase of the flood and the latter one was deposited during the falling phase.

Both sets of layers occurring in profile XI can be correlated, both in terms of sedimentological characteristics and stratigraphic position, with the layer in profile X. A distinctive feature of the grain size of the sediments in profile XI is the occurrence of the coarsest gravel fraction grains in the (iii) rhythmite Gm/GSFm at an ordinate of 39.9-40.1 m a.s.l. in profile X and the layer set (i) cyclothem SGFm/SGm/FSm at an ordinate of 40-40.15 m a.s.l. Therefore, it is reasonable to assume that they were deposited during the same flood. This may have been the flood of 1924, which was the largest event in the 20th century in Toruń. Floodwater reached 41.12 m above sea level, with a rapid increase and a very high flow rate of 7,800 $m^3 \cdot s^{-1}$ (Makowski, 1998). Its sedimentological effects were recorded by Szmańda (2005) in one of the exposures above a side dam in the area of the former Kępa Strońska, a few kilometers south of Toruń.

In conclusion, based on the results of sedimentological studies and the dating of wood and pottery, it should be stated that the structure of the basement of the studied archaeological excavation, since the Middle Ages, has been influenced by geodynamic processes related mainly to two natural factors: (i) channel and off-channel flows of the Vistula River; (ii) mass movements occurring on the slope of the elevated floodplain. These factors hindered the functioning of the monastery complex.

The sediments covering the outcrop and exposed in its walls are overbank alluvia deposited on the floodplain in the 19th and 20th centuries, which have been transformed by man and enriched with berm material, including coal dust.

The presence of artifacts, ash, and organic debris (plant and animal), as well as clay and gravel inserts in the alluvia occurring in the in situ position, is indicative of the proximity of the material supply sources and their short transport. Such conditions are typical of ice-jam winter floods. Floods of this type were very frequent in Toruń in historical times, as evidenced by large watermarks on the city walls and archival data (Ghazi et al., 2023). Linking the alluvial sediments described above to specific flood events requires further research.

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