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Late Neolithic and Middle Bronze Age barrows in Bukivna, Western Ukraine as a source to understand soil evolution and its environmental significance

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ABSTRACT

Barrows play an important role in paleoenvironmental studies. This research, conducted on macromorphology (descriptive), micromorphology (thin-section), physical and chemical properties of a burial mound necropolis located in the western part of Ukraine (near Bukivna village), aimed to reconstruct the climatic conditions and landscape of the area during the Late Neolithic and Middle Bronze Ages, when they were erected. The analysis of pedogenic and post-depositional processes has made it possible to determine the evolution of soils beginning around 4000 BP. Three phases of change in vegetation, climate, and soil conditions have been distinguished. Between 6000 and 4200 BP, the brown forest soil formed at the beginning of Subboreal period. Later, the formation of chernozems (*Chernozems*) took place between 4200 and 3300 BP, chernozems (*Chernozems*) formed, at an increasing rate as meadow and meadow-forest which led to the continental climate spread through the area, while in the Forecarpahians forest areas their transformation into gray forest soils (*Luvic Phaeozems*) is visible, and podzolized brown soils (*Dystric or Haplic Cambisols*) developed about 150 BP in a cooler and much more humid climate conditions than were present in the beginning of the Subboreal period. From the present study it was concluded that post-depositional processes, such as podzolization, lessivage, and illimerization, change the original properties of soils, while others, like the activity of fauna, result in krotovinas filled with original humus, and makes it easier to recognize fossil soils.

1. Introduction

Burial mounds occur in many regions of the world and constitute an important element of the funeral rites of prehistoric and historic communities. A zone with a high incidence of barrows includes the steppe areas of Eurasia (Anthony, 2007; Sudnik-Wójcikowska and Moysiyenko, 2013b; Chernykh and Daragan, 2014; Makarowicz et al., 2019). After the period of archaeological excavations, they were increasingly subjected to interdisciplinary research.

Often, burial mounds in the steppes were made of homogeneous loess material; they were created on chernozems and covered with modern soils (Mitusov et al., 2009). Results of geoarchaeological surveys in recent years has brought about paleoenvironmental reconstructions, which has allowed researchers to determine the intensity and direction of pedogenetic and diagenetic processes of soil formations in the last 5000 years (Zaitseva et al., 2005; Khokhlova, 2007; Khokhlova and Kuptsova, 2019; Alexandrovskiy et al., 2001; Alexandrovskiy, 2007; Alexandrovskiy et al., 2014; Demkin et al., 2014). Among the paleopedological, microbiological (Peters et al., 2014; Khomutova et al., 2019), and mineralogical analyses (the rate of change of clay minerals), micromorphology (Doroshkievych and Matwiishyna, 2014; Tóth et al., 2014; Matviishyna and Parkhomenko, 2019) and magnetic susceptibility were used for paleoclimatic reconstructions and understanding soil evolution (Khomutova et al., 2007; Alekseeva et al., 2007; Lisetskii et al., 2014). Moreover, attempts were made to reconstruct the vegetation based on palynological studies of the organic horizons (Kvavadze, 2006; Kvavadze et al., 2007, Kvavadze and Kakhiani, 2010, Harmata et al., 2013a; Kvavadze et al.,

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2015; Prikhod'ko et al., 2016). Flora study was also considered in terms of treating burial mound environments as steppe floral refugia (Rowińska et al., 2010; Sudnik-Wójcikowska and Moysiyenko, 2013a). A separate issue in the studies reviewed was the post-depositional processes, such as bioturbation, which may affect the stratigraphy of the mounds (Pietsch, 2013).

Barrows in the steppe area of the Carpathian Basin has been the subject of paleoenvironmental research in the last decade. Interdisciplinary research from Hungary on the basis of chemical, mineralogical, malacological and phytolits studies shows that in the period from 6000 BC, burial mounds were created on *Chernozems*, and also the soils developed on the mound (Barczi et al., 2006a, 2006b; Barczi et al., 2009; Pető and Barczi, 2011).

In the borderlands of the steppe and forest-steppe of East-Central Europe, the construction of barrows spread during the 3rd and 1st half of the 2nd millennium BC (Sulimirski, 1968; Makarowicz et al., 2018, 2019). Its occurrence was associated with the A-horizon of the Corded Ware culture. The next stage of mound building is associated with the Komarów culture, dated to the Middle Bronze Age (1800–1500 BC). It formed in areas of Podolia, the Eastern Subcarpathians and southern part of Volhynia. One of the largest concentrations of Komarów culture barrows was identified in Bukivna in the Upper Dniester Basin (Makarowicz et al., 2018).

The first research of the Bukivna necropolis took place in the 1930's (Bryk, 1932; Siwkówna, 1938). At that time, 13 mounds were excavated. Between 2010 and 2015, the studies were resumed. As a result of excavations and non-invasive surveys, about 150 barrows were registered within a 5 km radius of Bukivna. Part of them were investigated using magnetometry while 6 were excavated (Makarowicz et al., 2016, 2018). From 5 of the investigated barrows, 31 radiocarbon determinations were obtained. Radiocarbon dating indicated that the barrows had been in use from the first half of the 17th century to the second half of the 16th century BC. The breaks between the rise of subsequent mounds were set at approximately 35 years. The older phase of the barrow construction related to the Corded Ware culture, dating from 2400 to 2200 BC, was also identified (Table 1, Makarowicz et al., 2018).

The aim of this paper is to reconstruct and compare environmental – landscape, and climatic– conditions during the formation of burial mounds in the Late Neolithic and Middle Bronze Ages, with those of modern ones based on paleopedological and micromorphological studies. Another aspect of this research is to assess how post-depositional processes changed the lithological and geochemical composition of the mounds.

2. Study area

The barrow necropolis in Bukivna is situated in the western part of Ukraine in the Ivano-Frakivsk oblast (Fig. 1). This area lies on the borderline of the Subcarpathia Plain (Eastern Subcarpathia) and the Volhynia-Podolia Upland, on the edge of forest-steppe and forest zones (Mizerski and Stupka, 2005; Łanczont et al., 2002).

The archaeological site in Bukivna is one of the largest barrow cemeteries in this part of Europe. The groups of mounds are located on the right bank of the Dniester river, approximately 1.5 km from its bed, in the Bystrytsia-Tlumach Upland, part of the South Opillia Upland (Makarowicz et al., 2018). The main geomorphological units of the studied region are hills crossed by the dense valleys of rivers flowing down from the Carpathians to the Dniester valley. The uplands were cut during the Miocene period, and in the Pleistocene, they were covered with coarse sand and gravel. Currently, loess covers their surface (Kravchuk, 1999; Łanczont et al., 2002; Łanczont and Boguckij, 2007; Gębica, 2013; Gębica et al., 2013a, 2013b).

The elevated landforms are characterized by elongated and raised hills that are 350–400 m asl. Differences in relative height between the plateaus and valley bottoms exceed 110–150 m. The burial mounds occur in the uppermost areas. The groups of barrows in Bukivna are located within the watershed areas of the small tributaries of the Dniester. From the macroscale view, barrows are generally found along the ridge lines of the plateaus. Thus, most of the burial mounds were built in similar geomorphometric conditions (Makarowicz et al., 2019).

3. Modern environmental conditions (climate, soils, and vegetation)

The climate of Subcarpathia is temperate continental, transitional in the western part, more humid and warmer, to continental in the eastern part. According to the Köppen-Geiger classification it is a humid continental climate with mild winters, warm summers, no dry season, and strong seasonality. Winters are generally mild, with an average air temperature in January of around −5 °C, the summers are warm with an average July temperature up to 18 °C. Due to the neighbourhood of mountains, the total annual rainfall varies from 610 to 1000 mm. The region in which mounds occur is characterized by the sum of annual

Table 1
Radiocarbon dates from the studied barrows.

Barrow	Feature	Lab. no	Material	^{14}C BP	Cal BC (68,2%)	Cal BC (95.4%)	Context
2/I/2012	3	Poz-88,817	Charcoal	3275 ± 30 BP	1608–1581 (24.5%) 1561–1511 (43.7%)	1626–1497 (93.8%) 1474–1462 (1.6%)	Oak, log from a timber grave
2/I/2012	3	Poz-88,818	Charcoal	3365 ± 35 BP	1727–1725 (1.5%) 1692–1620 (66.7%)	1746–1603 (88.4%) 1585–1544 (6.7%) 1538–1535 (0.4%)	Oak, wooden vessel from a timber grave
2/I/2012	3	Poz-53,784	Charcoal	3390 ± 30 BP	1737–1715 (19,5%) 1696–1643 (48,7%)	1751–1619 (95,4%)	Oak, from a timber grave
2/I/2012	3	Poz-53,788	Charcoal	3300 ± 30 BP	1616–1595 (17,8%) 1589–1532 (50,4%)	1643–1504 (95,4%)	Oak, from a timber grave
2/I/2012	4	Poz-53,789	Charcoal	3355 ± 30 BP	1686–1619 (68,2%)	1740–1713 (7,7%) 1697–1602 (78,6%) 1585–1544 (8,5%) 1539–1535 (0,6%)	Oak, from a hearth
1/II/2013	–	Poz-58,471	Charcoal	3840 ± 35 BP	2397–2385 (4,5%) 2347–2271 (38,4%) 2259–2207 (25,4%)	2458–2202 (95,4%)	Oak, from a mound cross-section, part S
1/II/2013	–	Poz-58,549	Charcoal	3830 ± 35 BP	2339–2205 (68,2%)	2457–2417 (6,9%) 2409–2197 (85,9%) 2167–2150 (2,6%)	Oak, from a mound cross-section, part N

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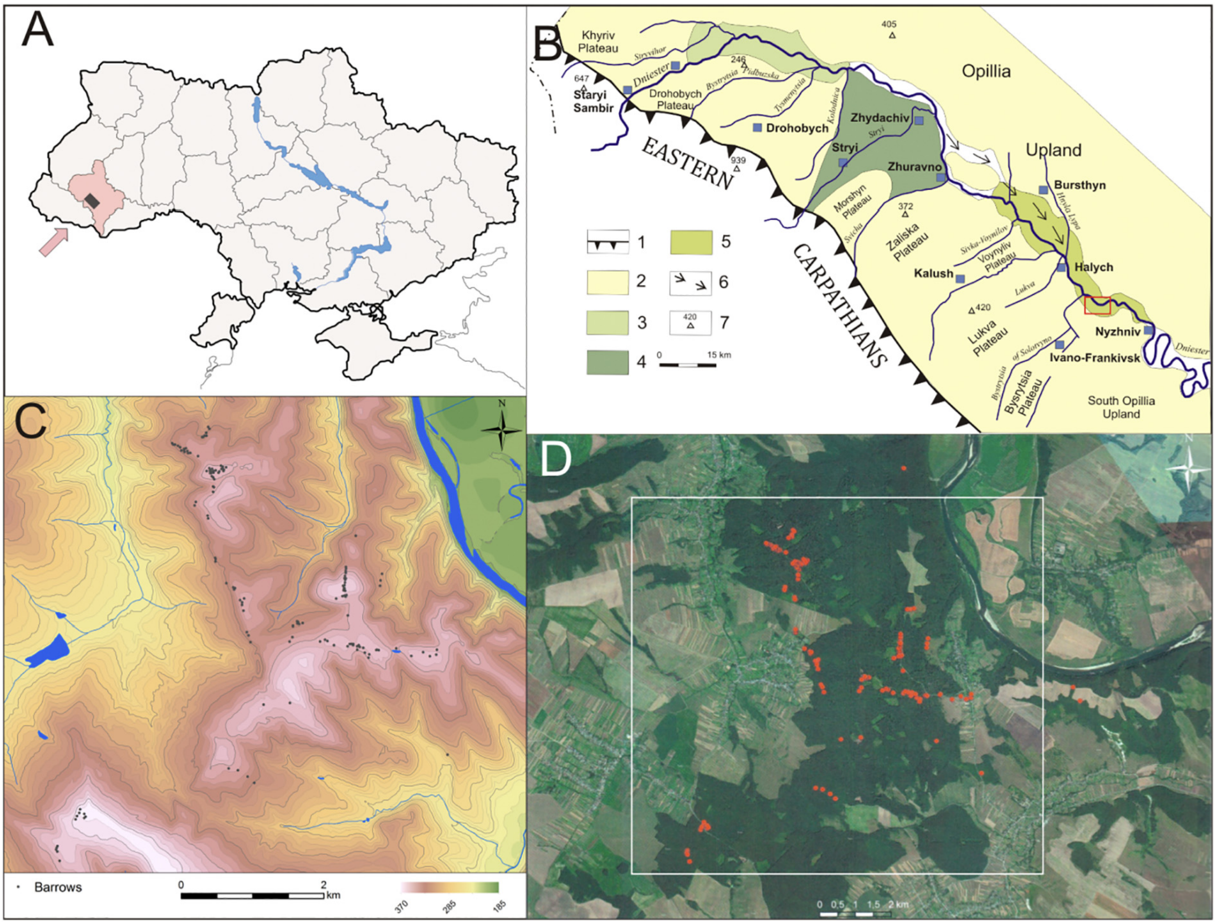

Fig. 1. Study area: A - location on a map of Ukraine and the Ivano-Frankivsk *oblast*, B - geomorphological division of Eastern Subcarpathia and the Podolia Upland, following Gębica and Yacyshyn, 2012, Gębica et al., 2013a: 1 - Carpathian fringe, 2 - high plains and uplands, 3 - Upper Dniester Basin, 4 - Stryi-Zhydachiv Basin, 5 - Halych-Bukachivtsi Basin, 6 - presumed direction flow of the Dniester in the Lower Pleistocene, 7- elevation (m asl), C - distribution of barrows on DEM, D - contemporary location of barrows in a forested area (Makarowicz et al., 2016).

rainfall in the range of 610–750 mm, the number of days without frost is 155–160 (in the region Kalush, Tysmenitsa, Tłumach) (Zastawnyj and Kusiński, 2003).

The soil cover in the studied region is diverse. It corresponds to the landform, amounts and/or types of irrigation, mesoclimate, vegetation, and land use. On the loess surface there are podzolized brown soils (*Dystric or Haplic Cambisols*), sod brown soils (*Eutric Cambisols*) and podzolized chernozems (*Luvic Chernozems)* (Kalynovych, 2013; Matviiv and Kravchenko, 2016; Kanivets, 2017; Papish, 2017). The natural trend of the Late Holocene evolution of the soils in the broadleaved forest and forest steppe zones (within the Podolia and the Dniester–Zbruch interfluve) was the formation of texturally differentiated gray forest soils from the chernozems with less differentiated profiles due to the expansion of forests over the meadow–steppe landscapes, which was favored by the humidization of the climate in the Holocene Subatlantic period (Dmytruk et al., 2014; Chendev, 2010). The effect of global change is the observed tendency to drought, smaller sums of precipitation, decreasing flows in rivers throughout Ukraine. Contemporary, the biggest changes take place in the steppe zone, and moderate in the broadleaves forest zone (Müller et al., 2016).

The study area belongs to the Central European province, a European area of deciduous forests (Peregrym and Andrienko, 2014). In landscape systems, anthropogenic transformations are visible. In foothill areas, 30% of the territory is made up of hornbeam and oak forests, and flooded forests consist of black alder, hornbeam, and elm. In the Bukivna region, these are beech - hornbeam forests. Grassy vegetation dominates in watershed, terrace, and floodplain areas. Among the synanthropic vegetation, *Artemisietea vulgaris* and *Plantaginetea majoris* are most often represented (Kalynovych, 2013).

4. Environmental conditions during the building of barrows

A rare number of palynological studies indicate that anthropogenic pressure on plant communities has been occurring since the Neolithic. The first traces were observed in samples from around 7530 BP (Harmata et al., 2006; Kołaczek et al., 2016). They are marked by a decrease in the percentage of *Ulmus, Quercus, Fraxinus*, and herbaceous growth, including species of *Poacceae, Chenopodiaceae, and Artemisia*.

The next phase is dated at 6440 BP (5480–5340 BC). The pollen sum of herbaceous plants indicates considerable deforestation linked to younger settling phases of the Neolithic. From about 4200–3800 BP, for the Upper Dniester, there is a trend towards expansion of meadow and forest-meadow species at the expense of arboreal species. This process intensified after 3500 BP (Matviishyna and Parkhomenko, 2019). Therefore, the burial mounds of the Late Neolithic and Middle Bronze Age were built rather in open landscapes dominated by meadows (Harmata et al., 2013a, 2013b; Kalynovych, 2013; Makarowicz et al., 2018).

5. Materials and methods

For detailed archaeological excavations and soil research, samples from two barrow groups were selected: barrow 1/II/2013 (group II) and 2/I/2012 (group I) (Fig. 2).

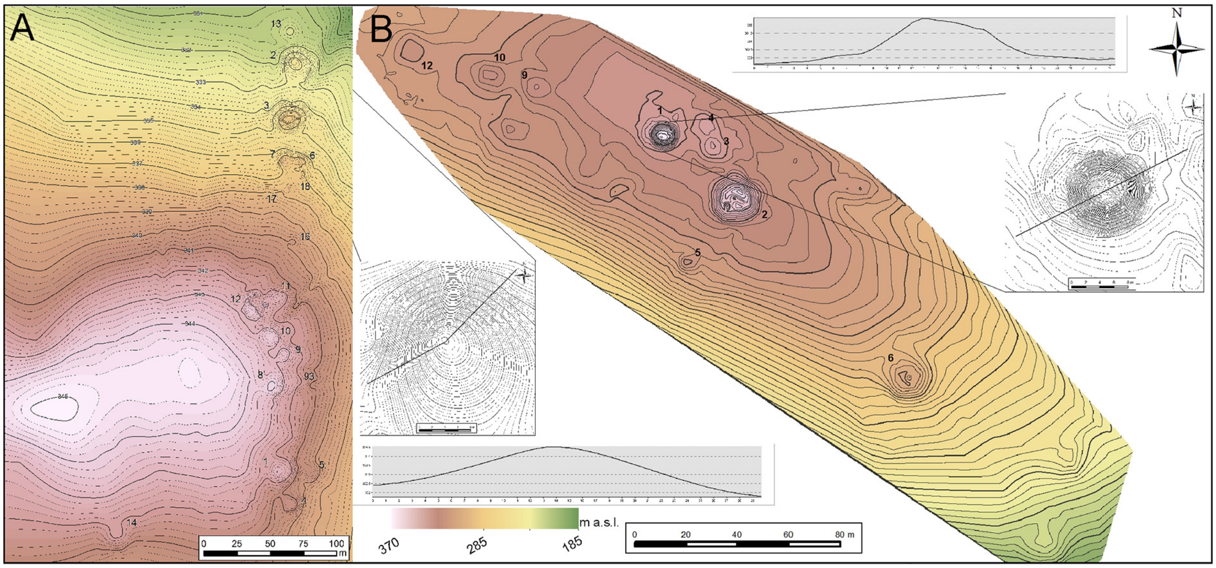

Fig. 2. Hypsometry of burial mounds in Bukivna: A – group I with barrow 2/I/2012, B – group II with barrow 1/II/2013 (elab. J. Niebieszczański).

Barrow 1/II/2013 is located within the southern group (group II), on the eastern slope of the ridge, which rises westwards to the height of 342 m asl (see Fig. 1C). The mound is oval shaped (15 × 13 m) and reaches a height of 1.3 m.

Barrow 2/I/2012 is in the northern part of the cemetery (group I), about 250 m from group II, on the northern slope, and about 10 m lower, on ordinate 332 m asl (see Fig. 1C). This barrow is also oval (22 × 18 m) and measures 1.8 m in height (Matviishyna et al., 2017b, 2017a).

Each barrow was documented based on a cross-section of the central part, representing contemporary soil, mound stratigraphy and the fossil soil. Near both barrows, at a distance of 100–200 m, trenches were made, to obtain natural and undisturbed Holocene soil cross-sections for the reference.

The macroscopic description of soil profiles and soil nomenclature were made in accordance with the Ukrainian Classification of Soils (Polupan et al., 2005). Soil classification was referred to World Reference Base for Soils Resources (2014) (Dent and Dmytruk, 2017). Physical and chemical properties for the barrows 2 were carried out on the basis of the methodology used in Ukraine (Veklich et al., 1979). The granulometric analyzes were performed by pipette method in modification of Kachinskii with pretreatment of soil by 4% solution of pyrophosphate Na ($Na_4P_2O_7$) (Vadyunina, 1986; Laktionova and Nakisko, 2014). The chemical composition of soils was determined according to the methodology (*Methodical Instructions for the Determination of Heavy Metals in Soils of Agricultural Land and Crop Production,* 1989) based on atomic absorption spectrometers (AMS) in an acetylene flame. One sample was tested from each separated soil horizon (except the C horizon of the soil under the barrow 2/I/2012). As the geochemical background, the arithmetic mean of the samples from all levels from the all studied barrows was assumed. Micromorphological studies were conducted according to Ukrainian standards (Veklich et al., 1979). For micromorphological research purposes, 21 samples were collected from each burial mound. They were extracted into Kubiena's (metal) boxes, cured with resin and then a thinly (0.02–0.04 mm) sectioned (Lee and Kemp, 1992). Based on the cross-sections, soil levels were identified.

As part of the macromorphology description, the following soil profiles were compared: reference (outside the barrows), on the surface and under the mounds (Fig. 3).

5.1. *Soil morphology*

5.1.1. *Macromorphology*

5.1.1.1. Reference cross-section. The reference soil cross-section for the barrow 1/II/2013 consists of a gray or dark gray sodium layer (A) that comprised of a silty light loam containing remains of tree roots. The next level of eluvial (E) is bipartite. The top layer (Eg) is light gray, poorly humified, with ocher inclusions and fine speckles of manganese. It shows evidence of gleying. At the bottom, ferruginous patches become more numerous due to iron hydroxide precipitates (Ex). Single krotovinas with a diameter of up to 5 cm are visible. Three horizons can be distinguished in the iluvial level. The first horizon (Bxg) is light brown with a bluish shade to it, with a marbled texture. This level is more compact, has medium-spheroid nodules and separate impermanent angular structures covered with iron hydroxide laminas from the top. Indistinct ferruginous-manganese speckles are present. The material compactness grows with depth. Pores left by plants are filled with dark humified material. Single krotovinas are occasionally found (6–10 cm in diameter). The second horizon (Btg) has a yellowish-ochre color, brown with single whitish and blue gleying patches. This is the most iron-rich horizon in the profile. Silty heavy loam is crossed by single krotovinas (3–4 cm in diameter). The last layer in the eluvial level (Bg) is characterized by a homogeneous, brown-ochre color, bearing blue gleying patches, manganese speckles and spheroid structures containing iron hydroxide.

The bedrock was recognized at the bottom of the cross-section (Cg). The color of this horizon is straw-yellowish-brown and is brighter, than the overlying horizon. It is poorly compacted and gleyed and is built by a homogeneous medium silty loam. In the Ukrainian classification, this soil has the characteristics of a sod-podzolic soil forest zone. In the WRB classification, this soil may correspond to Eutric Cambisols (Kanivets, 2017).

The reference cross-section for the barrow 2/I/2012, located 100 m west of the mound, shows similar soil horizons. Small differences between cross-sections from barrow 1/II/2013 and 2/I/2012 (Figs. 2, 3) may result from the slightly different geomorphological situations in which they are located. However, in this reference cross-section two stages of the profile formation are clearly visible with the change of the main soil-forming processes. The old soil and its second level of humus was observed at a depth of 0.32 m with a profile characteristic of gray and dark brown washed forest soils, with humus levels more developed than modern ones. After Matviishyna and Parkhomenko (2019) the contemporary soils were classified as brown-podzolic forest soils

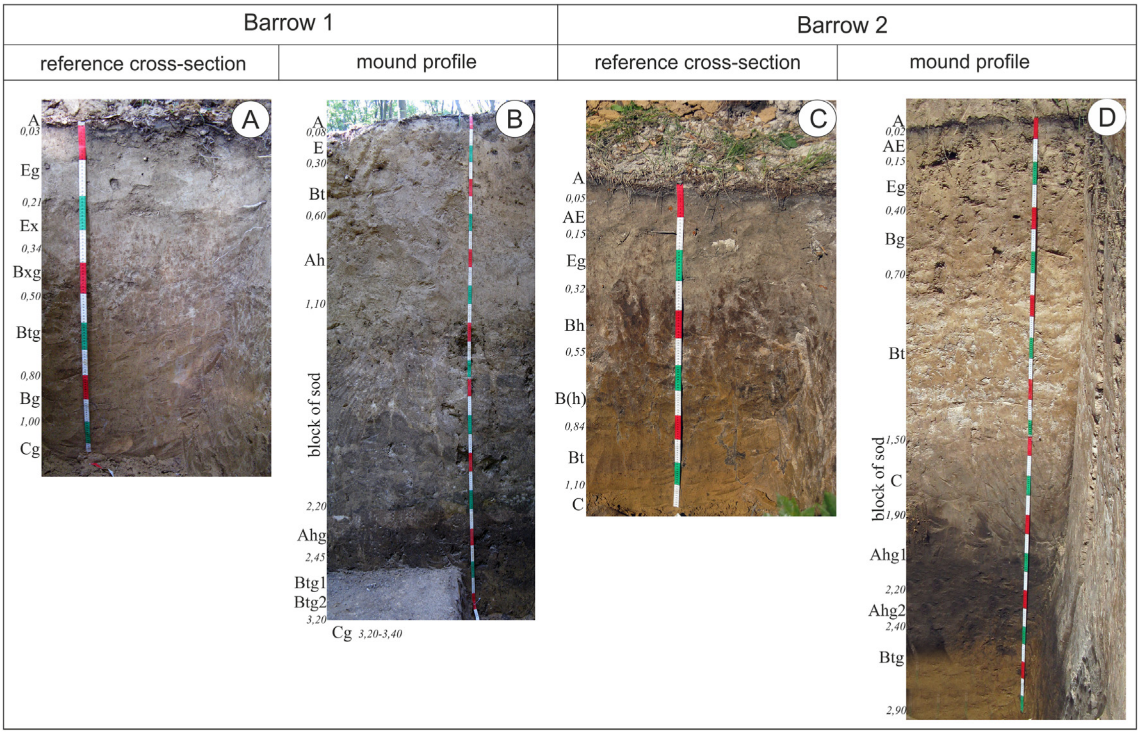

Fig. 3. Profiles of investigated soils: A – reference cross-section in a beech forest, 200 m southeast of the barrow 1, B – cross-section in central part of the mound, C – the reference cross-section, located 100 m west of the mound, D – cross-section in central part of the mound.

(*Dystric or Haplic Cambisols*) and the old soil in second level humus as gray forest soil (*Luvic Phaeozems*). There are the humic-eluvial and iluvial levels resulting from the pseudo-podzolisation in these soils. The water will stagnate with excess moisture above the iluvial level, which due to the heavy mechanical composition becomes a screen.

5.1.1.2. Barrows. The profile of the barrows 1/II/2013 is built from the top of the sod layer (A). Its color is dark-gray to black. It is formed from sod containing leaf fall and many loose grass roots. The eluvial level (E) is greyish-light-brown. The matrix consists of slightly silty loams with tree and grass roots. Single krotovinas are observable filled with matrix material. The next horizon corresponds to the level of washing (Bt) and is comprised of light-brown silty loam. It is a loess material from which the mound was built. It shows single krotovinas, round in cross-section and up to 0.1 m in diameter.

The next level (Ah) was the poorly pronounced brown sod forest soil (second buried horizon, without radiocarbon dating). A large number of tree root remains and single krotovinas filled with soil material are noticeable in the floor. Under this layer there is a loam–bedrock of brown soil. Below this layer one can see the blocks of old sod soil, whose location is related to the construction of the mound. The next level (Ahg) has dark-gray or even black color. On this dark background, bright patches of sprinkling SiO_2 stand out. It is crisscrossed by krotovinas and worm tunnels and features many whitish patches. Owing to *lessivage*, in the bottom part of the horizon, the brownish shades become more intense. This depth can be described as meadow or dark-gray forest soil. The next horizon (Btg) was colored gray, brown orange; there are spheroid structures with laminates of iron hydroxides, many krotovinas (7–15 cm in diameter) with homogenous black filling and noticeable concentrations of SiO_2. The matrix material, silty medium loam, –is gleyed. The next level (Cg) is loess colored, the loam is calcium carbonate free with few krotovinas containing light colored fillings. The activity of soil fauna decreases with depth. Below, in barrow 1 there are two illuvial levels (Btg, Btg2), that have a compact structure. They feature many krotovinas (7–15 cm in diameter) filled with gray, brown-gray, and brown material. In the lowest part of certain krotovinas, intensely homogeneous material was found, perhaps originating from a humic horizon. The material, silty medium loam, is gleyed. The next level (Cg) is correlated with the loess of the bedrock. The dating of the barrow corresponds to the late Corded Ware culture present in the area (2400–2200 BC.

As in the case of reference cross-sections for barrows 1/II/2013, soil on barrow 1/II/2013 is more similar to the sod brown forest soil (*Eutric Cambisols*). However, the soil under the barrow shows features of the podzolized chernozems (Ukrainian classification), which corresponds to the classification of WRB *Luvic Chernozems*.

In the second barrows 2/I/2012, as in barrows 1/II/2013, there is mainly a dark color soil, originating from the Bronze Age, covered with sod layers, on which the silty material characteristic of the parent rock was poured. Contemporary soil, covering the mound, is similar to the brownish-gray one, with humus-eluvial levels and the iluvial, compacted layers, which transform the mound material. The middle layers build an mound layering to a depth of 1.6 m, and below are layers of sod from surface layers of soil from the Bronze Age, taken from the surroundings of the mound. This way of building mounds was widespread in the steppe areas (Borisov et al., 2019) Fossil soil from the Bronze Age is similar to podzolised chernozems (*Luvic Chernozems*), distinguished by a dark gray color of the profile.

5.1.2. Micromorphology

5.1.2.1. A cross-section in the central part of the barrow (barrow 2/I/2012). The characteristics of contemporary soil include shades of a brown color, distinctly marked soil horizons, humic-eluvial, and 'washed through' illuvial, with a joint thickness of approximately 0.4 m. The presence of an illuvial horizon and observable brown spheroid-structure horizon, as well as hardpan layers down to a depth of 1.5 m in the mound material, may be characteristic traits of the well-developed, brown-earth and strongly podzolized, light-loamy soil that formed on the barrow mound, which shows single krotovinas (Figs. 3,4).

The barrow cross-section, between the depths of 0.7–1.5 m, is made up of sandy fine loams with hardpan laminas, which represents

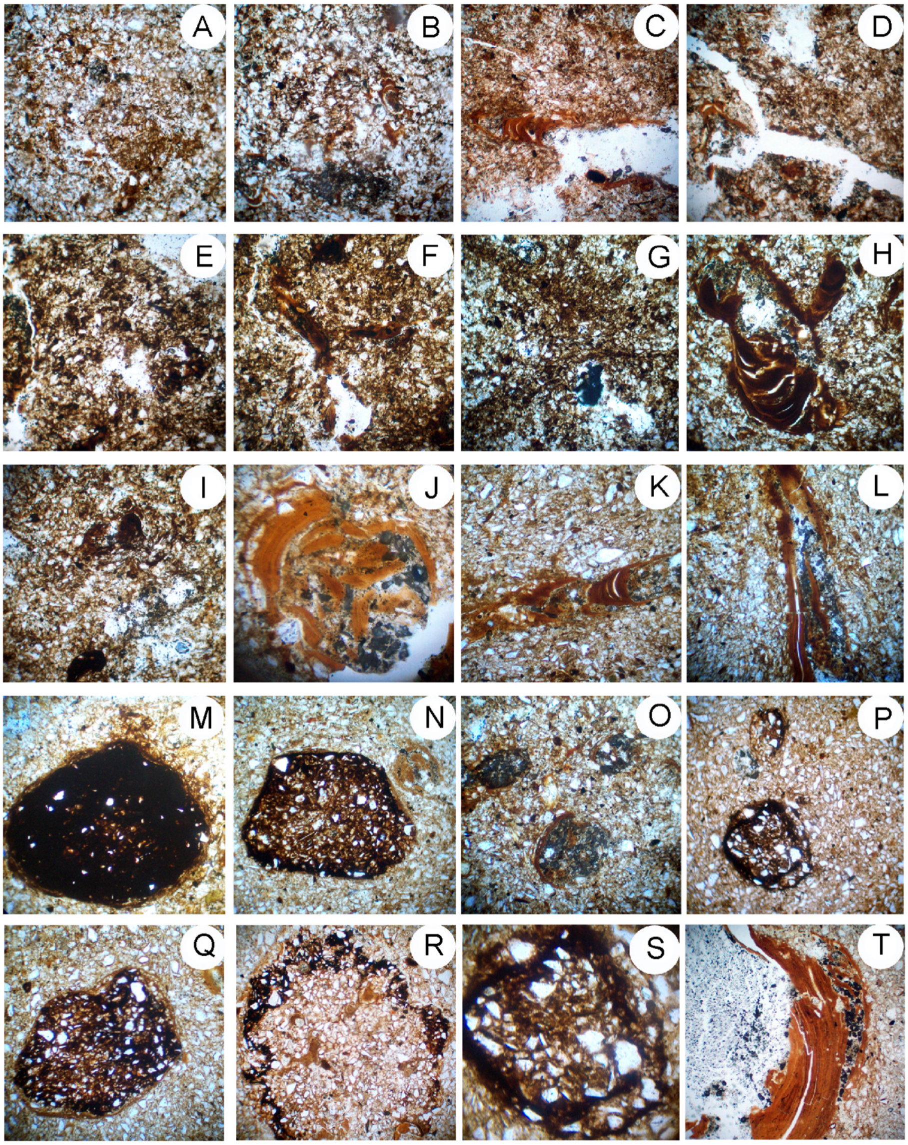

Fig. 4. Bukivna, barrow 2/I/2012 – micromorphology mound cross-section – contemporary and fossil soil: A-D, eluvial-humic horizon: simple and complex microaggregates, "washed" microparticles (A,B), crusted infiltrations of calomorphic clays (C), filling of pores (D); *E*-I – eluvial-humic horizon with signs of illuvial horizon: simple and complex microaggregates, "washed" microparticles (E), signs of redistribution of clay and humus (F,G), dark brown ferruginous infiltrations of calomorphic clays, including particles of coarse clay and humus (H), gray gleyed microparticles, small microhardpan (I); J-O, light-brown and dark-brown ferruginous infiltrations of calomorphic clays, with the inclusion of coarse clay and humus particles, structure in the form of fused blocks (J-L), dense microhardpans (N), light in the central part (U), blue gleyed spots and small micro-hardpans (O); P-T, bedrock horizon: various forms of micro-hardpans in concentric structures (P-S), calomorphic clay in pores (T) (after Matviishyna and Parkhomenko, 2019). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

podzolic soil formation processes. In its lower part, at a depth of 1.5–1.9 m, the mound is built of sod blocks. This material is grayer than that found in the mound overlying them and extends in indistinct horizontal layers. The remains of herbaceous plant roots are noticeable. In terms of color, this is a transitional horizon to the soil lying below.

The mound overlies an older soil observable due to its color. It is dark-gray, turning into gray, forest soil with a distinctive illuvial level. It is built of three parts: a humic-eluvial horizon (0.3 m) and a humic-transitory one with the traces of *lessivage* (0.2 m) (Fig. 4, A–D).

The soil also has an observable illuvial horizon with a characteristic brown color, spheroid structures, and iron-rich and clayed materials (Fig. 4, J–O). The fact that this soil belongs to the category of gray forest soils is borne out by its micromorphological traits: in the humic-eluvial horizon one can see a spongy structure and many 'washed through' micro-sections accompanied by single fine drips. The abundance and variety of calomorphic-clay cluster forms, and the cleave-block structure testify to the active processes of *lessivage* and washing through. Diagenesis is seen as a certain contradiction, i.e. the presence of dark-gray shades in upper humic horizons accompanied at the same time by a relatively high number of calomorphic clay drips, which may be connected to active podzolization and the permeation of solutions from the overlying contemporary soil.

In this cross-section, distinctly black material from the humic horizon is observed. The material could have developed underneath high grasses in more continental and perhaps cooler conditions than the present. The shades of brown in the soil coloring, increased claying, and a higher iron content at the illuvial horizon attest to the fact that the soil formed under a forest and the brown forest soils developed in a warmer climate than the present. The distinctiveness and high humus content of the upper humic soil horizons may testify to climate cooling and the pedogenesis becoming more continental.

Furthermore, the fact of pedogenesis taking place in a meadow and steppe landscape is attested to by the signs of the increased activity of burrowing animals, reflected in krotovinas and worm tunnels, as well as considerable saturation with humus and aggregates of material in the form of worm excrements, and the extensive network of pore connections. The illuvial horizon indicates the formation of brown soil in warm climate. Meadow soil (chernozems) with a high humus content, dark-gray color, and many krotovinas, suggest the existence of continental conditions during a Subboreal period. Formed on the mound surface, contemporary brown, strongly podzolized soil reflects the present climate conditions.

5.2. Physical and chemical properties

In the course of the long-lasting evolution of Chernozems and under

Table 2
Granulometric composition the soil horizon in barrow 2/I/2012 and reference cross-section.

Soil horizon (depth of sampling, cm)	Size of soil particles in mm, quantities in %						
	1–0,25	0,25-0,05	0,05-0,01	0,01-0,005	0,005–0,001	< 0,001	< 0,01
Referencing soils							
AE, 5–15	0,10	0,90	27,5	30,89	24,62	15,99	71,5
Eg,15–32	0,10	0,90	27,5	32,2	15,93	23,37	71,5
Bh,32–55	0,20	1,24	33,56	14,6	19,35	31,05	65,0
B(h),55–84	0,20	1,25	32,89	28,67	12,69	24,3	65,66
Bt,84–110	0,30	1,44	37,0	25,16	13,5	21,6	60,26
C,110–120	0,30	1,06	46,16	22,96	14,34	15,18	52,48
Soil on the barrow							
AEg,2–15	0,10	1,41	39,15	18,84	15,42	25,08	59,34
Eg,15–40	0,20	0,64	38,44	31,68	12,48	16,56	60,72
Bg,40–70	0,20	1,0	39,89	17,37	13,4	28,14	58,91
Bt,70–150	0,30	1,14	38,76	15,7	14,4	29,7	59,8
Bt, 150	0,30	1,21	43,29	26,85	15,15	13,2	55,2
C, Sod blocks,150–190	0,20	1,16	37,2	20,91	14,37	26,22	61,44
Soil under the barrow							
Ahg1,190–220	0,20	1,0		21,24	5,36	25,46	52,06
Ahg2,220–240	0,10	0,24	26,3	27,51	14,8	31,05	73,36
Btg,240–290	0,10	0,74	23,92	23,76	29,4	22,08	75,24
Average for reference cross-section	0,20	0,96	33,26	25,75	16,74	21,92	64,4
Average for soil on the barrow	0,22	1,08	39,91	22,09	14,17	22,54	64,8
Average for soil under the barrow	0,13	0,66	32,32	24,17	16,52	26,2	66,9

the influence of the processes of humus accumulation, leaching, gleyzation, podzolization and lessivage, the regular changes in granulometric composition of soils occurred. In addition, such composition of soils is derived from the parent rock.

In the reference cross-section one can observe a decrease in the content of clay fraction into the profile (Table 2). The largest content of the thickest components is found in the parent rock and has a composition similar to loess. The lightest granulometric composition occurs in mound sediments, which is obviously the result of its formation from bulk material taken from the area around the barrow. In the soil on the barrow, the distribution of many fractions is even, with the exception of the accumulation of finer components over the sod blocks. In the fossil soil, the biggest share of coarse silt is characteristic for the humus level and falls to the profile floor. The participation of the clay also increases towards the floor. These two tendencies are characteristic of chernozems. However, attention ought to be paid to the lack of analysis of the parent rock of the fossil soil, which makes it impossible to compare parameters of the granulometric composition.

The total content of heavy metals reflects the characteristics of lithology, but is also the result of redistribution processes. The main feature of the chemical composition is the decrease in the value of components such as copper, manganese, iron with depth (Table 3). The geochemical sorption barrier in the profile occurs above the parent rock (iluvial level). The contents of nickel, zinc and chromium correspond to the geochemical background. The maximum content of elements in the fossil humic level, and their lower content in the iluvium level may indicate the importance of the bioaccumulation process, which may suggest that the soil was formed in dry climatic conditions under lush grass vegetation.

Table 3
Chemical composition the soil horizon in barrow 2/I/2012 and reference cross-section.

Horizons and depth (cm)	Heavy metals (mg/kg)						
	Pb	Cu	Ni	Cr	Zn	Mn	Fe
Referencing soils							
AE, 5–15	16,6	3,85	4,70	7,40	25,9	145	4450
E(h)gl,15–32	7,50	5,20	6,15	8,20	20,2	381	6990
Bhe,32–55	9,90	6,0	8,95	7,40	20,6	95,0	7370
B(he),55–84	16,6	9,15	28,0	13,4	34,0	351	15,790
Bp,84–110	16,8	11,8	25,6	14,1	35,9	454	16,410
Ci,110–120	13,7	11,5	25,2	13,6	35,1	263	12,610
Soil on the barrow							
AEgl,2–15	14,4	3,65	5,65	6,65	24,5	196	8070
Ehgl,15–40	7,10	5,60	6,45	7,55	22,8	387	8200
Begl,40–80	10,4	8,60	13,4	8,70	29,8	173	11,200
Bpe,80–150	12,6	10,6	20,0	12,4	37,2	201	8360
Bpe,80–150	13,7	12,4	24,7	15,3	40,5	220	5200
Sod bloks,150–190	**12,6**	**10,6**	**22,2**	**13,8**	**32,2**	**218**	**12,190**
Soil under the barrow							
Aegl,190–220	13,3	9,55	21,2	10,9	35,0	291	10,430
Aeigl,220–240	13,8	9,35	26,2	11,6	36,2	324	13,670
B(e)hp.,240–290	10,4	7,75	14,6	9,50	27,0	230	9270
Average for reference cross-section	13,5	7,92	16,4	10,7	28,6	282	10,603
Average for soil on the barrow	11,6	8,17	14,0	10,1	31,0	235	8206
Average for soil under the barrow	12,5	8,88	20,7	10,7	32,7	282	11,123

6. Discussion

The soil registered underneath the barrow is an important palaeogeographic indicator of the natural conditions present during the emergence of the mound. The comparison of the fossil and contemporary soils in the barrow helps to capture tendencies in landscape and climate changes in the transition from the 3rd to the 2nd millennium BC and in the period when earlier soils developed together with contemporary soil formation conditions following from today's soil formation factors.

In all probabilities, already in the Late Neolithic and Middle Bronze Age, the soil formation had since taken place, corresponding to contemporary dark-gray forest podzolic soils (Fig. 5). The fossil soil was characterized by the formation of a humic-eluvial horizon with complex aggregates, network of winding pores, presence of 'washed through' micro-sections accompanied by intensive humus leaching and the moving of a ferruginous substance. This is the second humus horizon of contemporary soils. A lush grass cover resulted in an intense humus accumulation, which explains the dark-gray to black shades of a distinct humic horizon. The moisture supply was sufficient, without causing water-logging, as could be seen from the traces of burrowing animal activity. The abundance of grasses is borne out by the well-structured material, extensive network of pores and high saturation with humus. Intensive animal activity is visible in many krotovinas, filled with black and brown material, and worm tunnels. In the soil, an illuvial iron-rich

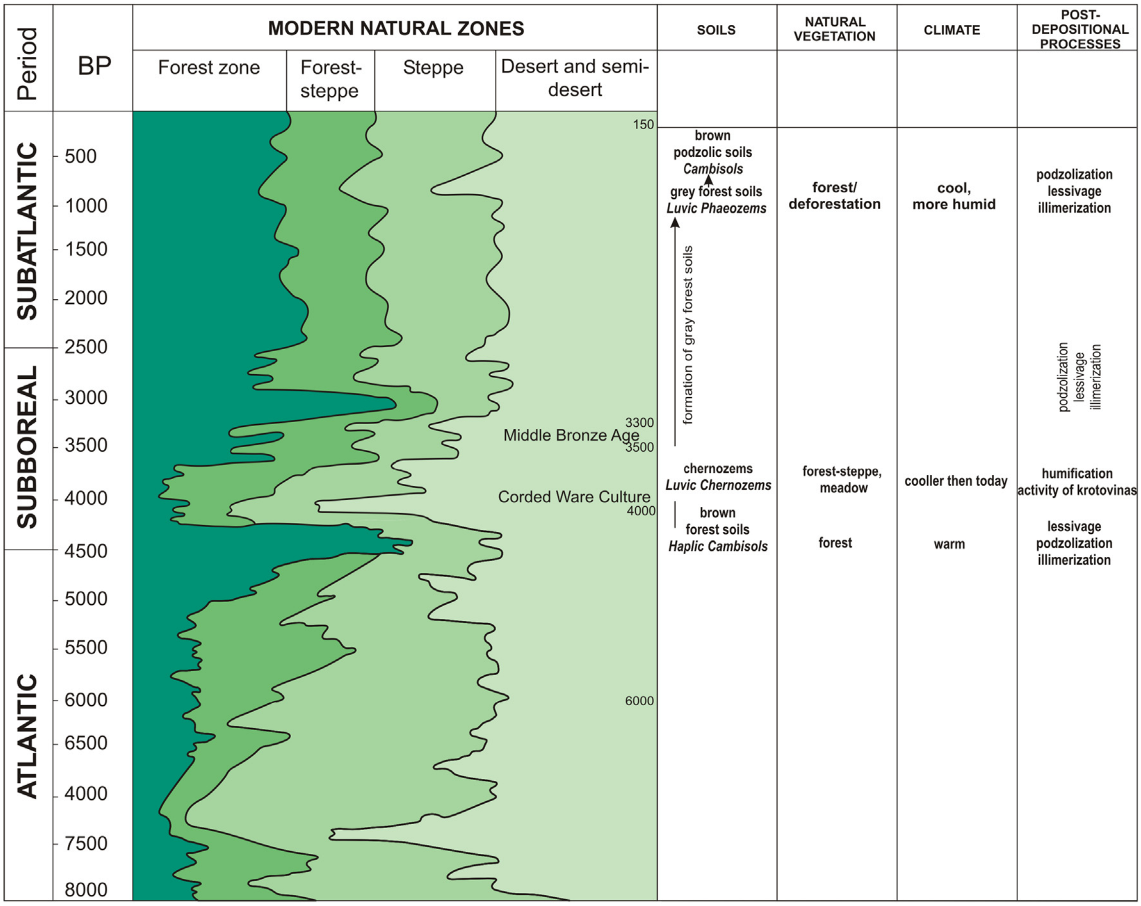

Fig. 5. Types of soils, natural vegetation, climate characteristics and post-depositional processes in Bukivna on the background changes in landscape zone boundaries (after Kotova and Makhortych, 2010 on base Spiridonova and Lavrushin, 1997).

horizon can be seen with all its characteristic features: spheroid structure, laminas, patches of iron and manganese hydroxides along the edges of separate structures, non-homogeneous coloring and blue gleying patches.

A well-developed, iron-rich and clayed illuvial horizon may confirm that the soil formed during an earlier stage at the beginning of the Subboreal period (about 4500–4000 BP), when brown forest soils were formed under relatively warm conditions. Later, about 4000 BP, these soils developed into meadow-forest soils that formed a humic horizon of considerable thickness (Kotova and Makhortych, 2010).

The changes in Late Neolithic and the Middle Bronze Age soil profiles were to some extent as a result of diagenesis related to the contemporary landscape and formation of soils under conditions of excessive moisture and waterlogging. The humic-eluvial and eluvial blue-light-straw-colored, ‘washed through’ horizons emerged in the contemporary soil. The latter had a sprinkling of SiO_2 powder and was faintly tinted with humus. The characteristic features of these horizons result from gleying and podzolization being, in turn, the effects of surface water stagnation over the screen formed by the fossil soil of a more compact mechanical composition (pseudo-podzolization, gleying). Excessive moisture made fossil soil material develop fissures through which finer dusty light clay penetrates underlying strata. Diagenesis, connected with the contemporary soil formation, slightly modified the Late Neolithic and the Middle Bronze Age soil material. This is seen in the superimposition of contemporary podzolization and gleying on the characteristics of old processes.

The soil profile may be described as characteristic of brown-podzolic (pseudo-podzolic) soil. The illuvial horizon may have formed about 4500–4200 BP, at the beginning of the Subboreal period. The formation of the humus horizon coincided with climate cooling and became more continental during the moderately warm climate period when vast forest areas were replaced by meadows, leading to the development of a dark-colored humic horizon). Later, the climate became even more humid, which resulted in periodic excessive soil moisture levels and the growth of upper wetland vegetation. The contemporary period relates to the formation of light-colored eluvial-gleyed horizon over the fossil soil screen. The processes of pseudo-podzolization and pseudo-gleying, are very characteristic of the brown excessively moist soil of Fore- and Transcarpathia (Zonn, 1973; Gerasimova et al., 2003).

Pedological and palynological data from Late Neolithic and Bronze Age settlements in the steppe zone of eastern Ukraine show the transition from the mild climate of the Atlantic period (6500–5500 BP) to the more continental climate of the Subboreal (Gerasimenko, 1997; Matviishyna et al., 2017b, 2017a). The diversity of vegetation decreased and several thermophilic and mesophilic taxa disappeared altogether during this transition. Kremenetski, 1997 shows, that the period between 6000 and 4500 BP was marked by a considerably less continental climate than the one today. Broad-leaved trees expanded farther to the north and east compared to their modern limits in Eastern Europe and West Siberia. The share of broad-leaved trees was largest in the forests of Eastern Europe. Present steppes and semi-desert belts were relatively wet during that time. Forests expanded and soils were less continental in the steppes of Ukraine, Southern Russia and Kazakhstan (Kremenetski, 1997). However, during this period, rhythmic oscillations indicating wet climate stages marked expansions of the forest-steppe, which divided the dry climate stages of steppes expansion. Between 5500 and 2500 BP, five separate shifts can be distinguished. Between 4500 and 3500 BP, the climate was cooler and more continental in the boreal belt, and drier in the arid belt. The broad-leaved forests were reduced (Gerasimenko, 1997).

All existing data prove that a serious and relatively rapid climate shift took place ca. 4500–4300 BP (Kremenetski, 1997, Kotova and Makhortych, 2010, Matviishyna et al., 2017b, 2017a). It was accompanied by changes in the human economy, which was detected mainly in the Eurasian steppes and forest-steppes. After 4500–4200 BP, nomadic groups penetrated some parts of the forest belt in East Europe and Siberia. At the same time agricultural communities collapsed in south-west Ukraine and Moldova, and were replaced by nomads (Kremenetski, 1997; Gerasimenko, 1997). This change corresponds to the period of strongest aridification between 4100 and 3500 BP. In pedological profiles, the decrease of humus accumulation, biogenic activity and chemical weathering in the soils is observable. The forest-steppe landscapes of the Early Subboreal were replaced by Artemisia-Gramineae steppes, representing the shift through three phyto-geographic subzones. Between 3400 and 3300 and 2800–2700 BP a new phase of more favorable climate was indicated in the southern regions of Eastern Europe, Kazakhstan and Siberia. The Late Holocene vegetation and climate shift was more pronounced in the northern and southern margins of forest belt than elsewhere (Kremenetski, 1997).

In the period preceding the Late Neolithic and Middle Bronze Age (dated to 4500–4000 BP), the studied area must have been occupied by beech-hornbeam forests, which contributed to the rise of brown saturated forest soils. Such soils also form today. The brown-earth nature of the soil-formation processes is visible in the lower layers of soil under barrows. Its material stands out, owing its heavy granulometric composition (heavy loam), rather poor profile differentiation, advanced illimerization, and mass claying and high iron content. The climate used to be warmer and more humid than today, resulting in strong mass weathering. The bottom part of the *lessivage* horizon has the greatest number of ferruginous-clayey loam drips, containing coarse clayey particles and standing out due to their vivid red-brown color. Soil transformation by burrowing animals is likely a result of the meadow processes occurring later.

The Corded Ware culture artifacts (4000–3800 BP) (in the barrows 1/II/2013) are associated with the humic horizon which is a dark-gray to black color. A forest landscape was then replaced by a mixed meadow-forest in the northern part of the forest-steppe zone. The nature of the dark-gray podzolic soil testifies to the natural disappearance of forests or man-made deforestation. It is unlikely that the barrows were placed in a forest. These were open spaces and later meadow steppes comprised of a diversity of grasses. They produced large amounts of biomass, resulting in the rise of a thick humic horizon of a dark-gray soil. The meadow-steppe conditions of soil formation are confirmed by profile humification and the presence of aggregates. The last are associated with intense worm activity.

7. Conclusions

The soil formation at the barrow cemetery may be described in three phases: Phase I (6000–4200 BP) – the formation of brown illimerized forest soils at the beginning of Subboreal period, when the climate was warmer than today; Phase II (4200–3300 BP, in the Late Neolithic and Middle Bronze Age) – the rise of meadows and meadow-forests and the formation of a dark-gray thick humic horizon underneath tall meadow grasses in a cooler and much more continental climate than today; Phase III – after 3300 BP to 150 BP – witnessed excessive moisture and the formation of bright-colored eluvial-gleyed, podzolic horizons in the conditions of surface waters stagnating over the material of old soils (second humic horizon for contemporary soils); the climate was cooler and more humid than at the beginning of the Subboreal period. Podzolization and washing through were under way, producing brown-podzolic soils.

The influence of pedological processes on the sedimentological and geochemical composition is indicated by a greater share of sandy fractions in the upper parts of the barrow cross-sections (clay particles are transported from the eluvial level and deposited in the illuvial level by *lessivage*), advanced illimerization, and high iron content in illuvial level. Podzolization contributes through leaching, to removal of iron compounds, humus, and clay minerals from the surface soil horizons by an organic leachate solution, and the deposition of some of these translocated materials in lower B-horizons. The recognition of these processes is important for the interpretation of iron compound accumulation, which if they are in the illuvial level, are associated with soil processes, while in other soil horizons, a large accumulation of iron may have anthropogenic, intentional nature, e.g. ocher. Among the post-depositional processes, the activity of soil fauna should be mentioned, especially the numerous krotovinas filled with the dark organic matter of primary soils and worm activity. Particularly visible is their activity in podzolized chernozems.

Burial mounds in Bukivna indicate that the area was inhabited by various communities. They existed in various environmental conditions. The Corded Ware culture settled the area when the forested landscape changed towards a meadow-forest and also a meadow with grasses. Apart from the climate, man has also contributed to deforestation of the area. In the Middle Bronze Age, despite the better climatic conditions, an open landscape was maintained, allowing Komarów culture to build mounds more easily.

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