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Environmental conditions of settlement in the vicinity of the mediaeval capital of the Cherven Towns (Czermno site, Hrubieszów Basin, Eastern Poland)

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ABSTRACT

Based on the results of geoarchaeological investigations carried out at the Czermno site (eastern Poland), which is associated with Cherven, i.e. the mediaeval capital of the Cherven Towns, we reconstructed the main stages of environmental changes and human impact in the surroundings of the site. The site is of great archaeological importance due to its historical context that is essential to identify the conditions of settlement formation in the Polish-Rus' borderland in the Middle Ages. The present study combines palaeoenvironmental and archaeological knowledge with chronostratigraphic data to infer the main stages of settlement, connected with the outset, functioning and collapse of the mediaeval capital of the Cherven Towns. The location of the site was analysed in the context of geological, geomorphological, climatic, hydrological and soil conditions as well as changes of the natural vegetation. An assessment was made of the anthropogenic transformation of the land relief and hydrological regime, which made it possible to reconstruct these components of the geographic environment in the period preceding the construction of the stronghold and the adjacent settlements. The results of our investigations show that, in the Middle Ages, (1) the climate was relatively cold and dry in the 7th-8th century AD, when settlement activity started in the vicinity of the site (as affirmed by chronostratigraphic data) (2) intensive transformations of the landscape (i.e. adaptation for settlement), were carried out on a large scale during the subsequent seven centuries (land levelling, reorganization of drainage, i.e. the construction of moats, ramparts and a log-paved roads), (3) the human impact on the environment was particularly strong (as indicated by reliable multi-proxy data) in the mid-9th century AD, at the end of the 10th and turn of the 11th century AD, and in the second half of the 12th century AD, (4) all these settlement phases were connected with a relatively warm and humid climate.

1. Introduction

Fortified settlements, i.e. timber-and-earth strongholds with diverse functions (administrative, military, as a place of refuge or religious cult), were a unique feature of the early mediaeval landscape (6th to 13th century AD) in Slavic territories (Christie and Herold, 2016). This was also the case in Polish territories where more than 500 strongholds, dating back to the 7th to 10th/11th century AD, were found (Dulinicz, 2011; Wojenka, 2011). A considerable number of them existed as early as the 8th century AD, and a lot of strongholds were built in the 9th century AD (Poleski, 2013; Biermann, 2016; Urbańczyk, 2016a, 2016b). The establishment of the Polish state by the Piast dynasty (Christianity was accepted in 966 AD) caused a drastic decrease in the number of functioning strongholds between the 10th/11th and 13th century AD. In the 10th century AD, the strongholds that did not accept the Piast rule were often destroyed, and only the ruling dynasty had the right to build fortified settlements (Buko, 2008; Kara, 2015).

Although the investigations of early mediaeval strongholds began in Poland before World War II, the vast majority of them were examined after 1945. The research was conducted mainly in western Poland;

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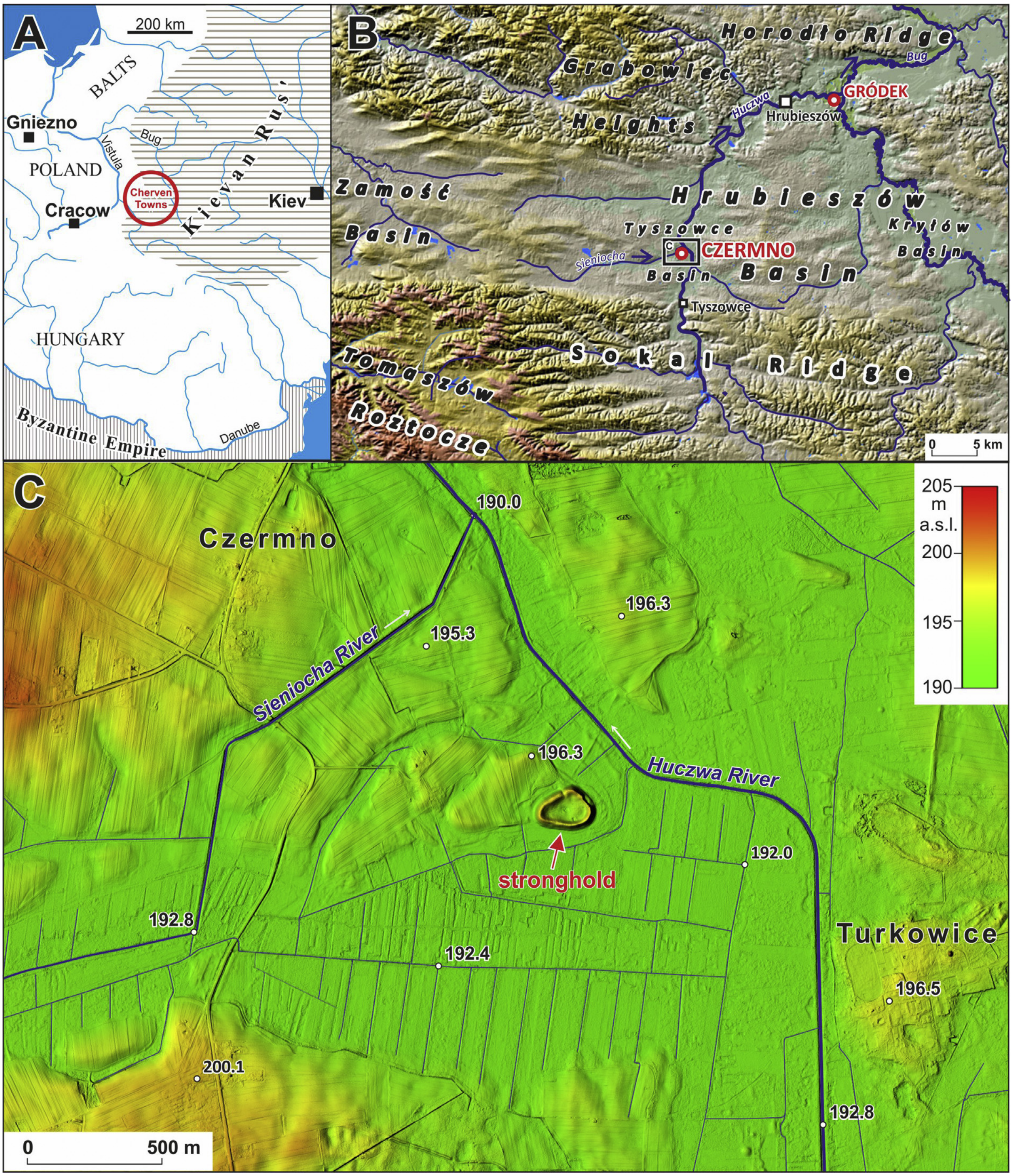

Fig. 1. Location of Czermno site on the background of: A – Europe in 10th century based on Wołoszyn (2013); B – mesoregions of Eastern Poland after Kondracki (2002); C – digital elevation model.

strongholds located in the eastern part of the country were studied to a smaller extent (Wołoszyn, 2012). The early Middle Ages in the borderland between eastern Poland and western Ukraine and Belarus have become the subject of intensive archaeological research only recently. This new research trend includes the investigations of the so-called Cherven Towns – one of the central areas of the Polish-Rus' borderland (Fig. 1A). The supposed location of the Cherven Towns, which were mentioned in the *Russian Primary Chronicle* (Cross and Sherbowitz-Wetzor, 1953), is in the area of the middle reaches of the Bug River, mostly on its left bank (Fig. 1B), and the early mediaeval stronghold at the Czermno site is assumed to have been their capital – Cherven (Fig. 1A). Although the thesis that the stronghold at Czermno was the historic Cherven was proposed as early as the first half of the 19th century, this identification was subject to dispute. The result of the latest research, including the palaeographic analysis of manuscripts of mediaeval Ruthenian chronicles, make the above thesis very plausible (Jusupović, 2017).

The current, interdisciplinary, geoarchaeological investigations of the Cherven Towns area, with the participation of the authors of this paper, started in 2012. The main objective of the research is a full, comprehensive reconstruction of the settlement and the environmental conditions in this area. In this paper we are trying to find answers to questions about (1) the time when the stronghold at Czermno was built, (2) the reasons for choosing this location for such a large structure, and (3) the role of environmental and anthropogenic determinants in the development of this settlement complex. It is equally important to identify the factors that caused the complete abandonment of this large settlement centre already in the Middle Ages.

The achievement of the main research objective involved: (1) determining the present-day environmental conditions in the surroundings of the Czermno archaeological site, (2) reconstructing the Holocene environmental conditions in this area, and (3) estimating the degree of its anthropogenic transformation. In particular, great significance was attached to the reconstruction of the morphological and hydrological conditions in the valley floors of the Huczwa and Sieniocha rivers during the early Middle Ages as well as transformations of the vegetation cover (including phases of human impact).

2. Background

2.1. Archaeological background

Excavations at the Czermno settlement complex were conducted by several research teams in the years 1940, 1952, 1976–1979, 1985, and 1997 (Florek and Wołoszyn, 2016a). Surface investigations were also conducted in the years 1984, 1991, 2008, and 2011–15 (Dzieńkowski and Sadowski, 2016). In the years 2010–2011, archaeological prospection was conducted, during which two treasures dating back to the 13th–14th century AD were discovered, among other finds (Bagińska et al., 2012). In the years 2011–2015, archaeological and environmental investigations were conducted in the outlying suburb settlement by a team led by P. Kittel and M. Poznański (Kittel and Poznański, 2012). The most recent archaeological excavations conducted in this area in the years 2013–2016 encompassed the area of the stronghold (2014–2016) and the inhumation cemetery in the outlying suburb settlement (2013). In 2014 wooden structures and cultural layers were examined in the excavations located in the Huczwa River valley (for literature see below).

The results of the archaeological investigations conducted so far indicate a continuous, though varied, development of settlement in the analysed area from the prehistoric times until the early Middle Ages (Dzieńkowski and Sadowski, 2016). The oldest traces of human existence in the Czermno area date back to the Late Palaeolithic (ca. 12.5 ka–10 ka BC), which corresponds to the warm oscillation of the Allerřd and cold oscillation of the Younger Dryas. More settlement points were dated to the Neolithic (about 5300–2200 BC), the Bronze Age and the Early Iron Age (about 2350–400 BC). This development collapsed in the subsequent centuries (from 300 BC; La Tčne and pre-Roman periods). The Roman period (from the beginning of the 1st century AD until the end of the 4th century AD) was the time of the greatest prosperity of prehistoric societies in the whole Polish territory, as indicated by a large number of artefacts. In the Late Roman period (about 300/310–350 AD) and the beginning of the Migration Period (turn of the 5th century AD), the existing settlement structures collapsed in the study area and the entire Polish territory (Rodzińska-Nowak, 2016).

There were numerous early mediaeval settlements in the vicinity of the settlement complex at Czermno, and mediaeval settlement formation was much more intensive that the one dated to prehistory. As many as 170 sites (featuring 197 relics of settlement) have been discovered in this area to date. These settlements were dated mostly to the 9th - 13th century AD. Early Slavic artefacts (6th–7th century AD) are very rare, the same is true of 8th century finds. The period 9th–10th century is documented by a larger number of finds, and the Early State Period (11th-–13th centuries) by an even larger body of data. Sites documenting the Early State Period sites fall into the following categories: strongholds (1), settlements (45), unspecified traces of settlement (20), cemeteries (7), platforms/log-paved roads (4) (Dzieńkowski and Sadowski, 2016, Fig. 2A and B).

The early mediaeval settlement complex at Czermno consists of the remains of a stronghold and a group of open settlements, situated in the Huczwa River valley. The area of the entire complex is estimated at approximately 75–150 hectares (Florek and Wołoszyn, 2016b). The stronghold and two suburb settlements are the most important settlement points. One – the adjacent suburb settlement – was of a defensive

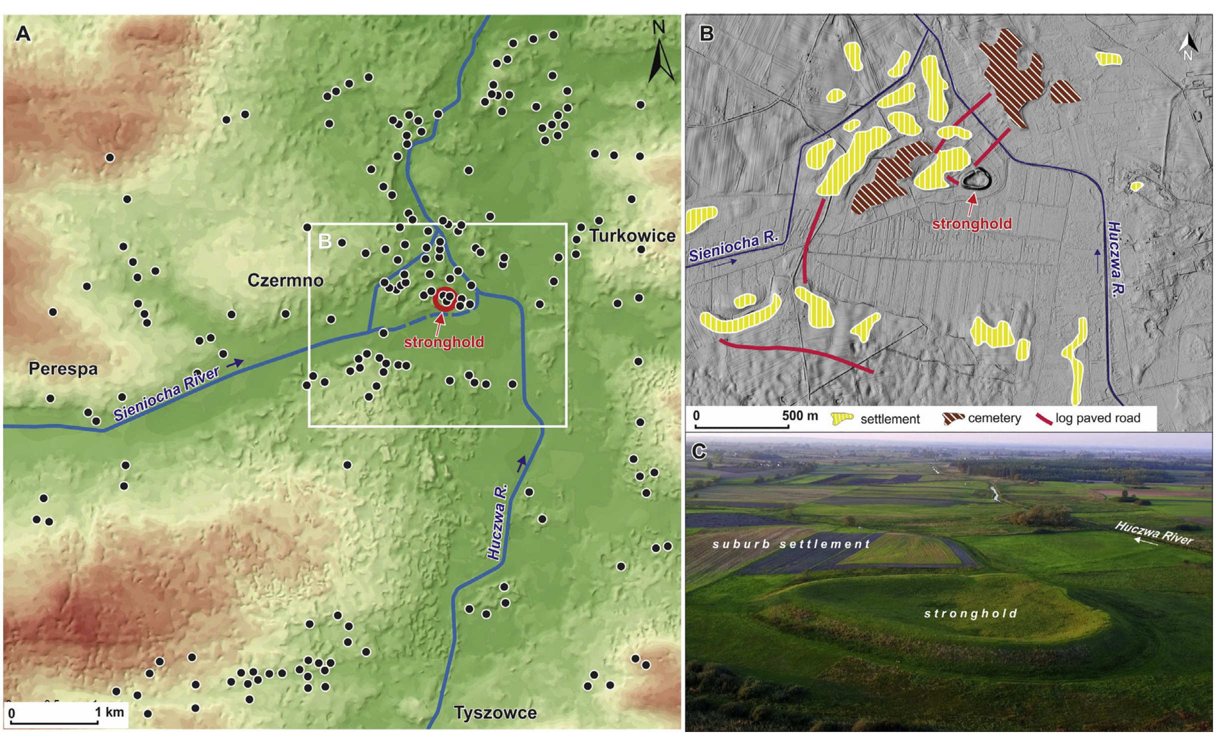

Fig. 2. Main results of archaeological studies in the surroundings of Czermno: distribution of Medieval archaeological sites (A) after Dzieńkowski and Sadowski (2016, modified) and its interpretation (B); aerial photo of the stronghold (photo: Mariusz Gala/Zdzisław Cozac Media Promocja).

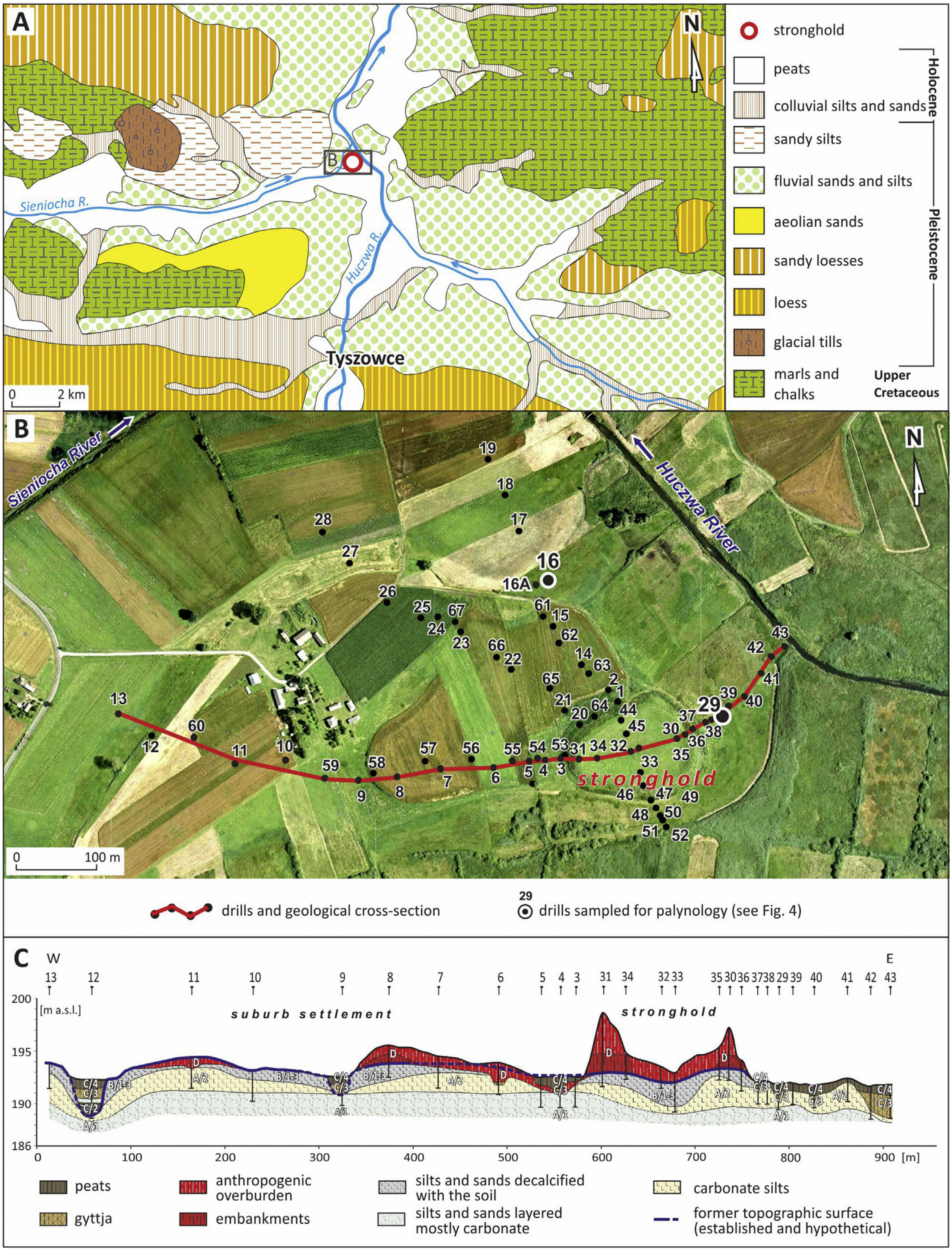

Fig. 3. Stronghold in Czermno and its nearest vicinity: A) on the geological map (after Rzechowski et al., 2009); B) on the aerial photo with the distribution of the drills; C) selected geological cross-section.

nature, while the other – the so-called outlying suburb settlement – was not fortified. They were connected with the surrounding settlements by log-paved roads which were found in different parts of the Huczwa River valley (Fig. 2B).

The analysis of archaeological data from the Middle Ages indicates that the Huczwa River with its left tributary, the Sieniocha River, was the settlement axis in the Czermno area. Almost 95% of settlements were situated at a short distance (100–300 m) from the rivers, and only a few were more than 0.5 km away from the rivers. The settlements were built on the higher terraces in the river valleys. Such location provided access to water, communication and good conditions for defence (Dzieńkowski and Sadowski, 2016).

A clear majority of the finds have been dated to the 10th–13th century AD. Based on the results of investigations (radiocarbon and dendrochronological dating) of the log-paved roads, conducted in the 1970s and 1980s and in the years 2012–2014, three phases of their functioning were distinguished: (1) the second half and the end of the 10th century AD, (2) the second half of the 12th century AD, (3) the second half of the 13th century AD (Florkiewicz and Urbański, 2016; Wołoszyn et al., 2016a). In the so-called outlying suburb settlement, 15 graves were found. Based on the burial features, i.e. skeletons aligned east-west with heads towards the west, the straight position of the bodies, and above all the equipment, we dated the graves to the 12^{th}–13th century AD (Wołoszyn et al., 2014; Kwiatowska and Kuźniarska, 2014).

The most important data were obtained in the excavations situated in the stronghold where the rampart construction was studied. The elements of the rampart were examined in an excavation 26 m long and 6 m deep. Since it did not cover the full section of the rampart, it was supplemented with boreholes. Based on the stratigraphy, two stages of the rampart construction were identified. This indicates that there were two phases in the functioning of the rampart. The external part of the rampart was absolutely dated. It was built from oak logs that were cut at the end of the 10th/turn of the 11th century (985, 983, 989, 1001 AD – Krąpiec, 2015a, 2015b – unpublished data). A large number of artefacts were found in the rampart layers, including the particularly interesting Late Avar belt fitting, which was dated to the 8th century AD (Wołoszyn et al., 2016b). The following finds are also noteworthy: Drohiczyn-type seals (11^{th}–13th century AD), cosmetic objects made of horn (11^{th}–13th century AD), iron arrowheads (8^{th}–13th century AD), and a significant number of ceramic vessels (8^{th}–13th century AD). Human bones found in the rampart were radiocarbon dated at 1220–1260 AD (Wołoszyn et al., 2018a,b).

The most important result of the archaeological investigations is the highly reliable dating of the collapse of the Czermno stronghold to the middle of the 13th century. Its fortifications were destroyed, under Mongol pressure, probably in the 1250s, which resulted in the gradual depopulation of the settlement (Wołoszyn et al., 2018a,b). It was more difficult to determine when the stronghold complex began to function. It certainly functioned at the end of the 10th century AD, but it is more difficult to assess the intensity of earlier settlement activity (8^{th}–10th century AD) whose presence is indicated by surface survey data and, above all, the results of palaeogeographic investigations.

2.2. Environmental background

The Czermno site is located in the central part of the Hrubieszów Basin (Fig. 1B), which is the western, marginal, sub-regional unit of the Volhynia Upland. This mesoregion is situated in the borderland between two main megaregions of the European continent: the Extra-Alpine Central Europe and the East European Plain (Kondracki, 2002). In the transition zone between these units, both the Central European and Eastern European elements of the landscape occur.

The entire Hrubieszów Basin was formed in soft carbonate rocks (marls and chalk) of the Upper Cretaceous as a result of denudation, but its formation was probably conditioned by tectonic structures. Morphologically, it is enclosed from the north and south by loess plateaux with high edges (up to 100 m) of complex tectonic-denudation-accumulation origin. The Hrubieszów Basin was situated in a subparallel depression, along which glacial meltwater flowed in the Pleistocene during the Sanian and Saalian glaciations. That is why this area shows a relatively small diversity of relief (relative elevations of about 30 m, Fig. 1C), and the thickness of Pleistocene deposits is strongly reduced. They occur mainly as infilling deposits in the floors of river valleys (Fig. 3A) (Maruszczak, 1972; Dobrowolski et al., 2015, 2016b).

Hydrologically, the whole area is part of the catchment of the Bug River (third-order stream) and is drained by its left-bank tributaries: Bukowa and Huczwa. The Hrubieszów Basin is characterised by the occurrence of groundwater at small depths, and low discharge of a small number springs. Total runoff from this area is relatively low (about 100 mm annually; see Michalczyk and Wilgat, 2008). This is mainly a consequence of relatively low precipitation (the total annual precipitation is about 550 mm), and its seasonality with the predominance of precipitation in the warm half of the year with high evaporation. The mean annual air temperature is 7.2 °C; it is the highest in July (17.7 °C), and the lowest in January (−4.3 °C). The amplitude of temperatures is 22 °C, which indicates the considerable influence of continental climate (Kaszewski, 2008).

A mosaic of soil types occurs in the Czermno area. The largest area is covered by Luvisols, usually occurring in a complex with Cambisols. They formed on silt formations, loams and clayey sands. On the eastern side of the Huczwa, a large area is covered by Rendzinas that developed on weathered limestones. Chernozems developed on loess occur further (> 10 km) to the north and south of Czermno (Dobrowolski et al., 2016b).

Hydrogenic soils of the Gleysol and Histosol type occur in the extensive valleys of the Huczwa and Sieniocha. Between Czermno and the edge of the Sokal Ridge, there is also a zone of Podzols developed on clayey sands. These soils are currently covered by forests with a varied composition, including a large proportion of pine and oak. From the phytogeographical perspective, there is a predominance of forest communities with predominating Tilio-Carpinetum forests, thermophilous oak groves, and carbonate meadows with a strong admixture of Pontic steppe vegetation (Matuszkiewicz, 2007; Fijałkowski and Izdebski, 2008).

3. Methods

Our studies included the following: (1) geospatial analysis of the site using GNSS and GIS techniques; (2) detailed geological and geomorphological surveys of the site's surroundings; (3) sedimentological analysis of deposits in the soil profiles and drill cores in order to identify the origin of the deposits, the depositional environments, and the direction and rate of natural and anthropogenic changes; (4) pollen analysis of biogenic deposits; (5) main geochemical analyses of inorganic and organic deposits; (6) radiocarbon dating of samples of selected biogenic deposits (peat and gyttja) and wood, (7) thermoluminescence dating of samples of inorganic deposits.

3.1. GNSS and GIS analysis

GNSS and GIS analysis was used to: (1) create an accurate topographic base map and a Digital Terrain Model; (2) precisely locate the

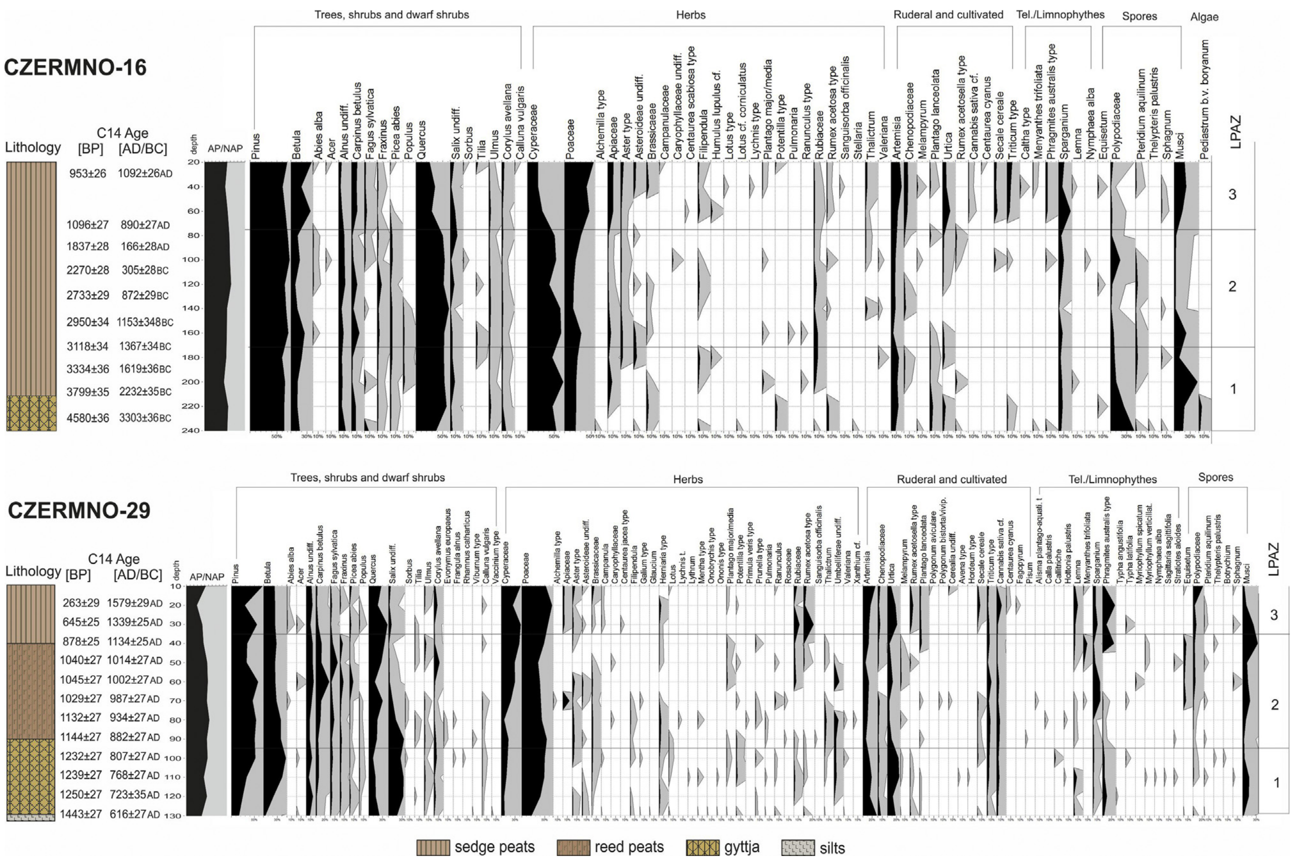

Fig. 4. Pollen diagrams CZ-16 and CZ-29 with the results of radiocarbon dating.

research excavations, archaeological finds and geological drillings, and, consequently, (3) reconstruct the relief before and during the functioning of the stronghold complex. Spatial analyses, together with the visualization of the Czermno site surroundings, were based on: (1) field measurements using GPS/GNSS receivers (Dobrowolski et al., 2011) and (2) Airborne Laser Scanning (LIDAR/ALS). In the first case, a Digital Elevation Model (DEM) was created with an accuracy of 2 m, based on a network of 37,000 GPS points (the so-called point map), which regularly covered the study area (44.4 ha, see: Figs. 2B and 7B). The second method resulted in the creation of a more detailed (horizontal accuracy of 1 m; vertical accuracy of 0.2 m) Digital Terrain Model (DTM). In the final stage, the GNSS/ALS data were visualised as 3D models using the 3D GIS technique.

3.2. Geological and geomorphological survey

Detailed geological and geomorphological surveys were conducted in the stronghold, the two suburbs, and their immediate vicinity including the floors of the Huczwa and Sienicha river valleys (Fig. 3A–C). Core drillings were performed every 10–50 m using a portable drill set with a gouge sampler (1 m long and 3 cm in diameter) and Instorf sampler (0.5 m long and 5 cm in diameter). In total, 67 drillings were made. They were located along the outlined transects using a GPS receiver. Cores of inorganic deposits with undisturbed internal structure were subjected to macroscopic lithofacies analysis according to the general rules published by Miall (1977, 1978) and Zieliński (1995). Based on the obtained results, depositional conditions were reconstructed. Cores of organogenic deposits taken from the palaeochannel of the Sieniocha, labelled CZ-16 (50°39′41,2″N; 23°42′27″E), and from the external moat, labelled CZ-29 (50°39′35,1″N; 23°42′37,9″E), were sampled for pollen analysis and AMS radiocarbon dating (Fig. 3B).

3.3. Pollen analysis

Pollen analysis was carried out on samples representing the youngest stages of biogenic deposition, which were taken every 20 cm from the upper part of the CZ-16 core (palaeochannel of the Sieniocha), and on samples taken every 10 cm from the entire CZ-29 core (external moat) (Fig. 4). Samples for microscopic analysis were prepared according to the Erdtman method (Faegri and Iversen, 1975). In total, 25 samples were analysed. The frequency of pollen in individual samples was different; from 200 to 1080 pollen grains were counted. The percentages of the individual taxa were calculated based on the sum of trees and herbs, excluding telmatophyta, limnophyta, and spores. Pollen diagrams were made based on the POLPAL software (Walanus and Nalepka, 1996).

3.4. AMS 14C dating

Radiocarbon dating was performed for samples of sediments with the highest content of organic matter (OM). 32 samples of biogenic deposits (peat and gyttja) were taken from two cores CZ-16, CZ-29 (Fig. 3B). The bulk samples were sieved to remove contamination with organic residue. The fine fraction (< 150 μm) was then treated with acid-base-acid as described by Hajdas (2008). An equivalent of 1 mg of

Table 1
Synthetic description of lithological units forming the main segments of deposits occurring in the floors of the Huczwa and Sieniocha river valleys near the Czermno site.

Segment/unit	Lithological description	Lithofacies code (after Miall, 1978, as modified by Zieliński, 1995)
Segment A – inorganic deposits (Pleni- and Late Weichselian)		
A/2	massive, carbonate-rich silt with the inserts of fine-grained sand in places	Fm; Sm
A/1	fine-grained, carbonate-free sand	Sm
Segment B – inorganic deposits (Pleni- & Late Weichselian), transformed by pedogenesis (Holocene)		
B/3	fine-grained sand with an organic admixture (soil horizon – A)	SCm
B/2	fine-grained sand with ferruginous nodules (soil horizon – Et)	Sm
B/1	fine-grained, clayey sand (soil horizon – Bt)	SFm; SFh
Segment C – biogenic deposits (Holocene)		
C/4	sedge and sedge-read peat	Cm
C/3	detritus or detritus-calcareous gyttja	FCm
C/2	sedge peat with gytja	Cm
C/1	detritus or detritus-calcareous gyttja, massive or streaky, locally with sand	FCm; SFh
Segment D – anthropogenic deposits (Holocene; Middle Ages)		
D	relocated soil packets, ramparts, dumps, agricultural wastes	SCD(G)m

carbon was combusted and graphitised for AMS analysis that was performed using the MICADAS system at ETH Zurich (Synal et al., 2007). In addition to regular calibration using OxCal 4.2, the radiocarbon ages of the top of the CZ-16 and the CZ-29 were calibrated using the deposition model (Bayesian procedure) within the OxCal v.4.2 calibration program (Bronk Ramsey, 2013).

3.5. *TL dating*

The thermoluminescence method was applied to determine the age of 4 samples of fluvial deposits forming the valley floor (profile CZ-25 – Fig. 3B) and the higher terrace in the Huczwa River valley (profile CZ-16a; Fig. 3B). The dose rate (d_r) was determined using the MAZAR-2011 gamma spectrometer. The concentrations of ^{226}Ra, ^{228}Th, ^{40}K in each sample were obtained from twenty measurements lasting 2000 s each. A sample pre-treated in this way was used to determine the equivalent dose (d_e) by the TL multiple-aliquot regenerative technique for quartz fraction 80–100 μm, according to the description published by Fedorowicz (2006). The TL age is the quotient of the equivalent dose and dose rate.

4. Results

4.1. *Geological situation*

Based on the detailed geological mapping, we were able to: (1) describe the succession of inorganic and biogenic deposits occurring in the valley floors of the Huczwa and Sieniocha rivers (Fig. 4), in the immediate vicinity of the Czermno stronghold, and (2) distinguish the natural and anthropogenic deposit segments. The succession includes four deposit segments, labelled A–D, differing in age and/or lithogenetic features (Tables 1 and 2).

4.1.1. *Segment A – inorganic deposits (Pleni- and Late Weichselian)*

4.1.1.1. Description. Segment A consists of two units, labelled A/1 and A/2 in stratigraphic order. Unit A/1 is composed of light grey,

Table 2
Examples of description of cores/lithological profiles of deposits occurring in the floors of the Huczwa and Sieniocha river valleys near the Czermno site.

Depth (m)	Segment/unit	Lithological description	Lithofacies code (after Miall, 1978, as modified by Zieliński, 1995)
CZ-16 core – palaeochannel of Sieniocha River			
0.00–1.65	C/4	sedge peat, well- and medium-decomposed, dark brown to black, abundant malacofauna	Cm
1.65–2.00	C/3	coarse detritus-calcareous gyttja, abundant malacofauna	FCm
2.00–3.05	C/2	sedge peat, black, with abundant malacofauna, with gyttja in the top part, sharp upper boundary, with the inserts of light grey silty sand with organic streaks, HCl +	Cm; SFh
3.05–4.00	C/1	coarse detritus gyttja, brown, with the inserts of light grey fine-grained sand with traces of streaks, HCl +	FCm; SFh
4.00–5.10	A/2	light grey silt (with organic material), HCl +	SFm
CZ-25 profile – archaeological excavation No 1/2013 in the deposits of higher terrace of the Huczwa River valley			
0.00–0.50	D	organic-mineral deposit, dark brown, with the fragments of pottery and Neogene rocks, HCl +	SCD(G)m
0.50–0.75	B/3	fine-grained sand, organic in the top part, grey, downwards light grey; soil horizon – A	SCm
0.75–1.15	B/2	fine-grained sand, with ferruginous nodules in places; soil horizon – Et	Sm
1.20–1.75	B/1	fine-grained sand, clayey, yellowish-grey, rust-coloured in places, traces of streaks in the bottom part, gradational boundary; soil horizon – Bt	SFm; SFh
1.75–2.25	A/2	sandy silt, light grey, carbonate-rich, sharp upper boundary	Fm
2.25–3.10	A/1	fine-grained sand, white, HCl-	SFm
CZ-29 core – the middle part of the external moat			
0.00–0.40	C/4	herbaceous peat, well-decomposed, dark brown to black, slightly mineralized in the top part	Cm
0.40–0.90		sedge-reed peat, medium-decomposed, dark brown, with abundant plant detritus (0.45–0.50 m) and malacofauna (0.80–1.00 m)	Cm
0.90–1.30	C/3	detritus gyttja, light brown, HCl +	FCm
1.30–2.50	A/2	massive silt, white, locally with the inserts of fine-grained sand with plant detritus, HCl +	Fm; Sm
2.50–3.10	A/1	fine-grained sand, HCl-	Sm

carbonate-free, fine-grained sands, silty sands, and silts. These deposits are identified in exposures and drillings to the depth of about 5 m. Sands and silts forming this unit pass gradationally into carbonate-rich silts and sandy silts of unit A/2.

4.1.1.2. Interpretation. he deposit succession of segment A is a record of fine-grained deposition in fluvial and fluvio-lacustrine environments. It is the last, upper part of the Pleni- and Late Weichselian deposits that occur in the Huczwa River valley; their total thickness is about 10 m (Wojtanowicz, 1974). The gradational transition between fine-grained, carbonate-free sands and silts of unit A/1 and carbonate-rich silts of unit A/2 suggests a gradual decrease of flow energy.

4.1.2. Segment B – inorganic deposits (Late Weichselian), transformed by post-depositional pedogenesis (Late Weichselian and Holocene)

4.1.2.1. Description. Segment B consists of three units. Unit B/1, corresponding to the lower part of the segment, is composed of yellow-rust-coloured silty sands (massive in the top, and usually streaky in the bottom) with a thickness of about 0.5 m. Unit B/2 (0.2–0.4 m thick) is composed of light grey, fine-grained sands with local ferruginous nodules. The top part of the segment – unit B/3 – is composed of dark grey, fine-grained sands with organic admixture, up to 0.2 m thick.

4.1.2.2. Interpretation. Segment B represents the top part of the Late Weichselian fluvial-lacustrine deposits which have been transformed by pedogenesis in the Holocene. Therefore, its successive units correspond to the genetic horizons of Luvisol: unit B/1 is the equivalent of the Bt horizon, unit B/2 – of the Et horizon, and unit B/3 – of the A horizon.

4.1.3. Segment C – biogenic deposits (Holocene)

4.1.3.1. Description. Segment C, forming the top part of the valley floor, is 0.5–4.5 m thick. The deposit sequence includes four main lithostratigraphic units labelled chronologically from C/1 to C/4.

Unit C/1 is composed of coarse detritus gyttja (about 1 m thick) with inserts of fine-grained, streaky sand in the bottom part. It passes gradationally upwards into massive sedge peats with a thickness of about 1 m (unit C/2), locally with malacofauna. The top boundary of this unit is sharp, accentuated by the occurrence of thin (0.1–0.3 m), sandy-silty inserts. Unit C/3 is thin (0.3–0.5 m), and it is composed of detritus-calcareous gyttja with abundant malacofauna. This lacustrine deposit passes gradationally into massive, well- and medium-decomposed sedge peats of unit C/4.

4.1.3.2. Interpretation. The whole segment C is composed of Holocene biogenic deposits which fill the palaeochannels of the Huczwa and the Sieniocha. Detritus gyttja of unit C/1 is a record of a stage after a river meander was cut off and transformed into a water body (i.e. oxbow lake). The oxbow lake became gradually shallow and underwent paludification, as indicated by the occurrence of peats of unit C/2. The sharp boundary, accentuated by sandy-silty inserts, between the peats and the overlying lacustrine deposits can be interpreted as a phase of the relatively short reactivation of channel flow, its subsequent cutoff and another transformation into an oxbow lake, as indicated by the occurrence of detritus-calcareous gyttja (origin of unit C/3). The gradational transition between lacustrine deposits and peats (unit C/4) is a record of a stage in which the water body gradually became shallow and boggy. Besides the natural paludification of oxbow lakes, the origin of unit C/4 may also be related to peat sedentation in artificial basins (moats).

4.1.4. Segment D – anthropogenic deposits (Holocene; Middle Ages)

4.1.4.1. Description. Segment D is composed of mineral-organic deposits with different lithology and thickness (0.2–6.0 m), usually overlying segment B, and less often – segments A and C. Segment D consists of two units. Unit D/1, up to 3.0 m thick, is a sandy-silty diamicton with pockets of organic material. Unit D/2 (up to 3 m thick) is a sandy-organic, carbonate-rich, massive diamicton with numerous sharp-edged fragments of pottery, bones, and Neogene rocks.

4.1.4.2. Interpretation. Unit D/1 consists of anthropogenic deposits. They were accumulated during intentional earthworks (levelling the land and building the ramparts) carried out in the Czermno settlement complex. The origin of unit D/2 should be linked to the cultural layers, the expansion of the ramparts, and the subsequent degradation of the whole settlement complex (disintegration of the timber and timber-and-earth structures).

4.2. Pollen analysis

The pollen diagram from the **CZ-16** core (taken from the palaeochannel of the Sieniocha) was divided into 3 local pollen assemblage zones (LPAZ) (Fig. 4):

4.2.1. Zone 1 – Pinus - Quercus - Artemisia LPAZ (240–170 cm)

The zone is characterised by high *Pinus* and *Quercus* pollen values. The pollen frequencies of *Betula* and *Alnus* are 2.6–6.0% and 1.5–2.9%, respectively. The curves of *Ulmus*, *Carpinus* and *Picea* pollen are low but continuous. *Corylus* pollen appears periodically. Cyperaceae pollen reaches the highest values among herbaceous plants. The zone is also characterised by high pollen frequencies of *Artemisia*, *Plantago lanceolata*, *Urtica* and Cerealia. The latter predominate in the bottom part of the zone where pollen of *Sparganium* and spores of Polypodiaceae also reach higher values. The colonies of *Pediastrum* appear sporadically.

4.2.2. Zone 2 – Pinus - Quercus - Carpinus LPAZ (170–70 cm)

The zone, similarly to the one above, is characterised by high *Pinus* and *Quercus* pollen values. *Carpinus* and *Fraxinus* pollen values increase periodically, especially in the bottom and middle parts of the zone. *Betula* pollen values decrease, especially in the middle part of the zone. *Alnus* pollen values slightly increase. The curves of *Ulmus* and *Picea* pollen are still low but continuous. The continuous curve of *Fagus sylvatica* pollen appears in the upper part of the zone. Cyperaceae pollen is still predominant among herbs. *Artemisia* pollen values decrease. The pollen of ruderal plants and indicators of human economic activities appears sporadically. A low but continuous curve of *Pteridium aquilinum* is a distinctive feature. The frequency of *Sparganium* pollen decreases in the middle part of the zone.

4.2.3. Zone 3 – Betula - Poaceae - Artemisia LPAZ (70–20 cm)

The zone is characterised by increasing *Betula* and *Carpinus* pollen values. The frequencies of *Corylus* pollen slightly increase. *Quercus* and *Alnus* pollen values decrease. Among herbaceous plants, the pollen frequencies of Cyperaceae distinctly decrease and those of Poaceae increase. The pollen values of *Artemisia*, Chenopodiaceae, *Urtica*, Cerealia and *Cannabis sativa* also increase. The pollen frequencies of aquatic and wetland plants, especially *Sparganium* and *Phragmites*, are higher.

The pollen diagram from the **CZ-29 core** (taken from the deposits filling the external moat, Fig. 3B) was divided into 3 local pollen assemblage zones (LPAZ) (Fig. 4).

4.2.4. Zone 1 – Salix - Urtica LPAZ (130–95 cm)

The zone is characterised by high *Salix* pollen values (5.5–12.4%) and increasing pollen frequencies of *Betula* and *Pinus*. *Quercus* and *Alnus* pollen values reach 1.9–11.7% and 1.4–5.6%, respectively. The pollen values of *Carpinus*, *Fagus*, *Ulmus* and *Fraxinus* are relatively low. *Tilia* and *Acer* pollen appears sporadically. The pollen values of shrubs are

Table 3
AMS radiocarbon dates collected from the CZ-16 and CZ-29 cores (Czermno site). Calibrated ages (Calendar time intervals) were obtained using and the deposition model (Bayesian procedure) within the OxCal v.4.2 calibration program (Bronk Ramsey, 2013).

Sample code	Lab No	Depth (cm)	Material	Age ^{14}C (BP)	Calibrated age (95.4% confidence level)	
					calibrated ranges	age-depth model ranges
CZ-16 core – palaeochannel of Sieniocha River						
CZ-16/30	ETH-53672	30	peat	953 ± 26	1023AD – 1154AD	1026AD –1159AD
CZ-16/50	ETH-53673	50	peat	386 ± 26		Outlier
CZ-16/70	ETH-53682	70	peat	1096 ± 27	890AD–1012AD	782AD–998AD
CZ-16/90	ETH-53683	90	peat	1837 ± 28	86AD– 244AD	87AD– 245AD
CZ-16/110	ETH-53684	110	peat	2270 ± 28	400BC–210BC	400BC–210BC
CZ-16/130	ETH-53685	130	peat	2733 ± 29	930BC – 814BC	930BC – 814BC
CZ-16/150	ETH-53686	150	peat	2950 ± 34	1262BC–1048BC	1258BC–1048BC
CZ-16/170	ETH-53687	170	gyttja	3118 ± 34	1489BC – 1284BC	1451BC – 1284BC
CZ-16/190	ETH-53688	190	gyttja	3334 ± 36	1732BC – 1521BC	1727BC – 1512BC
CZ-16/210	ETH-53689	210	peat	3799 ± 35	2401BC – 2064BC	NA
CZ-16/230	ETH-53690	230	peat	4580 ± 36	3499BC –3108BC	
CZ-16/250	ETH-53691	250	peat	too small		
CZ-16/265	ETH-53674	265	peat	4236 ± 36	2916BC –2694BC	
CZ-16/280	ETH-53675	280	peat	8780 ± 37	8165BC – 7677BC	
CZ-16/300	ETH-53676	300	peat	9078 ± 36	8332BC –8236BC	
CZ-16/320	ETH-53677	320	gyttja	9803 ± 39	9311BC –9230BC	
CZ-16/340	ETH-53678	340	gyttja	10155 ± 40	10076BC –9676BC	
CZ-16/360	ETH-53679	360	gyttja	9691 ± 38	9266BC –8921BC	
CZ-16/380	ETH-53680	380	gyttja	9922 ± 38	9648BC – 9284BC	
CZ-16/400	ETH-53681	400	gyttja	9525 ± 40	9132BC –8741BC	
CZ-29 core – the middle part of the external moat						
CZ-29/20	ETH-53692	20	peat	263 ± 29	1510AD–1950AD	1491AD–1668AD
CZ-29/30	ETH-53693	30	peat	645 ± 25	1280AD– 1400AD	1283AD– 1395AD
CZ-29/40	ETH-53694	40	peat	878 ± 25	1040AD – 1230AD	1047AD – 1222AD
CZ-29/50	ETH-53695	50	peat	1040 ± 27	900AD – 1040AD	991AD – 1038AD
CZ-29/60	ETH-53696	60	peat	1045 ± 27	900AD – 1030AD	983AD – 1022AD
CZ-29/70	ETH-53697	70	peat	1029 ± 27	960AD –1040AD	959AD –1016AD
CZ-29/80	ETH-53698	80	peat	1132 ± 27	770AD – 990AD	887AD – 981AD
CZ-29/90	ETH-53699	90	peat	1144 ± 27	770AD –980AD	784AD –980AD
CZ-29/100	ETH-53700	100	gyttja	1232 ± 27	680AD – 880AD	730AD – 884AD
CZ-29/110	ETH-53701	110	gyttja	1239 ± 27	680AD – 880AD	697AD – 839AD
CZ-29/120	ETH-53702	120	gyttja	1250 ± 27	670AD – 870AD	674AD –772AD
CZ-29/130	ETH-53703	130	gyttja	1443 ± 27	570AD –655AD	577AD –655AD

low, the frequencies of *Corylus* pollen range from 0.4 to 1.5%, and *Euonymus europaea* and *Frangula alnus* pollen appears sporadically. The pollen of *Urtica* and Poaceae reaches high values among herbaceous plants. Cerealia, *Cannabis* and other anthropogenic indicators are present. Among aquatic and wetland plants, the highest are the pollen values of *Phragmites*, *Sparganium* and *Lemna*.

4.2.5. Zone 2 – Carpinus - Fagus LPAZ (95–25 cm)

The zone is characterised by increased *Carpinus* and *Fagus* pollen values and decreased *Salix* pollen values. Pollen frequencies of *Betula* decrease, while those of *Pinus* are still high in the bottom part of the zone and decrease in its upper part. The *Alnus* pollen curve increases. The curve of *Quercus* pollen is similar even though it shows a distinct temporary decrease. The pollen frequencies of *Corylus*, *Picea* and *Fraximus* are higher in the upper part of the zone. Among herbs, the pollen values of Cyperaceae increase, while those of Poaceae slightly decrease. The pollen frequency of *Urtica* periodically decreases. *Cerealia* pollen is present. The pollen curve of the *Triticum* type is still continuous. The frequencies of *Sparganium* pollen and Polypodiaceae spores increase in the upper part of the zone.

4.2.6. Zone 3 – Urtica - Poaceae LPAZ (25–10 cm)

The zone is characterised by increased pollen values of herbs, especially Cyperaceae, Poaceae, cereals, hemp and ruderal plants (*Urtica* and Chenopodiaceae). *Carpinus* and *Fagus* pollen values decrease. The pollen frequencies of *Quercus* and *Pinus* fluctuate, while those of *Corylus* slightly increase. Among aquatic and wetland plants, *Phragmites*, *Lemna* reach high pollen values, while those of *Sparganium* are slightly lower.

4.3. AMS 14C dating and the age–depth model

The results of AMS radiocarbon dating of biogenic deposits are presented in Table 3. With the exception of one sample (CZ-16/50, ETH-53673) all the ages are in stratigraphic order. The too-young age of the outlier was most probably caused by contamination with fragments of roots, therefore the < 150 μm fraction was used for analysis of all samples.

The Bayesian approach makes it possible to improve the precision of calendar chronology (Fig. 5).To a certain degree, this is the case for Cz-29, for which the calendar ages of the model have slightly narrower ranges (Table 3). A higher resolution of the sampling would further improve the chronology.

The obtained age of the bottommost part of the CZ-29 core (for the samples of gyttja) could be interpreted as too old in the context of archaeological data. Consequently, it might be argued that the chronology overestimates the time of the construction of moat because of potential hard-water effect when dating bulk sediment. Such effect cannot be totally ruled out, however the chronology of the upper 90 cm based on radiocarbon ages from the peat section (hard-water free) is coherent with the lower section. Moreover, the whole CZ-29 is coherent with chronology of CZ-16, which is mostly a peat section.

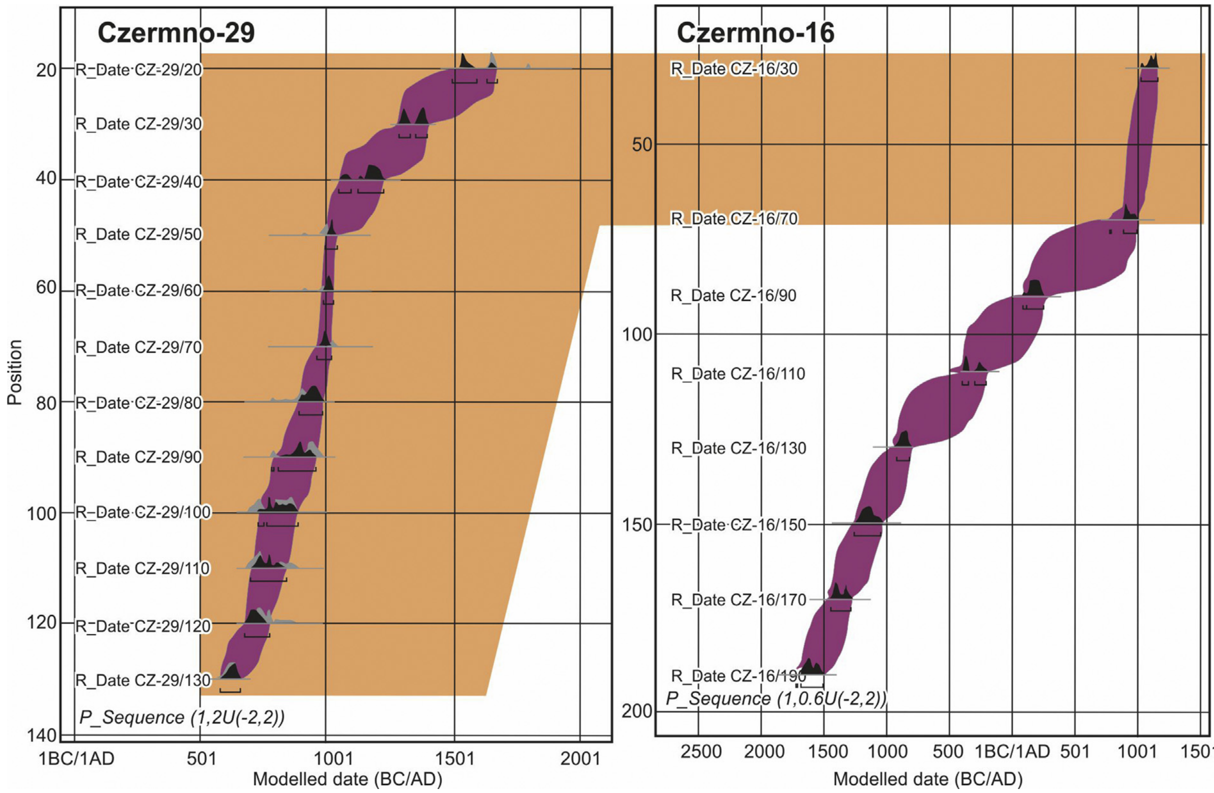

Fig. 5. Age-depth models of the cores CZ-16 and CZ-29. All samples were recalibrated using OxyCal v4.2.4 Bronk Ramsey (2013); r.5 IntCal13 atmospheric curve (Reimer et al., 2013).

4.4. TL dating

The results of TL dating of inorganic deposits are presented in Table 4. The gathered data generally confirm the Weichselian age of the substratum and probably suggest the lithogenetic transformation of the top part of the unconsolidated mineral deposits during the freeze-thaw cycles in periglacial conditions (see Dobrowolski and Fedorowicz, 2007; Dobrowolski et al., 2012).

5. Environmental reconstructions

Based on the detailed studies of natural and anthropogenic deposit succession, we reconstructed the main stages of evolution of the study area (particularly the relief, river channel patterns, and vegetation cover) in the Late Glacial and Holocene, and especially in the Subatlantic period (the last two millennia).

5.1. Reconstruction of palaeorelief

5.1.1. Pre-mediaeval stage (Pleni-Weichselian – Subatlantic)

During the last glaciation (i.e. Weichselian), a backwater lake was formed in the basin-shaped widening of the Huczwa River valley (i.e. the Czermno basin) as a result of progressive aggradation in the river valleys of a higher order (Rzechowski et al., 2009). Various fine-grained deposits of segment A, deposited by weak and fluctuating flow, alternate vertically or laterally. The denuded loess covers of the Sokal Ridge, bordering the Hrubieszów basin in the south, were the main source of mineral material deposited in the lake. Subaqueous and probably intense aeolian accumulation was favoured by the small distance (about 5 km) between the Czermno basin and the edge of the Sokal Ridge (Fig. 1B).

At the end of the Pleistocene and turn of the Holocene, the fluvial-lacustrine deposits were dissected to the depth of several metres by the river channels. At present, they form a higher terrace. At Czermno, at the confluence of the Sieniocha and Huczwa rivers, this terrace is fan-shaped. The fan was formed because the tributary river was drift-dammed by the recipient. The period of river downcutting left several palaeochannels of the Sieniocha, mainly filled with peat (Fig. 3C). They are arch-shaped and are generally WSW–ENE oriented (Figs. 1C and 6).

5.1.2. Mediaeval stage (7/8th–13th century AD)

The settlement complex at Czermno was located on the former Pleistocene fan of the Sieniocha River where it flows into the Huczwa River. The stronghold and the adjacent suburbs were located on the

Table 4
Thermoluminescence age of fluvial sands and silts from the Czermno site.

Sample	No lab. UG	Depth [m]	Lithology	^{226}Ra [Bq/kg]	^{232}Th [Bq/kg]	^{40}K [Bq/kg]	Dose rate d_r [Gy/ka]	Equivalent dose d_e (Gy)	TL age [ka]
CZ-16/1	6953	1.50–2.0	sands	20.5 ± 0.2	30.4 ± 0.3	492 ± 45	2.49 ± 0.23	30.1 ± 2.8	12.1 ± 1.6
CZ-16/2	6954	4.25–4.50	silts	4.9 ± 0.1	2.9 ± 0.1	135 ± 13	0.62 ± 0.06	70.8 ± 6.9	104 ± 17
CZ-25/1	6955	0.90–1.00	silts	10.8 ± 0.1	7.9 ± 0.1	292 ± 27	1.31 ± 0.12	14.0 ± 1.2	10.7 ± 1.4
CZ-25/2	6956	1.30–1.35	silts	5.9 ± 0.1	9.0 ± 0.1	249 ± 24	1.10 ± 0.10	20.1 ± 1.9	18.3 ± 2.4

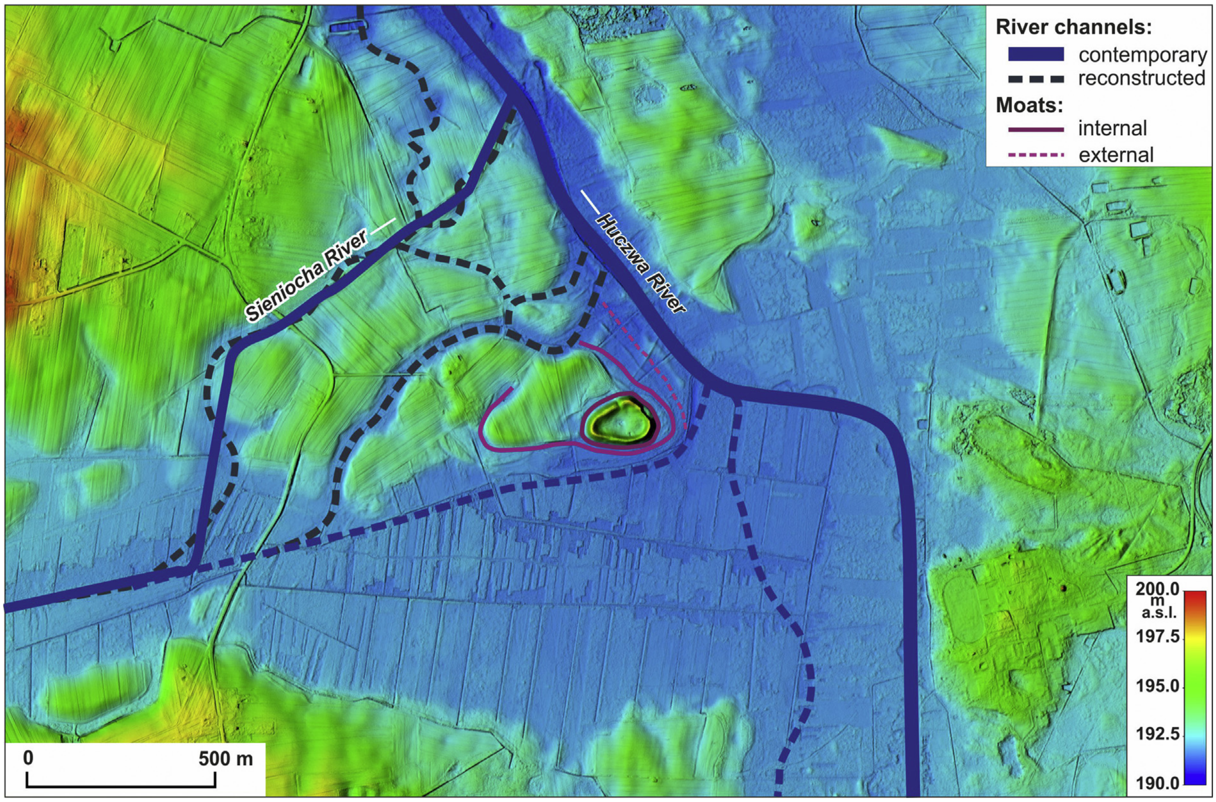

Fig. 6. Reconstruction of river channels and system of moats in the vicinity of the Czermno settlement complex.

higher surface of the river terrace, and some palaeochannels were transformed into moats. The edges of the terrace promontory separating the channel zones of the Huczwa and Sieniocha rivers were elevated by 2–3 m (lithological unit D/1) using the material obtained during the alignment of the terrace edges and digging of the moats. The timber-and-earth fortifications of the stronghold were built on this embankment. Similar work was done on the outskirts of the adjacent suburb settlement, where the embankment was also topped with the timber-and-earth fortifications. Within the suburbs, the ground was levelled in some places for building purposes, as indicated by packages of substratum material (lithological unit D/1) overlying the Holocene soil (segment B) in the depressions, which are buried at present.

The deposits of unit D/2 represent the top layer of the ground within the stronghold and suburbs. Their physical features and structure indicate that it is a cultural layer. In the suburbs and in the stronghold courtyard, it is several decimetres thick.

Within the rampart of the stronghold, the thickness of the unit D/2 locally exceeds 3 m. This indicates that the stronghold fortifications were repaired during within a few centuries of their use (Wooszyn et al., 2015). The ramparts of the stronghold are well preserved to the present day. They are 5–7 m high now, and the inclination of the slopes is considerable: on the inside it is 10–15°, and on the outside it is 20–30°. On the other hand, the rampart of the adjacent suburb settlement has been considerably reduced by agrotechnical work. The moats became shallower by a few decimetres due to the sedentation of peat (unit C/4).

5.2. Palaeohydrological reconstruction

The backwater lake, which existed in the Czermno basin during the Weichselian, was drained in the Late Glacial as a result of the downcutting of the Pleistocene valley floor by the Huczwa River. The alluvial fan of the Sieniocha River was dissected at the same time. The largest palaeochannel of the Sieniocha carried water at the beginning of the Holocene. However, based on the analysis of radiocarbon-dated deposits in the CZ-16 core, we found that it was cut off from the main stream already in the Preboreal and Boreal periods (till 10 200 cal BP) and functioned as an oxbow lake that was gradually overgrown.

High-resolution, multi-proxy environmental reconstructions carried out in the upper section of the Sieniocha River valley (Komarów site – distance *ca.* 15 km towards west from Czermno) indicate significant fluctuations of temperature and humidity in the study area during the Middle Ages (Dobrowolski et al., 2016a). Distinctly cooler and dry climate oscillations are recorded between 1400 and 900 cal. BP (500–1050 AD). Due to the low level of groundwater, the conditions in the river valleys were favourable to carrying out hydrotechnical work necessary for the construction of fortifications. Probably after their completion, the water level was intentionally raised, as evidenced by the occurrence of lacustrine deposits in the surroundings of the site. In the period from the mid-11th century AD to the end of the Middle Ages, the climate was changing to warmer and more humid (Dobrowolski et al., 2016a). These conditions were favourable to the widespread accumulation of biogenic sediments in the floor of the Huczwa River valley.

The relief of the floors of the Huczwa and Sieniocha valleys indicates that the drainage pattern in this area was different from the present-day one (Fig. 6). The Sieniocha River, in its lower course, flowed south of the settlement complex, and its confluence with the Huczwa River was situated near the stronghold (Rzechowski et al., 2009). The present-day average discharge of the Huczwa River downstream of Czermno is circa 3 m^3/s, and at its confluence with the Bug River it exceeds 4 m^3/s (Michalczyk and Wilgat, 2008). The discharge of the Bug River downstream of the mouth of the Huczwa River (near the early mediaeval Gródek/Wołyń site – Fig. 1B) is about 40 m^3/s, so the Bug is a relatively large river. In the Middle Ages, the average discharges were probably similar to the present-day ones, but they were certainly less changeable due to the predominance of forest-covered areas that retained water.

5.3. Reconstruction of the plant cover

The reconstructed history of vegetation cover in the surroundings of Czermno covers the Neoholocene stage of its development (CZ-16 core), especially the Middle Ages (CZ-29 core).

5.3.1. 3400–1400 years BC (Fig. 4/CZ-16; LPAZ 1)

In this period, pine forest and mixed coniferous forest communities with *Pinus* and *Quercus* predominated in the surroundings of the study site. The role of deciduous forests was relatively limited. Only thermophilous oak forests (*Potentillo albae-Quercetum*) could be more important, as well as forest communities (alder and with an admixture of elm, spruce and ash) occupying wet and waterlogged habitats, and willow thickets. Forests were not dense, and fern communities of the Polypodiaceae family developed in the clearings, especially in the period from 3400 to 2240 years BC. High frequencies of Cyperaceae and Poaceace pollen indicate the occurrence of open areas. Indicators of livestock-pastoral farming and cereal cultivation confirm the human impact on the vegetation cover. Ruderal and nitrophilous taxa may indicate the presence of human settlements. High frequencies of sedge pollen and moss spores are connected with the development of sedge-moss mires. The occurrence of colonies of *Pediastrum* algae is probably connected with the existence of open water bodies. This indicates a relatively humid environment, which is evidenced by the continuous pollen curve of *Sparganium* and sporadic occurrence of *Phragmites*, *Lemna* or *Menyanthes trifoliate* pollen.

5.3.2. 1400 years BC–7th century AD (Fig. 4/CZ-16; LPAZ 2)

From 1400 years BC, the proportion of deciduous forests with hornbeam slightly increased, especially about 1260 and 560 years BC, even though pine and oak forests were still predominant. At that time, forests with *Alnus*, *Fraxinus*, *Ulmus* and *Picea*, growing on wet and waterlogged habitats, also became more widespread. Large areas were occupied by open communities with sedge and grasses, with a lower proportion of Bryales mosses. In the case of anthropogenic indicators, the predominance of the pollen of ruderal plants, particularly Artemisia, was found.

5.3.3. 7th–8th century AD (Fig. 4/CZ-29; LPAZ 1)

The lower curves of *Sparganium* pollen and Bryales spores indicate dry climate conditions at the beginning of the 7th century AD, with a tendency for increased humidity in the successive decades of that century. At that time, willow-birch thickets grew in the Huczwa River valley, as indicated by the high pollen values of *Salix* and *Betula*. Sandy habitats (i.e. higher terraces) were covered by coniferous forests. Mixed pine-oak forests could occupy habitats that were richer in nutrients. Small areas in the surroundings of the study site were covered by deciduous forest. Oak-lime-hornbeam forests (*Tilio-Carpinetum*) could occur in fertile habitats, and riverine forests with *Fraxinus* and *Ulmus* grew on wetter grounds. Alderwoods with *Alnus glutinosa* and an admixture of spruce developed in waterlogged habitats. High pollen values of ruderal plants (*Artemisia*, *Urtica*, Chenopodiaceae) and cultivated plants indicate human economic activity. The increasing pollen values of *Triticum* indicate the intensification of cereal cultivation. The pollen frequency of Telmatophytes indicates relatively wet conditions since the beginning of the 8th century AD as well as the existence of water bodies with *Lemna*, *Myriophyllum* and *Nymphaea alba*. The decreasing pollen values of *Phragmites* may evidence a tendency for the climate to become drier at the end of this period.

5.3.4. 9th–13th centuries AD (Fig. 4/CZ-29; LPAZ 2)

From the end of the 8th century AD, the role of willow-birch shrubs became considerably smaller, and the proportion of wetland species was also small. The results of multiproxy studies from Komarów site situated in the upper part of Sieniocha river catchment (see Dobrowolski et al., 2016a) suggest rather dry condition of climate in this period. In the Czermno site this interpretation seems to be confirmed by low pollen values of *Phragmites* and *Sparganium*. The progressive increase in humidity and the accompanying rise of groundwater levels started only in the 10th century AD. The communities with *Sparganium*, and then with *Phragmites*, developed again. Aquatic species of the *Myriophyllum* genus also appeared. The occurrence of moss spores and *Menyanthes trifoliata* pollen indicates the existence of a transitional mire. Deciduous forests with *Carpinus* and *Fagus* in fertile and moderately wet habitats as well as forests on wet habitats with *Alnus*, *Fraxinus* and *Picea* occupied larger areas. In coniferous and mixed coniferous forests, the proportion of pine decreased and that of oak increased. The increased pollen values of *Corylus* and *Polypodiaceae* indicate that these forests became less dense. The development of deciduous forests, the changes in the species proportions of mixed coniferous forests, and a simultaneous decrease of pollen values of cereals, particularly *Secale cereale* and *Cannabis sativa*, may indicate a decline in economic activity from the end of the 11th century AD to the mid-12th century AD. The proportion of ruderal indicators decreased significantly, which may indicate a change in land use.

5.3.5. 13th century AD–the present (Fig. 4/CZ-29; LPAZ 3)

The increased pollen values of herbaceous plants and anthropogenic indicators evidence significant deforestation and increased human economic activity starting from the 13th century AD. The most significant change that occurred in the forests was a decrease in the proportion of deciduous trees (*Carpinus*, *Fagus*, and *Fraxinus,* and, from 1670, *Quercus* as well). The intensification of human economic activity from 1370 AD is marked by an increase in the pollen frequencies of nitrophilous plants (*Urtica, Chenopodiaceae*), pastoral farming indicators (*Plantago lanceolata*), fallow plants (*Rumex acetossella*) and cultivated plants (*Secale cereale, Triticum type, Fagopyrum* and *Cannabis sativa*). Quite high pollen values of *Phragmites* and *Sparganium* indicate a considerable paludification and growth of rushes.

6. Discussion

6.1. Settlement development

Both excavations and surface investigations indicate that a well-developed settlement existed in the Czermno area from the Neolithic to the early Middle Ages (Fig. 7). During this long period, however, there were stages of both intensification and recession of settlement activity. Two periods, characterised by varying settlement activity, are well-documented palynologically: 3400–1400 BC and the Middle Ages. The settlement activity of the Funnel Beaker, Globular Amphora and Early Bronze cultures developed in the first period. The pollen record for this period is characterised by high pollen values of herbs, which evidences the occurrence of open areas and clearings in the forests. Ruderal and nitrophilous species indicate the existence of permanent settlements. Indicators of livestock-pastoral farming and cereal cultivation are also present in the pollen diagrams. The human impact on the landscape in the period when the Lusatian Culture developed, as well as in the Pre-Roman and Roman periods, are also recorded in the pollen spectra, even though they are less visible. These periods were characterised by the expansion of deciduous forests with hornbeam, and, on wet and waterlogged habitats, forests with *Alnus*, *Fraxinus*, *Ulmus* and *Picea*. However, large areas covered by open communities with herbaceous plants still occurred.

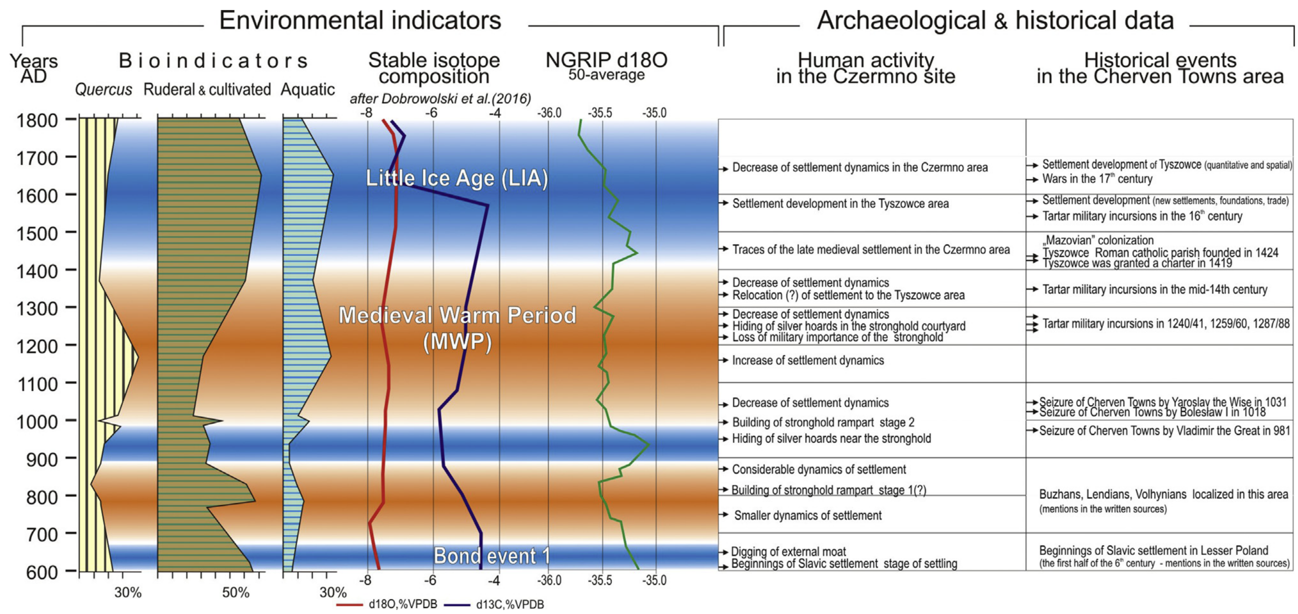

Fig. 7. Correlation of environmental, archaeological and historical proxies of the Czermno site – orange zones indicate warm periods and blue – cold ones. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Another period of intensified settlement and economic activity in the study area, recorded in the pollen diagrams as high pollen values of cultivated and ruderal plants, occurred in the 7th century AD (Fig. 7). It was in that period that probably also the first hydrotechnical work (i.e. digging of an external moat – recorded by AMS) was carried out under relatively low groundwater level conditions in the Huczwa River valley. A considerable decline in economic activity, which occurred at the 8th century AD, is recorded as lower pollen values of cereals and fodder crops. Humidity progressively increased in that period (Dobrowolski et al., 2016a). However, it is difficult to estimate the real scale of the early Slavic settlement (7th–8th century AD) because the described bioindicators of anthropogenic activities are not accompanied by archaeological data. The results of archaeological and environmental investigations are actually similar. It should be stressed that it is extremely difficult to capture early Slavic settlement both at the Polish and European level. Due to the scarce traces of the early Slavic culture, absolute dating is beginning to play a dominant role in the investigation of settlement chronology (Dulinicz and Moździoch, 2013). So far, archaeological investigations at Czermno have been focused mainly on the stronghold area. It cannot be ruled out, however, that older fortifications (7th–9th century AD) were built in a different location than the stronghold proper. Some parallels can be drawn based on investigations of other large early mediaeval settlement complexes at the sites in Stradów and Przemyśl (Poleski, 2004).

The end of the 8th and turn of the 9th century AD was characterised by climate warming and recorded as a period of a dynamic increase in the pollen frequencies of cereals and ruderal plants. At the same time, hygrophilous and aquatic plants reached their maximum pollen values, which evidences increasing humidity and a rise in groundwater level. A considerable decrease in the pollen values of oak (CZ-29 core) indicates intensive felling or even clearance of oak trees in the first two decades of the 9th century AD. Such an intensification of human activity in the study area can be probably linked with the first phase of the construction of the stronghold fortifications or/and wooden infrastructure connected with the settlement, e.g. log-paved roads. The settlement activity in this period is evidenced by a considerable increase in the quantity of artefacts discovered during surface archaeological prospections. The compatibility of pollen analysis results and the results of archaeological investigations of early mediaeval strongholds was documented in other regions of Poland (Chudziak, 2004; Grygiel and Jurek, 2014; Makohonienko, 2014; Kittel et al., 2018).

The settlement near Czermno was stable from the mid-9th century AD to the end of the 10th century AD. Under cooler and drier climate conditions, a relative decrease of cereal cultivation occurred simultaneously with a slow regeneration of oak forests. A distinct, abrupt but short-lived (about 2 decades) increase in human activity occurred at end of the 10th and turn of the 11th century AD, and was related to the improvement of climatic conditions (increase of humidity and mean annual temperatures). Intensive agriculture, evidenced by increased pollen values of anthropogenic indicators, was accompanied by the felling of oak trees on a large scale. The results of pollen analysis are confirmed by the results of archaeological excavations and dendrochronological dating (999, 1020 AD) of timber from the fortifications. A similar age (1030 AD) of these structures was obtained earlier by Urbański (2000). Therefore, this period was the second well-documented phase of the construction of the stronghold rampart and log-paved roads linking the stronghold with the suburbs in the waterlogged area. The most numerous and valuable artefacts date back to the end of the 10th century AD. *The Russian Primary Chronicle* (Cross and Sherbowitz-Wetzor, 1953) reports that battles took place between Poland and Rus' for the territories situated in the middle reaches of the Bug River at the end of the 10th century AD. A distinct decline in economic activity in the stronghold surroundings lasted from the end of the first half of the 11th century AD to the mid-12th century AD. This is evidenced by the development of deciduous forests, changes in the species proportions of mixed coniferous forests, and decreasing area of cereal cultivation.

The subsequent intensification of human economic activity, which started in the mid-12th century AD, coincided with the Mediaeval Climate Optimum. Pollen indicators evidence considerable deforestation as well as increased area of pastureland, fallow land, and cropland. These trends have continued to the present day. The results of archaeological research indicate that it was a period of new prosperity for Cherven, which certainly was a centre of trade. This is evidenced by numerous artefacts dating back to the 12th–13th century AD, notably the over 1000 seals of the Drohiczyn type that constituted a kind of customs mark (Wołoszyn et al., 2016c). In the 13th century AD, and particularly in its second half, the Czermno stronghold gradually lost its military function and became a necropolis. This is indicated, among others, by numerous burials discovered in the stronghold, including those on the rampart (Wołoszyn et al., 2018a,b), as well as two treasures discovered in the stronghold courtyard that were dated to the end of the 13th century AD and/or the beginning of the 14th century AD (Piotrowski and Wołoszyn, 2012). Paradoxically, they reflect the end of the functioning of the stronghold, not its prosperity: the treasures buried near the surface have been preserved to our times due to the depopulation of the stronghold and its becoming a cemetery.

6.2. Determinants of the stronghold's location

What were the factors that determined the location of the Cherven stronghold on the Huczwa River? The success of centres such as Mikulčice in Great Moravia (Poláček, 2014), Poznań (Koćka-Krenz, 2013) or Kraków in Poland in the Piast era (Poleski, 2010), and Novgorod, Gniezdovo or Kiev in Rus' (Androshchuk, 2013; Makarov, 2017) was determined by their location close to large rivers – important travel and trade routes. The Bug River was undoubtedly of great importance as a waterway already in the 10th century AD; this is evidenced by the results of archaeological and historical research (Wąsowiczówna, 1959; Łosiński, 2002; Skrzyńska-Jankowska, 2007). However, the Huczwa River, on which the Czermno site is situated, could not play a similar role in the history of the Polish-Rus' borderland. According to the source materials from the early Modern Period, the Huczwa is not classified as a very important waterway (Janeczek, 2016; cf. Freund, 2007). However, the discharge of the lower Huczwa River, at a relatively low gradient, could be sufficient for local transport. In the early Middle Ages, the Huczwa River was probably a branch of the Bug River, which was a navigable waterway (cf. remarks about the accessibility of the Łęczyca medieval stronghold – Makohonienko, 2014). Additionally, the latitudinally oriented routes played a more important role in trade and travel in that period (Wąsowiczówna, 1959; Dunin-Wąsowicz, 2011).

It seems that the stronghold was located in the boggy valley of the Huczwa River, at its confluence with the Sieniocha River, mainly due to the defensive properties of this place. A similar situation took place in the case of the stronghold at Belz (modern Ukraine), located 40 km SE of Czermno. Belz is surrounded by the Solokiya River, its branch, and its tributary – the Rzeczyca River (Petryk et al., 2004). These rivers and the surrounding wetlands made the stronghold very difficult to capture, which was widely reported in written source materials (Janeczek, 2016).

It should also be stressed that oak and pine forests occurring near the Czermno settlement complex provided an abundance of good building material (Figs. 4 and 7). The pollen record indicates that these two tree species were intensively felled in two periods: in the first decades of the 9th century AD, and at the end of the 10th and turn of the 11th century AD. Successful cereal cultivation and livestock-pastoral farming on the relatively fertile soils and extensive meadows provided food for the stronghold's inhabitants. This is recorded in the pollen diagrams as high pollen values of cereals and herbs (Figs. 4 and 7).

6.3. Determinants of Cherven's collapse

The main question of our research is: what were the factors that determined the collapse of the Cherven stronghold on the Huczwa River? As a settlement centre, it underwent a crisis at the end of the 11th and turn of the 12th century AD, which was probably determined by political factors. This collapse is clearly visible in the pollen record. From the second half of the 13th century AD, Cherven did not function as a fortified stronghold despite the development of settlement in its surroundings. Such a spectacular collapse was probably caused by various factors of political-historical, socio-economic and natural character.

Mongols certainly contributed to the destruction of the stronghold. They laid siege to Cherven in 1240 but it seems that the end of the fortifications at Czermno was caused by events that directly preceded the second Mongol invasion of Poland (1259/1260). Namely, in late autumn of 1259 the Mongol military commander Burundai forced the dukes of Galician-Volynian Rus' to destroy fortifications (including Cherven) in territories under their rule. This was meant to prove their loyalty to the Golden Horde (Perfecky, 1973; Dąbrowski, 2012). Although Cherven is mentioned (for the last time) as late as 1289, it seems that its time of prosperity as a stronghold with a great strategic significance had already ended. In all probability it was in the late autumn of 1259 that the fortifications of Czermno/Cherven were demolished and they became part of a cemetery (Wołoszyn et al., 2018a,b). Czermno was overshadowed by the neighbouring centres, particularly Belz, which rapidly developed and became the capital of the Duchy of Belz from the 12th century AD, and a small town of Tyszowce, which became a local centre in the 15th century AD (Janeczek, 2016). The limited role of the Huczwa River as a navigable waterway could also hinder the further development of Cherven and its participation in the urbanisation process in the 14th and 15th century AD. The progressing deforestation had to cause the occurrence of more frequent and longer periods of low flow in the Huczwa River.

7. Conclusions

The results of the new geoarchaeological analysis carried out at the Czermno site – the historical, mediaeval capital of Cherven Towns – provide new information about the history of settlement in this area during Middle Ages, and its links with environmental changes. The main results of our studies show that:

(1) In the early Middle Ages, the beginnings of settlement and economic activity in the Czermno area date back to the end of the 7th century AD. The first hydrotechnical work in the Huczwa River valley (i.e. digging of an external moat), carried out under relatively low groundwater level conditions (due to a relatively cool and dry climate), should be linked with this period.
(2) Intensive transformations of the landscape (i.e. adaptation for settlement) were carried out on a large scale during the subsequent five centuries. They involved land levelling and reorganization of drainage by means of the construction of moats, ramparts and log-paved roads.
(3) Reliable multi-proxy data indicate that human impact on the environment was particularly strong (i) in the mid-9th century AD (probably the construction of the stronghold rampart [?] and/or log-paved roads as well as intensive agricultural activity), (ii) at the end of the 10th and turn of the 11th century AD (well-documented construction of the stronghold rampart, expansion of the suburbs), and (iii) in the second half of the 12th century AD (the flourishing of trade at Czermno).
(4) All these main stages of human activity were connected with a relatively warm and humid climate.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.quaint.2018.05.042.

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