Combining relative chronology and AMS ^{14}C dating to contextualize 'megasites', serial migrations and diachronic expressions of material culture in the Western Tripolye culture, Ukraine

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ABSTRACT – *Scholarship regarding the Eneolithic Cucuteni-Tripolye cultural complex of Romania, Moldova and Ukraine has recently focused on 'megasites' of the Western Tripolye culture (WTC) in Central Ukraine. However, in order to properly contextualize such unusual phenomena, we must explore the broader typo-chronology of the WTC, which is suggestive of a high degree of mobility and technological transfer between regions. We report 28 new AMS ^{14}C dates from sites representing diagnostic types and propose a high-resolution chronological sequence for the WTC's development. Our results support the relative chronology and offer an opportunity to propose a new chronological synthesis for the WTC.*

KEY WORDS – *Eneolithic; Cucuteni-Tripolye; migration; chronology; radiocarbon*

Združevanje relativne kronologije in AMS ^{14}C datumov pri kontekstualizaciji 'mega-najdišč', zaporednih migracij in diahronih izrazov materialne kulture na območju zahodne kulture Tripolje v Ukrajini

IZVLEČEK – *Študije eneolitskega kulturnega kompleksa Cucuteni-Tripolje, ki se razprostira na območju Romunije, Moldavije in Ukrajine, so se nedavno osredotočile na 'mega-najdišča' kulture zahodnega Tripolja (ang. kr. WTC) na območju osrednje Ukrajine. Da bi lahko ta nenavaden pojav postavili v ustrezni kontekst, moramo najprej preučiti širšo tipo-kronologijo WTC, ki kaže na visoko stopnjo mobilnosti in prenosa tehnologij med regijami. V članku predstavljamo 28 novih AMS ^{14}C datumov iz najdišč, ki predstavljajo diagnostične tipe. Predlagamo kronološko visoko ločljivo sekvenco razvoja. Naši rezultati podpirajo relativno kronologijo in nudijo priložnost za vzpostavitev nove kronološke sinteze kulture WTC.*

KLJUČNE BESEDE – *eneolitik; Cucuteni-Tripolje; migracije; kronologija; radiokarbonski datumi*

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Introduction

Large settlements (known in the literature as 'giant-settlements' or 'megasites') belonging to the Cucuteni-Tripolye cultural complex (CTCC) have in recent years become the focal point of international interest in Ukrainian archaeology. Previously known to Western readers mainly through a selection of regional-scale archaeological monographs (*e.g., Anthony 2007; Fletcher 1995; Kohl 2007*), these sites now attract international attention through the results of Swiss-Ukrainian, British-Ukrainian, German-Ukrainian, and US-Ukrainian projects conducted over the last dozen years (*e.g., Gaydarska 2020; Menotti, Korvin-Piotrovskiy 2012; Müller* et al. *2016; Ohlrau 2020*).

The largest CTCC settlements, which reached sizes of 100–320ha and date to *c.* 4100–3400 BC, are located in the Southern Bug-Dnieper Interfluve (SBDI; the Cherkassy and Kirovograd oblasts of modern-day Ukraine). According to the CTCC taxonomy, they belong to the Western Tripolye culture (WTC). Studies of the archaeological materials and population dynamics of these settlements indicate that they were formed as the result of populations migrating along the forest-steppe corridor, which extends across Central Ukraine from the Dniester to the Dnieper River valleys (*Diachenko 2012; Diachenko, Menotti 2017; Harper 2016; 2019; Harper* et al. *2019; Ryzhov 1993; 1999; 2003; 2015*). Similar hierarchies in settlement size have also been noted in other regions and among other cultures within the CTCC, but these settlements did not reach such extreme dimensions as those in Central Ukraine. For instance, in the Prut-Dniester and Dniester-Bug interfluves, as well as in the Middle Bug region, the largest WTC sites did not exceed a size of *c.* 60ha (*Diachenko 2016a; 2016b; Diachenko, Zubrow 2015; cf. Rud* et al. *2019b*).

It is of little surprise that reconstructions of the demographic development, economy, and social structure of the inhabitants of the WTC giant-settlements, *i.e.* the largest settlements of Neolithic and Eneolithic Europe, inspire controversy. To a great extent, these reconstructions and interpretations stem from different understandings of the durations of the giant-settlements and their internal chronologies. As in any discussions of archaeological time, construction of a temporal framework for the giant-settlements may vary greatly depending on the weight assigned to relative versus absolute dating techniques. Relative approaches are usually criticized for the host of other stylistic and cultural factors that may influence pottery seriation beyond a strictly temporally derived typo-chronology (*e.g., Gaydarska, Chapman 2016*). Meanwhile, absolute dates are only as good as the contexts and materials from which they are taken. Common discussions of ^{14}C dates may often appear imprecise due to reliance on 2σ (or 95%) uncertainty ranges and the popular misconception that these ranges signify duration or intensity of occupation, rather than the range of probable occurrence for a discrete event (*Carleton, Groucutt 2021*).

Current demographic and socio-economic reconstructions suggested for the WTC giant-settlements are grounded in three major approaches to their duration and micro-chronology. The first approach proposes the sequential functioning of structures at the settlements, which were inhabited for several centuries and all existed synchronously (*Ohlrau 2020; cf. Palaguta 2020*). The second approach places settlement duration at *c.* 200 years but assumes only seasonal occupation of the majority of dwellings (*Chapman 2017*). Both temporal frameworks are mainly based on consideration of the 2σ ranges of large datasets of radiocarbon data. Our paper contributes to further development of a third approach, which combines highly targeted AMS ^{14}C dating with the traditional relative chronology to create a chronological synthesis. This approach supports the idea that giant-settlements existed more or less sequentially with each being inhabited for around 80 to 100 years (*Diachenko 2012; Harper 2016*).

However, our project goes well beyond the giant settlements and addresses a far broader spatial and chronological range, examining material from diagnostic sites throughout Western and Central Ukraine and generating 28 new AMS ^{14}C dates from eight sites (Fig. 1). Of these, three sites lie within the SBDI, four in the Dniester Basin, and one in Eastern Volhynia. Despite being an archaeological culture that originates in the Prut-Dniester region, the sample of known WTC sites has an extensive space-time bias towards the area of giant-settlement development owing to scholarly priorities since the early 1970s. Consequently, knowledge of the origins of the WTC is confined to just a few studies (*e.g., Ryzhov 2007*), and the Republic of Moldova and Ukraine are home to thousands of Eneolithic sites that remain unpublished or as-yet unstudied.

By dating sites and examining settlement data from outside the SBDI we strive to recontextualize the development of the WTC towards its point of origin, in regions and micro-regions at the other end of the forest-steppe corridor. Our results, in concert with other recent AMS ^{14}C dates from throughout the WTC, aid in resolving the chronology of both the giant-settlement phenomenon and the CTCC as a whole. Notably, we establish new temporal termini: five new dates from Kosenovka provide a *terminus ante quem* for the Vladimirovskaya-Tomashovskaya giant-settlement sequence, while two dates from Golyshev indicate the end of Tripolye CII in Western Volhynia. Evaluation of settlement data, organized according to a new chronology that synthesizes relative and absolute dating, allows for the examination of rates of change in material culture and the serial movement of populations across the landscape. These are issues that affect our understanding of CTCC ways of life at both large and small settlements alike.

The Cucuteni-Tripolye cultural complex

Taxonomy and chronology

The CTCC (*c.* 5050–2950 BC) forms the north-eastern periphery of the Neolithic and Eneolithic cultural complexes of Southeast Europe ('Old Europe'). Sites attributed to this complex extend west-to-east from the Carpathian Mountains to the eastern bank of the Dnieper River, and north-to-south from Volhynia to the coast of the Black Sea. Cucuteni-Tripolye pottery is represented by a diverse selection of vessel forms and decorative motifs. During the early and middle twentieth century, specialists began to make coarse typological distinctions relying on the presence of incised ornamentation, painting, or a combination of the two, stylistic trends which vary through space and time. The identification of these trends enabled the gradual development of a taxonomy of divisions within the CTCC, and eventually led to fine-grained schemes of relative chronology at local and regional levels.

Earlier CTCC ceramics display incised decoration, and are sometimes painted after firing, while later ceramics are painted prior to firing. Considering these differences in ornamentation styles, Vladimir Dumitrescu suggested that the complex be divided along chronological lines, between the Precucuteni and Cucuteni-Tripolye cultures. He also underlined significant differences in ornamentation schemes between the Cucuteni and Tripolye components of the overall complex, arguing that Cucuteni and Tripolye should be distinguished from one another (*Dumitrescu 1963*).

The periodization of the Cucuteni sites, constructed from stratigraphic observations at multi-layer sites, is based on the scheme of Hubert Schmidt. Schmidt combined the sites into three sequential periods: Cucuteni A, AB, and B (*Schmidt 1932*). Further contributions allowed for the subdivision of these periods into smaller phases. These are the Cucuteni A1, A2, A3, and A4, Cucuteni AB1 and AB2, and Cucuteni B1, B2, and B3 phases (*Cucoș 1999; Dumitrescu 1945; Mantu 1998; Nițu 1984*).

The periodization of the Tripolye sites, which is still used in a corrected and elaborated form, was proposed by Tatiana Passek (*1935; 1949*). She divided sites into three chronological groups: Early (A), Middle (B), and Late (C and γ). The Middle Tripolye settlements were further distinguished into the Tripolye BI and BII periods. Later research by Natalia Vinogradova suggested that an additional transitional period, Tripolye BI-II, should be placed between Tripolye BI and BII and synchronized with Cucuteni A-B (*Vinogradova 1982*). In the case of Late Tripolye sites, Passek's scheme was extended by spatial division. Sites located in the north – in Volhynia

Fig. 1. Geographic reference, showing the northern extent of the CTCC with major regions labelled, as well as ^{14}C-dated sites and other major type-sites mentioned in the text.

and the Middle Dnieper region – were labelled 'Tripolye C', while sites located in the south – in the Prut, Dniester, and Lower Southern Bug regions – were labelled 'Tripolye γ'. This resulted in the subdivision of Late Tripolye into Tripolye CI, γI, CII, and γII (*Passek 1949*). Contemporaneous sites in Romania are referred to as Horodiștea-Foltești or, more recently, Horodiș tea-Erbiceni or Horodiș tea-Erbiceni/Gordinești. These sites were at first considered to be a separate chronological horizon and later as an individual culture or cultures (*Dumitrescu 1963; Lazarovici 2010; Nestor 1950; Petrescu-Dîmbovița 1950; Sîrbu 2019*).

Tamara Movsha (*1972*) proposed replacing the term 'Tripolye CI' with 'Tripolye BIII', and related only Tripolye CII sites (after Passek *O.c.*) to the latest period of the culture. Vladimir G. Zbenovich (*1974*) and Valentin Dergachev (*1980*) also noted that Tripolye CI (after Passek *O.c.*) settlements, dwellings, and ceramics are more similar to Tripolye BII materials than to those of Tripolye CII. Hence, Dergachev claimed that Late Tripolye corresponds exclusively to Tripolye CII/γII in Passek's scheme (*Dergachev 1980*). Late Tripolye sites were further divided into two sub-periods labelled simply '1' and '2' according to chronological ordering (*Dergachev 1980*). Taras Tkachuk, and Sergei Ryzhov, considering different issues with the transition from Tripolye CI to Tripolye CII (after Passek *O.c.*), used more neutral terms like "*late Tripolye CI–early Tripolye CII sites*" or "*Tripolye CI-II*" (*Ryzhov 2007; 2012; Tkachuk 2005; 2011*). To some extent, these neologisms were caused by different rates of development in the material culture in different regions of the CTCC, which we attempt to address in the analysis presented here.

More recently, Ryzhov (*2007; 2012; forthcoming*) proposed applying a modified version of Movsha's changes to the Tripolye periodization. According to him, most of the Tripolye CI sites should equate to the Tripolye BIII period, while a new period designated CI should be limited to sites previously attributed to the final phases of Tripolye CI and the early phases of Tripolye CII; *i.e.* the sites of the Badrazhskaya, Koshilovetskaya, Lukashevskaya, and Kosenovskaya local groups and those contemporaneous with them (*Ryzhov 2012; forthcoming*). Tkachuk continues to use the term "*late Tripolye CI–early Tripolye CII*" (*e.g., Tkachuk 2011*). The idea of separating the latest Tripolye local groups into individual cultures was also suggested recently (*e.g., Burdo 2007; Petrenko 2009*). However, it was not accepted by all experts. Here we promote the use of the periodization developed by Ryzhov, which current research shows to be the most apt for describing continuities and discontinuities in Tripolye material culture.

Further work on pottery seriation identified the Ariușd culture in Transylvania, while the Tripolye component of the cultural complex was subdivided into two cultures. These are the Eastern Tripolye culture (ETC) and Western Tripolye culture (WTC). ETC materials are distinguished based on ceramics with mostly incised ornamentation, as well as certain diagnostic types of clay figurines and dwellings (*Tsvek 1980; 2006*). Tripolye sites with ceramic assemblages characterized by painted ornamentation are associated with the WTC (*Ryzhov 2007; 2012; forthcoming*).

The current view of the CTCC is of a large taxonomic unit subdivided into five smaller taxa: Precucuteni, Ariușd, Cucuteni, ETC, and WTC. Sites within cultures that have similar ceramic assemblages are further grouped into types. These types of sites compose the local groups that in turn form the 'genetic' lines of development of the culture (*Dergachev 1980*; note here that the term 'genetic' refers not to biology, but exclusively to trajectories in the development of pottery technology, morphology, and ornamentation). We use the term 'Tripolye' when the ETC and WTC are simultaneously considered or apply it in respect to the periodization of sites, for example, 'Tripolye BII', 'Tripolye CII'.'

Until recently the synchronization of the Cucuteni and Tripolye periodizations was based on a linear (though not consciously recognized as such) concept of cultural evolution, presuming that changes in pottery shapes and decoration were rapidly disseminated as regional archaeological horizons that displaced previous materials. However, mathematical modelling, partly confirmed by radiocarbon chronology, indicates a delay in the development of the eastern part of the CTCC in comparison to its western part. The same trend is also assumed for cultural units of lower orders in the taxonomic hierarchy (*e.g., Diachenko, Menotti 2015*). In the case of the ETC, the formation of site clusters was initially characterized by different ceramic traditions coexisting within the same micro-regions, while further interactions between populations of these clusters resulted in rapid change of pottery assemblages. Synchronous long-distance migrations of sub-populations bringing new pottery styles to new areas and further re-colonization of already populated niches created a complex patchwork of cultural change, featuring the simultaneous use of old and new stylistic traditions within the same cultural complex (*Harper* et al. *forthcoming*). The WTC presents a similarly complex mosaic of differential rates of material change.

Local groups of the Western Tripolye culture

The WTC formed in the Middle Dniester and Upper Dniester regions and its ceramics, while exhibiting a diversity of forms and decoration, share a common and readily recognizable stylistic lineage (Fig. 2). Its roots are visible in the late Tripolye BI sites, from which emerged the sites of the Kadievtsy type. However, precise distinction of the earliest WTC sites requires further accumulation of empirical data and their analysis (*Ryzhov 2007*). The relative chronology of early sites is intensively debated (compare *Ryzhov 2007; 2012; Tkachuk 2019*). The earliest WTC local groups, Zaleschitskaya and Solonchenskaya, along with the Polivanov Yar-type sites, are ascribed to Tripolye BI-II (*Ryzhov 2007*), a nebulous period with comparatively few sites that has recently appeared to be a stylistic variant of Tripolye BI rather than a period unto itself (*Diachenko 2016b; Harper* et al. *forthcoming; Palaguta 2007*). We tentatively assign these sites, which lack any absolute dates, to the range of 4250–4100 BC. It seems probable that this range will narrow once absolute dates are obtained for these sites.

The Solonchenskaya group, through the sites of the Nezvisko III type, formed the genesis of the Shipinetskaya local group in the Upper Dniester region, while the Zaleschitskaya local group formed the basis for the Rakovetskaya group in the Middle Dniester region (*Ryzhov 2007*). This transition is dated to the beginning of Tripolye BII. There are two major views on the taxonomy of the WTC during the first part of Tripolye BII: Ryzhov (*2003*) follows Vladimir Sorocin (*1990*) and subdivides the Rakovetskaya group into two subsequent site-types, Rakovetskij and Mereshovskij. An alternative view considers these two units as distinct local groups (*Diachenko, Sobkowiak-Tabaka forthcoming; Levinzon 2019; Tkachuk 2015*).

The formation of WTC settlements in the western part of Eastern Volhynia and in the Middle Bug region, where complexes of this kind were not known previously, marks the migration of Rakovetskaya and Mereshovskaya group populations to the north and east (*Kruts, Ryzhov 2000*). The migration of Rakovetskaya and Mereshovskaya group populations resulted in the formation of the Voroshilovskaya group in the Middle Bug region and Vladimirovskaya group in the SBDI around 4100 BC (*Ryzhov 2015*). The subsequent migration wave of Mereshovskaya and Shipinetskaya group populations to the east is dated to *c.* 3950–3900 BC. This migration is reflected in the rapid transformation of ceramic styles and abnormally high population growth reflected by settlements of the first phase of the Nebelevskaya group in the SBDI and, probably, the Nemirovskaya group in the Middle Bug region (*Diachenko 2016a; Gusev 1995; Harper 2016; Ryzhov 1993*).

Mereshovskaya group sites were the basis for the formation of the Petrenskaya local group in the Middle Dniester area at the end of Tripolye BII (*Ryzhov 2003; Sorocin 1990; Tkachuk 2019*). However, the late Mereshovskaya group sites located to the north and east of the Dniester represent a certain ‘delay’ in ceramic assemblages in comparison to the contemporaneous pottery sets coming from the early settlements of the Petrenskaya group. The earliest Petrenskaya group sites are dated to the range of *c.* 3950–3900 BC (*Diachenko, Sobkowiak-Tabaka forthcoming*).

Tripolye BIII in the Dniester-Bug region corresponds to the development of the Chechelnitskaya local group. The mechanisms of its formation and the attribution of the earliest sites to the group are debated (*Ryzhov 2007; Tkachuk 2005*). The WTC settlements of Tripolye BIII in the Middle Bug region are assigned to the Gorodischenskaya group (*Gusev 1995*).

The transition from Tripolye BII to Tripolye BIII in the SBDI corresponds to the early sites of the Tomashovskaya local group, which formed *c.* 3850–3800 BC from a portion of the sites of the Nebelevskaya local group. It should be noted that settlements of both groups existed synchronously in neighbouring micro-regions during the range of 3850–3700 BC (*Diachenko, Menotti 2012*). Similar to the formation of the Nebelevskaya local group, the formation of the Tomashovskaya local group corresponds to a shift in pottery assemblages and an increase in population indicative of elements of the Shipinetskaya local group migrating east (*Ryzhov 2003*).

Settlements of the Petrenskaya local group in the Middle Dniester region developed in the range of 3950–3700 BC. However, the continued functioning of the latest sites of this group in peripheral areas somewhat later than 3700 BC is not excluded (*Diachenko, Sobkowiak-Tabaka forthcoming; Tkachuk*

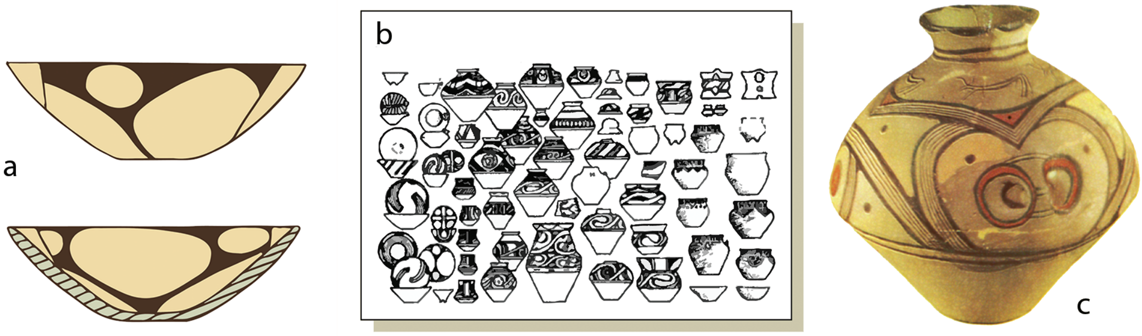

Fig. 2. Examples of WTC ceramics:* a *bowl from Mereșeuca-Cetățuia, Mereshovskaya phase 2 (*Sorocin 1990*);* b *Nebelevskaya phase 2 ceramic forms and ornamentation (*Ryzhov 1993*);* c *vessel with painted* 'owl face' *scheme and bull decorations from Vărvăreuca 15 (*Markevich 1981*).

2008). Considering the presence of imports from settlements belonging to the second phase of the Tomashovskaya local group at Bernashevka 2 (*Ryzhov 2003; Tkachuk 2008*), we suggest the subdivision of the second stage of the second phase of the Petrenskaya group into two sub-stages. In the core area of the Prut-Dniester interfluve, Petrenskaya group sites were replaced by settlements of the Vărvăreuca 15 type and Badrazhskaya local group *c.* 3700–3650 BC. It is important to note that Vărvăreuca 15-type sites and the Badrazhskaya local group belong to Tripolye CI, while pottery assemblages of synchronous cultural units to the east and north of the Dniester are attributed to late Tripolye BIII.

Sites of the Lomachintsy-Vyshneva type were spread between the Prut and Dniester during late Tripolye BIII to early Tripolye CI. This site-type became the base for the formation of the Tripolye CII Brynzenskaya group in the Prut-Dniester interfluve, and, through long-distance migration, the Tripolye CII Khorjev group in Volhynia and the Tripolye CI Kosenovskaya group in the SBDI (*Dergachev 1980; Ryzhov 2007*). Further development of the WTC in the Prut-Dniester interfluve corresponds to two 'genetic' lines starting with, respectively, the Vykhvatinskaya and Brynzenskaya local groups (*Dergachev 1980*). The Brynzenskaya local group influenced the formation of the Tripolye CI Koshilovetskaya group in the Upper Dniester region (*Ryzhov 1998; 2007; cf. Tkachuk 1998; 2005*). The Kocherzhintsy-Shulgovka type dates from Tripolye CI to the very beginning of the Late Tripolye period in the SBDI and arose from the Kosenovskaya local group (*Dergachev 2004; Ryzhov 2002; cf. Tkachuk 2008*). The co-existence of Tripolye CI and CII local groups and site types indicates uneven rates of cultural change in different regions. Generally, the highest rates of change are observed in the core area of the WTC's development, the Prut-Dniester interfluve.

The Brynzenskaya local group became the basis for the formation of the Late Tripolye Gordineshtskaya and Horodiștea groups as well as several types of sites in the Upper Prut region, Upper and Middle Dniester, the northern part of the Southern Bug region and the SBDI (*Dergachev 1980; 2004; Ryzhov 2007; cf. Tkachuk 2011; 2014*). According to Viacheslav Bicbaev (*1994*), the transition from the Brynzenskaya to Gordineshtskaya local groups included an intermediate chronological step represented by sites of the Kirilen type. More recently, it has been suggested that this site type is synchronous with sites of the early Gordineshtskaya local group (*Sîrbu 2019*). The Vykhvatinskaya local group provided the basis for the formation of the Usatovskaya group in the North Pontic region and the Foltești group in Romanian Moldavia. However, early sites of the Usatovskaya group are generally synchronous with early sites of the Vykhvatinskaya group, with only a short delay in development (*Dergachev 1980; 2004*).

The final picture of the relative development of the WTC is extremely complex, an interwoven mass of stylistic changes that has been pieced together over decades of careful study by ceramic specialists. However, the interrelationships among the various local groups and site types provides a structure for guiding strategies of absolute dating, which may in turn be used to test the accumulated assumptions of the relative chronology.

Methods

AMS radiocarbon dating and analysis

We produced 28 AMS dates on faunal bones at the Penn State Accelerator Mass Spectrometry Laboratory (PSUAMS) in 2018. Samples were taken from the collections of the Institute of Archaeology of the National Academy of Sciences of Ukraine in Kiev, Ivan Franko National University in Lviv, and the Tripolye Culture Museum in Lehedzyne. They originate from sealed contexts at eight well-studied WTC type-sites, mostly from within or underneath the archaeological remnants of burned houses (known as *ploshchadki* in Ukrainian and Russian). These sites were excavated between 1959 and 2017 in campaigns led by Sergei Ryzhov, Elena Tsvek, Dmitriy Chernovol, Pavlo Nechitailo, Vladimir Kruts, Vladislav Chabaniuk, Valentina Shumova, Tamara Movsha, Mikhail Makarevich and Nikolai Peleschishin.

Bone collagen for ^{14}C and stable isotope analyses was extracted and purified at the Pennsylvania State University using a modified Longin method with ultrafiltration (*Kennett* et al. *2017*). With an X-acto blade, bones were cleaned of adhering sediment and the exposed surfaces removed. Samples consisting of 600–1000mg of finely cut fragments were demineralized for 24–36 hours in 0.5N HCl at 5°C. Residue from this process was rinsed to neutrality in multiple changes of Nanopure H_2O, and then gelatinized for 10 hours at 60°C in 0.01N HCl. The resulting gelatine was lyophilized, weighed, and visually inspected to determine the percent yield as a first evaluation of the degree of bone collagen preservation, with yields in the 0–3% range generally being rejected. Following this, the gelatine was rehydrated into a solution and pipetted into pre-cleaned Centriprep (*McClure* et al. *2010*) ultrafilters (retaining ≥30kDa molecular weight gelatine) and centrifuged 3 times for 20 minutes, diluted with Nanopure H_2O, then centrifuged 3 more times for 20 minutes to desalt the solution. Carbon and nitrogen concentrations and stable isotope ratios were measured at the Yale Analytical and Stable Isotope Center with a Costech elemental analyser (ECS 4010) and Thermo DeltaPlus analyser. Sample quality was evaluated by examining the % crude gelatine yield, %C, %N, and C:N ratios prior to being sent on to AMS ^{14}C dating. C:N ratios for the 28 dated samples fell between 3.12 and 3.49, indicating acceptable collagen preservation (*Van Klinken 1999*). In those cases where ultrafiltration returned an unacceptably low gelatine yield, samples were processed according to the XAD amino acid purification method (after *Lohse* et al. *2014*).

Having passed demineralization and quality control measures, the purified collagen samples proceeded to the gas line, where they were combusted for three hours at 900°C in vacuum-sealed quartz tubes with CuO and Ag wires. Sample CO_2 was reduced to graphite at 550°C using H_2 and an Fe catalyst, with reaction water drawn off with $Mg(ClO_4)_2$ (*Santos* et al. *2004*). Graphite samples were then transferred to the AMS, pressed into targets in Al cathodes and loaded on the target wheel. Received ^{14}C ages were corrected for mass-dependent fractionation with measured $\delta^{13}C$ values (*Stuiver, Polach 1977*) and compared with samples of Pleistocene whale bone (backgrounds, 48 000 ^{14}C BP), late Holocene bison bone (*c.* 1850 ^{14}C BP), late AD 1800s cow bone and OX-2 oxalic acid standards for calibration.

The reported uncertainty of the dates ranged from 15–35 ^{14}C years, with the majority falling at ±20. All calibrated ^{14}C ages were calculated using OxCal version 4.4 (*Bronk Ramsey 2020*) using the IntCal20 northern hemisphere curve (*Reimer* et al. *2020*). Results are reported in Table 2 (see also Supplementary Data, Table S1).

Aside from two obvious outliers dating to the Middle Bronze Age (PSUAMS-4627) and Medieval period (PSUAMS-4452), data were placed into a Bayesian sequence consisting of ten phases (Supplementary Data, Tables S3, S4). Boundaries were entirely delineated by site, presumed habitational layer and ^{14}C ages, agnostic of extensive *a priori* assumptions about the relative sequence of sites. Layers are indicated by sequential Roman numerals within parentheses, such as (I) or (II), and are not indicative of official nomenclature or previously applied numbering schemes. A further two minor outliers, PSUAMS-4589 and PSUAMS-5096, were removed due to poor model agreement (the manual outlier detection method, after *Bronk Ramsey 2009*). The intent of this exercise was twofold: to test whether calibrated ^{14}C probability distributions that have a high degree of overlap, especially during the periods of Tripolye BII and BIII, may be arranged into a sequence resembling the *c.* 50–100 year resolution prescribed by the relative chronology; and to highlight two situations (Lipchany and Konovka I) in which the received data disagree with the material classification of the sites.

Consideration of calibrated radiocarbon dates and derivative statistics (like summed probability distributions) is prone to all manner of ill-considered and dubious popular applications, such as ascribing habitational periods or 'intensity' to calibrated ranges. Similarly, Bayesian sequencing may often be poorly designed and implemented in a manner that locks in the confirmation bias of researchers, rather than for its intended purpose of resolving sequences of dates and testing chronological assumptions. The fourth millennium BC is characterized by several calibration curve plateaus that causes radiocarbon probability distributions to assume wide, bi- or tri-modal appearances, rendering calibrated 2σ ranges imprecise and often overlapping despite dates having quite distinct ^{14}C ages. It is important to remember that ^{14}C dates represent singular events (the time at which an organism died and ceased carbon fixation) and that consideration of the mean (μ) calibration, as well as the duration of modelled phases, should also feature heavily in interpretation of results.

Analysing the diachronic spatial distribution of WTC local groups

In order to understand the space-time development of WTC local groups, we analysed a dataset of 158 settlement sites with well-defined chronological assignments and site size data (Supplementary Data, Table S5) in QGIS software. The chronology of the sites was determined according to our past projects in regional analysis (*e.g., Diachenko 2012; 2016b; Harper 2016; Harper* et al. *2019*) and updated according to the new ^{14}C dates presented in this study. These sites were divided into three main analytical groups based on their geographic positioning: the Prut and Dniester Basins, the Southern Bug Basin, and the Southern Bug-Dnieper Interfluve (Fig. 3). It should be noted that the sites of the Dniester-Bug interfluve have their own specific ceramic assemblages (*e.g., Rud* et al. *2019b; Ryzhov 2007*), so this region is usually treated separately. However, given the size and geographic distribution of the sample, we divided these sites for the purposes of this study. Excluding the SBDI, which has been subject to extensive study elsewhere (*Diachenko 2012; Diachenko, Menotti 2012; Diachenko, Zubrow 2015*), these groupings were then subdivided into a further seven micro-regions. The intent is to explicate large-scale trends in population development, while also being able to highlight individual settlement events and population movements on the local scale.

Population estimates are generated according to Harper's (*2016*) variant of the SARP model for estimating archaeological populations (originally pro-

Lab ID	Site	Process	^{14}C age	δ13C	δ15N	%C	%N	C:N	cal BC (2σ)	cal BC (μ)
PSUAMS-4590	Golyshev (I)	UF, >30kDa gelatin	5255±25	–21.0	7.5	38.8	13.8	3.28	4230–3980	4075
PSUAMS-4453	Lipchany	UF, >30kDa gelatin	5220±20	–21.8	9.9	43.2	15.2	3.32	4050–3970	4015
PSUAMS-4451	Lipchany	UF, >30kDa gelatin	5200±25	–22.0	7.2	43.9	15.5	3.31	4045–3965	4005
PSUAMS-4450	Lipchany	UF, >30kDa gelatin	5075±25	–21.0	7.7	44.0	15.5	3.32	3960–3795	3870
PSUAMS-5095	Peshchanoe	XAD amino acids	5045±20	–17.5	9.6	38.5	14.4	3.12	3945–3785	3870
PSUAMS-5094	Peshchanoe	XAD amino acids	5045±20	–18.7	7.7	13.1	4.8	3.21	3945–3785	3870
PSUAMS-4589*	Rubanyj Most	UF, >30kDa gelatin	5040±20	–21.2	7.9	46.8	16.9	3.24	3945–3775	3870
PSUAMS-4587	Rubanyj Most	UF, >30kDa gelatin	5015±20	–19.6	6.8	46.1	16.3	3.30	3940–3710	3825
PSUAMS-4630	Rubanyj Most	UF, >30kDa gelatin	4995±20	–20.0	5.4	55.7	19.8	3.27	3910–3705	3770
PSUAMS-5097	Kam.-Podolskij (Polskij Rynok)	XAD amino acids	4990±25	–19.9	11.0	19.2	7.1	3.14	3915–3700	3770
PSUAMS-4454	Konovka (I)	UF, >30kDa gelatin	4975±20	–20.9	8.3	42.9	15.2	3.31	3795–3700	3745
PSUAMS-5096*	Peshchanoe	XAD amino acids	4960±20	–19.9	7.0	23.7	8.6	3.21	3790–3665	3735
PSUAMS-4629	Rubanyj Most	UF, >30kDa gelatin	4955±25	–21.6	10.2	82.9	29.2	3.32	3785–3660	3730
PSUAMS-4584	Konovka (I)	UF, >30kDa gelatin	4950±20	–21.1	6.7	41.5	14.4	3.36	3780–3660	3725
PSUAMS-4588	Rubanyj Most	UF, >30kDa gelatin	4950±20	–21.5	9.9	42.1	14.6	3.36	3780–3660	3725
PSUAMS-4695	Kam.-Podolskij (Polskij Rynok)	XAD amino acids	4910±20	–20.5	8.8	21.6	7.8	3.23	3710–3645	3680
PSUAMS-5106	Kosenovka	UF, >30kDa gelatin	4810±20	–20.8	8.3	39.8	14.5	3.21	3650–3530	3580
PSUAMS-5105	Kosenovka	XAD amino acids	4760±20	–20.8	7.4	33.4	12.5	3.13	3640–3515	3570
PSUAMS-5104	Kosenovka	UF, >30kDa gelatin	4750±20	–21.7	8.8	46.5	17.0	3.20	3640–3380	3565
PSUAMS-4628	Konovka (II)	UF, >30kDa gelatin	4725±20	–21.0	9.9	43.2	14.8	3.41	3635–3375	3515
PSUAMS-5103	Kosenovka	XAD amino acids	4720±20	–21.0	11.0	22.2	8.2	3.17	3635–3375	3500
PSUAMS-5107	Kosenovka	UF, >30kDa gelatin	4690±35	–21.2	7.5	42.7	15.5	3.22	3630–3365	3470
PSUAMS-4586	Stena 2	UF, >30kDa gelatin	4465±20	–19.0	7.7	39.9	14.3	3.25	3335–3025	3205
PSUAMS-4585	Stena 2	UF, >30kDa gelatin	4465±20	–20.3	7.3	41.5	14.8	3.27	3335–3025	3205
PSUAMS-4696	Golyshev (II)	XAD amino acids	4440±20	–21.3	5.5	14.4	5.2	3.25	3330–3010	3115
PSUAMS-4697	Golyshev (II)	XAD amino acids	4400±20	–21.2	5.5	23.9	8.3	3.35	3095–2925	3010
PSUAMS-4627*	Konovka	UF, >30kDa gelatin	3640±20	–21.7	7.0	42.7	14.3	3.49	2125–1940	2005
PSUAMS-4452*	Lipchany	UF, >30kDa gelatin	470±15	–21.1	5.5	41.8	14.7	3.31	AD 1420–1450	AD 1435

* omitted outliers

Tab. 2. PSUAMS radiocarbon dates and stable isotope measurements for eight WTC sites.

posed by *Ammerman* et al. *1976*). While SARP is a general model in its operating principles, this variant has been specifically developed and adapted for parsing large quantities of settlement data pertaining to the Neo-Eneolithic period in Eastern Europe (*Harper 2016; forthcoming*). The model calculates the population at a given time reference (t) by assigning settlement area (a) to an appropriate value of t for all settlements k. Time references correspond to the 50-year intervals prescribed by the regional relative chronology, and in this particular case the analytical window is defined as 4200–3300 BC (roughly from the beginning of Tripolye BII to the end of Tripolye CI). Data were selected on the basis of having reliable chronological assignments, but in those cases where ambiguity exists or phases occupy multiple 50-year intervals, the model divides a equally over multiple values of t.

While values of a are known for *c.* 73% of the sampled sites, there are a number of cases where a site's chronology is well-known while its morphological characteristics are not. In these situations, the model notes all incidences where values of a are equal to zero and imputes a size value (u) based on the median settlement size at the appropriate value of t. Distributions of settlement size values, both theoretically and observationally, assume a descending log-normal trend and therefore must be log-transformed, analysed, and then back-transformed to generate accurate statistical data. Values of u applied here are based on previous calculations made for settlements found over the entire area of Romania, Moldova, and Ukraine (*Harper 2016*; see also Supplementary Data, Table S6).

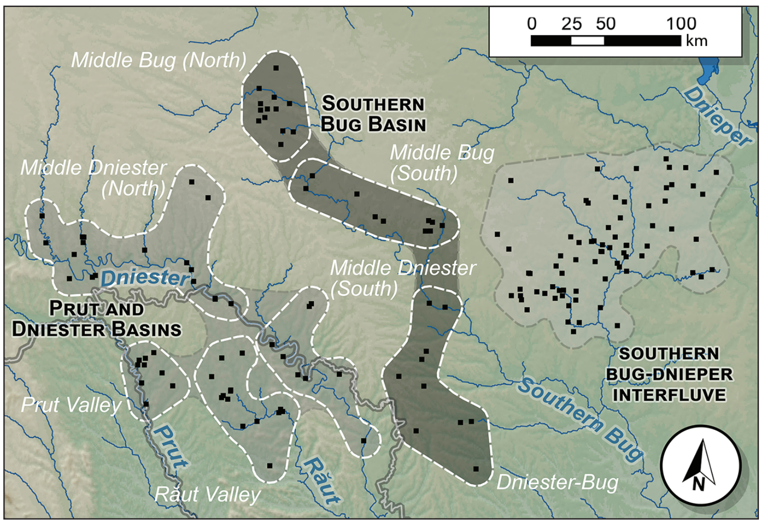

Fig. 3. Extent of the demographic analysis. Major regions are shaded, and micro-regions indicated by white outlines. Point data represent the locations of the 158 settlements analysed.

Results

The absolute sequence of WTC sites

The AMS ^{14}C dates obtained by our project generally correspond well to the relative sequence of sites and are in agreement with comparable AMS ^{14}C dates on bone samples (Fig. 4). The earliest date obtained at the multilayer site of Golyshev (PSUAMS-4590), originating from the excavations of Nikolai Peleschishin (*1998*), is represented by the ranges of 4230–3980 cal BC (2σ) and 4105–4035 cal BC (modelled). Sławomir Kadrow (pers. comm., 3 May 2021; see also *Pozikhovskyj 2010*) contends that this is indicative of a distinct occupation belonging to the Rzeszów phase of the Malice culture. Our date fits the chronology of this cultural unit and suggests that Western Volhynia was inhabited by its population during the time range corresponding to late Tripolye BI and early Tripolye BII (*Kadrow 2013*). This synchronization is also corroborated by Malice imports and influences on WTC pottery assemblages (*e.g., Skakun, Starkova 2003; Tkachuk 2019*).

The next site in our sequence, the Middle Dniester site of Lipchany, is one case in which ^{14}C dates and relative chronology do not correspond to each other. The three dates (PSUAMS-4450, -4451, -4453) from Ploshchadka 1 (*Zbenovich, Shumova 1989*) are substantially older than we expected from the site's dominant pottery assemblage, which is identified as Phase 3 of the Petrenskaya local group. However, during excavations at Lipchany considerably older pottery sherds were also found below Ploshchadka 1. Taking into account the site's modelled range of 4090–3895 cal BC, we assume that the bones recovered from Ploshchadka 1 are most likely indicative of a Mereshovskaya local group occupation, which is as-yet poorly understood. The dates are comparable to recent AMS dates from Trostianchik, which dates to Mereshovskaya phase 2, stage 1 (*Rud* et al. *2019a*). The translation of much of the Petrenskaya local group relative sequence (*Ryzhov 2003*) into a framework of absolute calendar dates is enabled by recently obtained dates for the Late Mereshovskaya site of Kamenets-Podolskiy (Tatarysky) (*Diachenko, Sobkowiak-Tabaka 2020*). The ceramic assemblage of this settlement indicates its synchronicity with the Early Petrenskaya group sites in Northern Moldova, which similarly exhibit synchronicity with the settlements of Mereshovskaya phase 2 in the Middle Dniester and settlements of Nebelevskaya phase 1 in the SBDI (*Diachenko, Sobkowiak-Tabaka, forthcoming*).

While the fine-grained Tripolye relative chronology is mostly composed of units with a duration of 50 years (*Kruts 1989; Markevich 1981*), it is important to note that this is a partial abstraction and that the lifetimes of settlements exhibit some local and regional variability, seldom adhering exactly to ceramic phases. The settlement of Peshchanoe in the SBDI (3950–3780 cal BC on 2σ; 3895–3790 cal BC [modelled]) is one case in which radiocarbon data are a close but inexact match to those expectations. Our dates are taken from Ploshchadka 2, excavated in 2005 (*Chernovol, Ryzhov 2006*). In terms of relative chronology Peschanoe is assigned to phase 1 of the Nebelevskaya local group (*c.* 3950–3900 BC), and shares a very similar ceramic assemblage with the eponymous giant-settlement of Nebelevka. However, the ^{14}C data are somewhat later than expected, coinciding with our expectations for Nebelevskaya phase 2, stage 1 (compare with *Diachenko, Menotti 2012*). The dates from Peshchanoe are in close agreement with the general ^{14}C sample from Nebelevka (*Chapman* et al. *2018; Millard 2020*), though it may be that Nebelevka was founded first and Peshchanoe was established later yet retained 'conservative' ceramic traditions for a time amid the development of Nebelevskaya phase 2 settlements. It should be noted that Ryzhov (*1993*) and Tkachuk (*2005*) do not exclude the possibility that Peschanoe is a somewhat younger settlement than Nebelevka. These results highlight the fact that rates of change in material culture scale to all levels, from the super-regional to the local.

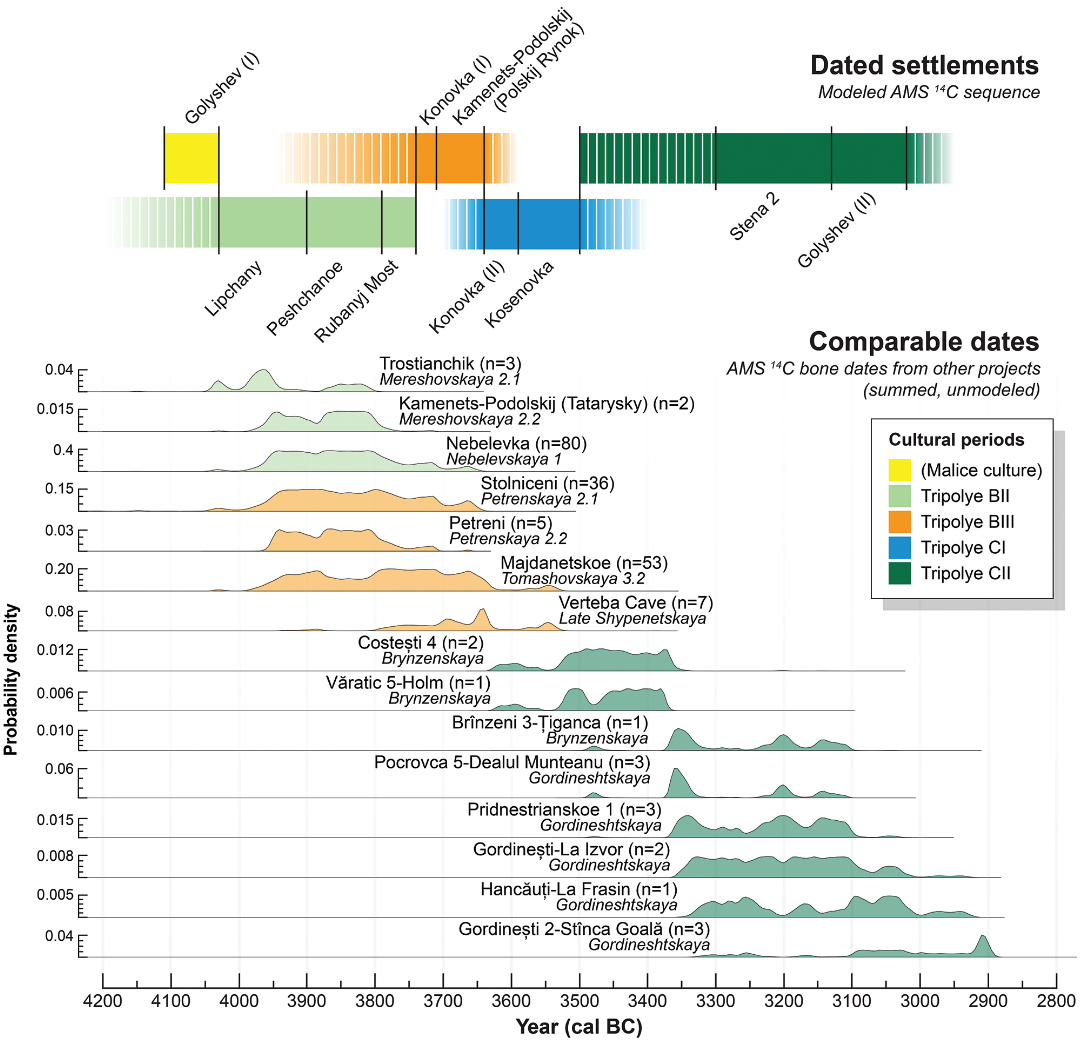

Fig. 4. A Bayesian sequence of sites dated in this study, shown in relation to the periodization of the Tripolye culture (above). The duration ascribed to each site is determined as the span between the mean values of the model boundaries (black lines; see Supplementary Data, Tables S3, S4). The received dates are comparable to other recent AMS ^{14}C bone dates from WTC sites (below, see Supplementary Data, Table S2).

The first occupational event identified by the dates from the site of Konovka-Putsyta originates from Ploshchadki 3 and 12 (*Shmaglij* et al. *1985*), which contain ceramic assemblages matching the earlier part of the Shipinetskaya local group (Tripolye BII). The absolute dating of the Shipenetskaya local group is mostly unknown, though we may compare our results against seven AMS dates on human remains from Verteba Cave (*Lillie* et al. *2017*), which are associated with Late Shipinetskaya (Tripolye BIII) pottery that Tkachuk synchronizes with the earliest phases of the Badrazhskaya local group (*Tkachuk 1998*). However, the ^{14}C results are still far younger than expected (3800–3650 cal BC on 2σ; 3740–3710 cal BC [modelled]), closer in age to middle-late Tripolye BIII. In this respect, we assume that there is further occupation at this site dated to the middle of Tripolye BIII. However, this assumption requires further confirmation.

Our five dates from Rubanyj Most all come from Ploshchadka 1, excavated in 1989 (*Tsvek, Movchan 1990*). Results from this site (3945–3710 cal BC on 2σ; 3790–3740 cal BC [modelled]) correspond almost exactly with the presumed position and duration of the settlement's relative chronological phase (Nebelevskaya phase 2, stage 3; *c.* 3800–3750 BC). This confirms the previously suggested overlap between the late settlements of the second phase of the Nebelevskaya local group to the earlier sites of the Tomashovskaya group in the SBDI, including the giant-settlement of Dobrovody (*Diachenko, Menotti 2012*). This assumption is also supported by finds of Tomashovskaya group ceramics at this site.

The dominant ceramic assemblage of the giant-settlement of Majdanetskoe belongs to Tomashovskaya phase 3 stage 2 and showcases numerous influences from the Chechelnitskaya local group, as well as similarities that allow synchronization of this site to the early Badrazhskaya group settlements (*Tkachuk 2008*). While there are numerous AMS dates from Majdanetskoe, these occupy an exceedingly broad temporal range (*e.g., Olhrau 2020*) and date a diverse set of features. Majdanetskoe is a highly unusual site in terms of its layout and developmental trajectory, and may indeed include multiple phases of occupation. However, further consideration of the chronology of this site requires extensive study of its ceramic inventories. The influences seen in ceramics of Tomashovskaya phase 3 stage 2 are crucial for the inter-regional synchronization of the WTC settlements located in the Dniester region and the SBDI and necessitate a date of *c.* 3700–3650 BC. Consequently, we follow the observations of Taras Tkachuk (*2008*), who underlines the synchronous development of the Late Petrenskaya, Early Badrazhskaya and Late Tomashovskaya group sites.

Two dates were obtained from Ploshchadki 2 and 3 at Kamenets-Podolskiy (Polskij Rynok), a recently excavated site (unpublished excavations by D. Chernovol and P. Nechitailo). Our results (3935–3680 cal BC on 2σ; 3710–3645 cal BC [modelled]) confirm the chronological position of phase 3 of the Petrenskaya local group and associated site types, confirming earlier chronologies made based on material culture exchange and older ^{14}C dates (*Diachenko, Harper 2016; Diachenko, Menotti 2015; Diachenko, Sobkowiak-Tabaka forthcoming; Ryzhov 2003; Tkachuk 2008; cf. Markevich 1981*). Two sites in Kamenets-Podolskiy (Tatarysky and Polskij Rynok) have now been dated, both of which help to situate the relative chronology of the Petrenskaya group sites (*Ryzhov 2003*), especially with regards to charting the development of the Pentrenskaya phase 2 sites. Available relative chronological data suggest that these sites developed sequentially during the period of *c.* 3900–3700 BC, indicative of two stages within this phase (most notably represented by the sites of Stolniceni and Petreni, respectively). AMS radiocarbon data from Stolniceni and Petreni agree with this interval, though remain somewhat ambiguous as to the sequence of the sites (*Hansen, Uhl 2016; Țerna* et al. *2019*). Our dates from Polskij Rynok establish a *terminus ante quem* for the Petrenskaya local group as a whole. Confirmation of this group's sequence is crucial for its support of the concept that the development of the CTCC was defined by multilinear cultural evolution (with different rates of cultural change characterizing different groups), as well as the ramifications it has for the proper reconstruction of migratory behaviour and cultural transmission in the WTC. This chronology is also supported by the date obtained from Ploshchadka 2 at Konovka-Putsyta (II) (3630–3375 cal BC on 2σ; 3645–3585 cal BC [modelled]), which confirms assumptions for the chronology of the Badrzazhskaya local group, which replaced the Petrenskaya group in the Middle Dniester region (*Diachenko, Harper 2016; Diachenko, Menotti 2015; Tkachuk 2008*). The core area of the WTC experienced different rates of cultural change, with a far earlier transition from Tripolye BIII to Tripolye CI in the Middle Dniester region in comparison to the Middle Bug region and SBDI.

Until now, chronologies assumed the presence of a hiatus between the settlements of the Tomashovskaya and Kosenovskaya local groups, owing to a poor understanding of the development of Tripolye CI and a reliance on older conventional ^{14}C dates from the eastern part of the complex (*e.g., Diachenko, Harper 2016; Kruts 1989; Ryzhov 2007; cf. Tkachuk 2008*). We obtained five new dates from the site of Kosenovka, from materials excavated from two ploshchadki in 1984 and 2004 (*Movsha 1987; Kruts* et al. *2005*). According to these results (3645–3365 cal BC on 2σ; 3585–3500 cal BC [modeled]), belonging to the first phase of the Kosenovskaya local group, we may amend the chronology of the SBDI so that the Kosenovskaya local group directly follows the end of the Tomashovskaya local group. This substantially revises the latter part of the giant-settlement sequence in the region and prompts a reassessment of the scale of migrations from the Dniester Valley to the east.

Finally, turning to the Tripolye CII sites dated by our project, we have two dates from the 1959 excavations at Stena 2 (*Makarevich 1960*) and a further two dates from Golyshev taken from samples uncovered in 1972–1973 (*Peleschishin 1998*). The chronology of Stena 2 (3335–3025 cal BC [2σ]; 3300–3135 cal BC [modeled]) and Golyshev (II) (3330–2920 cal BC on 2σ; 3135–3025 cal BC [modeled]) fit our views on the position of the Gordineshtskaya local group (*Diachenko, Harper 2016; cf. Videiko 1999*). Our dates are corroborated by AMS dates on Late Tripolye sites in the Dniester region, which are beginning to present a coherent chronology for the Brynzenskaya and Gordineshtskaya local groups. While our project lacks absolute dates for the Brynzenskaya local group, four recent dates from Costești 4, Văratic 5-Holm, and Brînzeni 3-Țiganca (*Rybicka 2019; Sîrbu* et al. *2020*) fill in this gap very well. We omit one anomalously old outlier from Brînzeni 11(9) (*Sîrbu* et al. *2020*); while this site is ascribed to the Brynzenskaya local group, multiple habitational layers exist there, and the results of its ceramic assemblage have never been formally published (*Țerna, Heghea 2017*). Our dates for the Gordineshtskaya local group are directly comparable to other AMS bone dates from mortuary sites like Pocrovca 5-Dealul Munteanu and Gordinești-La Izvor (*Sîrbu* et al. *2020*), the kurgan complex at Pridnestrianskoe (*Klochko* et al. *2015*), as well as the settlements of Hancăuți-La Frasin and Gordinești-Stînca Goală (*Rybicka 2019; Sîrbu* et al. *2020*).

Taken as a whole, the chronology of the WTC Late Tripolye groups agrees with our previous assessment, made before the availability of AMS-dated materials, that the Brynzensakaya and Gordineshtskaya local groups existed during the periods of *c.* 3500–3300 and 3300–3000/2950 BC, respectively (*Diachenko, Harper 2016*). The neighbouring Vykhvatinskaya and Usatovskaya local groups, located in the lower reaches of the Dniester and the steppe of the northwestern Black Sea littoral, are not as well dated. However, they more or less correspond with these same periods (*Dergachev 1980*), albeit with a lightly later transition. It is important to stress that, due to the presence of numerous Funnel Beaker and Baden-style influences in its ceramic complex, Golyshev is considered as the latest known Tripolye settlement in Western Volhynia (*Pozikhovskyj 2019*). Along with other recent radiocarbon dates, its chronology adds to the contention that *c.* 2950 BC constitutes the younger limit for the CTCC.

Diachronic change in WTC local group populations

On the regional level, the influence of giant-settlements of the SBDI is immediately and obviously discernible (Fig. 5). However, it is just as interesting (if not more so) to direct our attention to the serial settlement and abandonment seen within micro-regions along the forest-steppe corridor (Fig. 6). Our sample is biased towards the SBDI, so our results should be considered not in terms of definitive population sizes in different regions but taken as a general representation of demographic trends.

Several important observations can be made from this analysis:

❶ The Middle Dniester region is characterized by a permanent increase in population during Tripolye BII and Tripolye BIII, which explains why migrations were not directed to this area. Instead, migrants preferred regions to the east and north of the Dniester.

❷ The trend towards population decline in the Dniester region *c.* 4100–4000 BC corresponds to a demographic increase to the east. This trend corresponds to the spread of Rakovetskaya and Mereshovskaya-group ceramic traditions in the Dniester-Bug interfluve, the Middle Bug region and the SBDI (*Ryzhov 2007*). At the same time, migrants colonized the western part of Eastern Volhynia (*Kruts, Ryzhov 2000*). As shown by our dating of the Malice culture occupation at Golyshev, this territory was settled by post-Linear Pottery groups and the Lublin-Volhynian culture before it was further occupied by the WTC and Funnel Beaker-culture populations (*Kadrow 2013*).

❸ Two abnormally high increases in population in the Middle Bug region and SBDI are correlated with significant influences from Shipenetskaya group pottery traditions on the formation of ceramic styles of the Nemirovskaya and, later, Kurilovskaya local groups in the Middle Bug region and, respectively, Nebelevskaya and Tomashovskaya groups in the SBDI (see *Ryzhov 2007* for a detailed discussion of changes in these ceramic complexes).

❹ Demographic trends obtained for the Prut and Răut regions are inverse to each other, suggestive of west-east migration between these sub-regions. Further archaeological investigations in these areas are warranted, to examine whether our results are suggestive of trends of significant changes in pottery styles.

❺ The population decrease in the Dniester-Bug region after 3700 BC corresponds to an increase in population in the SBDI, suggesting another west-east migration wave. In terms of material culture, this event is also visible in significant amount of influences from the Chechelnitskaya group pottery traditions on Tomashovskaya group ceramic assemblages from the second stage its third phase (*Rud 2007; Ryzhov 2007; Tkachuk 1990*).

❻ The increase in population between 3650 and 3600 BC in the southern part of the Middle Bug region corresponds to a demographic decrease in the SBDI and northern part of the Dniester region. This trend corresponds to the formation of syncretic complexes combining Chechelnitskaya, Petrenskaya, Kurilovskaya, and Tomashovskaya group pottery styles in the Middle Bug region (*Ryzhov 2007*).

Discussion

The obtained dates make a significant contribution to the understanding of diachronic changes in WTC ceramic styles and enable us to make several modifications to the current periodization and chronology (Fig. 7). The dates obtained for Tripolye BII sites continue to blur the transition between Tripolye BI and BII, indicating that the turn of the 4th millennium BC saw a great diversity in ceramic forms. While it was previously assumed to be a meaningful chronological category throughout the Tripolye culture, Tripolye BI-II ceramic assemblages should now be reconsidered only as regionally dispersed continuations of Tripolye BI stylistic traditions, synchronized with the latest sites of Tripolye BI and earliest sites of Tripolye BII (*Diachenko 2016a; Palaguta 2007; Tkachuk 2019*). This assertion fits with previous observations regarding the relative rarity of settlements attributed to this 'period' (*Dergachev 2007; Rassamakin 2012*) and is consistent with analysis of ETC settlements in the SBDI, which form a distinct cultural sequence overlapping with the WTC giant-settlement phenomenon. ETC sites ascribed to Tripolye BI-II exhibit a high degree of variability in terms of radiocarbon dating, indicative more of stylistic lineages than an archaeological period (*Harper* et al. *forthcoming*). In the WTC and ETC alike, our chronological revisions support a return to Passek's (*1949*) general classifications for Tripolye BI and BII.

Different regions and sub-regions inhabited by WTC populations demonstrate a chronological overlap with earlier

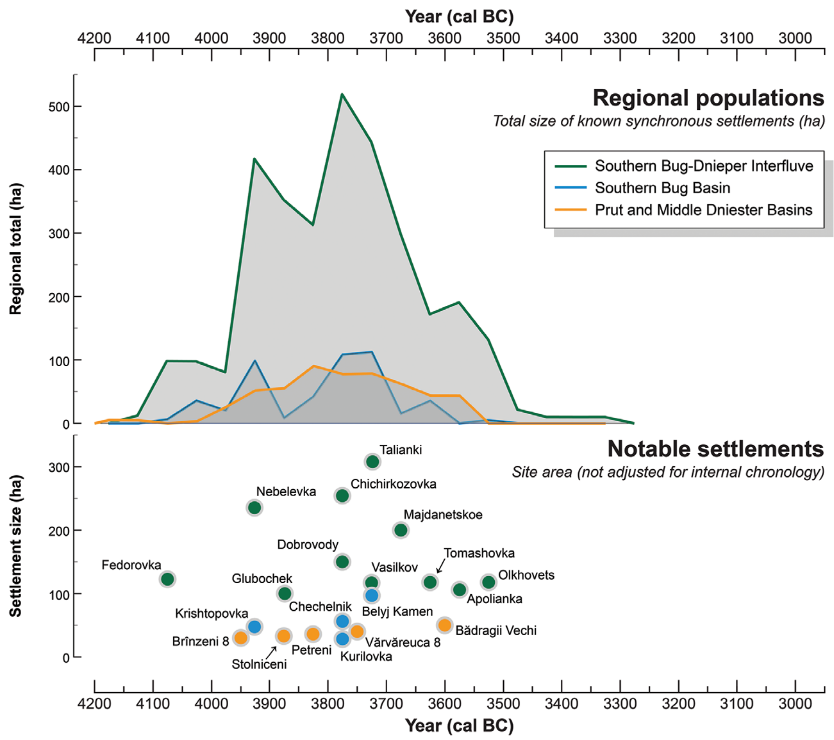

Fig. 5. Population trends across the three major regions of the study area, as calculated by Harper's derivative of the SARP model. The settlements of the SBDI are substantially larger than those of other WTC- inhabited regions, with few settlements outside this region even approaching the 'giant' category.

and later traditions, which confirms previous relative synchronizations made based on material exchange. These overlaps are characterized by decreasing rates of cultural change from west to east in the years preceding 3300 BC, as was suggested by mathematical simulations (*Diachenko, Menotti 2015*). More specifically, the beginning of Tripolye BIII in the Dniester region is dated to 3900 BC (the early settlements of the Petrenskaya local group being characterized by ceramic traditions of Tripolye BII; see *Ryzhov 2003*), while in the Middle Bug region it is dated to 3850 BC. Pottery assemblages from the early sites of the Tomashovskaya local group demonstrate the synchronous presence of Tripolye BII and BIII styles, with the beginning of Tripolye BIII in the SBDI dated to 3800 BC.

The transition from Tripolye BIII to Tripolye CI ceramic styles is even more complex. In the southern part of the Dniester region this transition is dated to 3700 BC, when Tripolye BIII traditions were still dominant among ceramic assemblages at late Petrenskaya group sites in the northern part of the Dniester region. Considering the newly obtained dates for Kosenovka, the transition from Tripolye BIII to Tripolye CI in the SBDI is dated to 3600 BC. Approximately at the same time, *c.* 3600 BC, ceramic assemblages of the Dniester region are characterized by the transition from Tripolye CI to Tripolye CII. The Kocherzhintsy-Shulgovka-type sites of the SBDI indicate the transition from Tripolye CI to Tripolye CII in the region *c.* 3400–3350 BC (see also *Diachenko, Harper 2016; Kushtan 2015; Rassamakin 2012*).

The population model presented in this paper expounds on previous studies of demographic development and migration of the WTC populations, which found strong correlations between migratory behaviour, transformations in ceramic assemblages, and ecological and climatic factors (*Diachenko 2012; 2016a; 2016b; Diachenko, Menotti 2012; 2017; Diachenko, Zubrow 2015; Harper 2016; 2019; Harper* et al. *2019; Weninger, Harper 2015*). Our analysis indicates a constant increase in population in the core area of the WTC (the Dniester region), with the colonization of the areas to the east and north of the Dniester being the result of long-distance migrations. The latter are represented quantitatively as shifts from zero population to certain numbers indicating the colonization of new areas, and also as abnormally high increases in population (which also correspond to changes in pottery assemblages). Therefore, population pressure in the core area is considered the main factor in the dispersal of WTC populations to Central Ukraine. The mechanism is quite

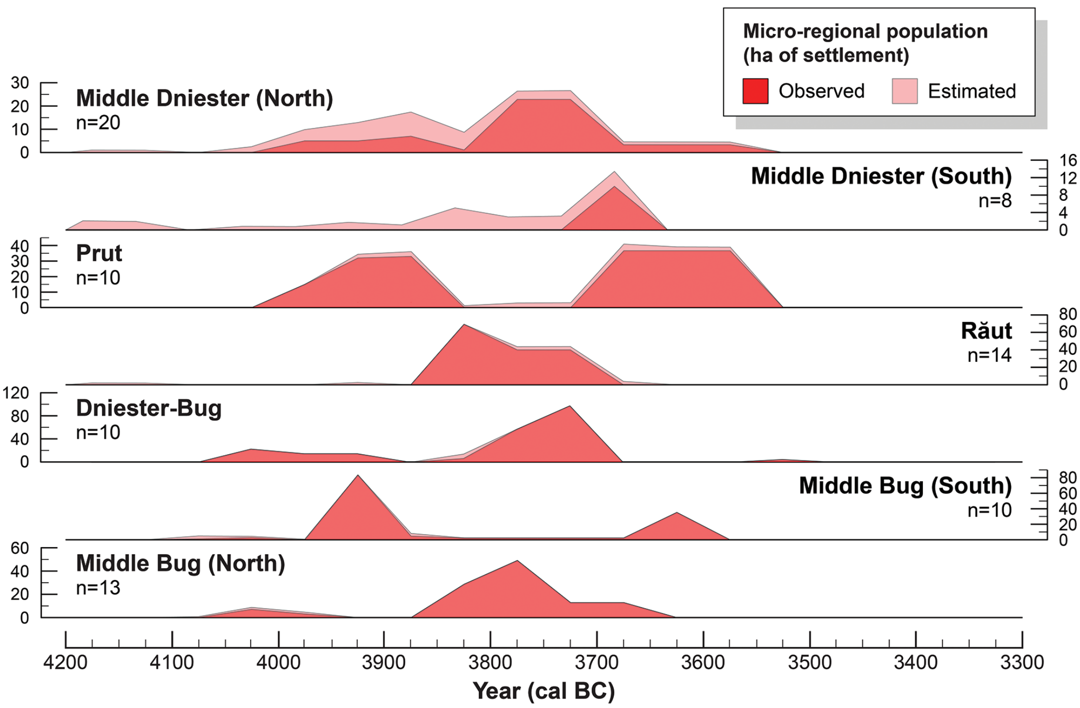

Fig. 6. Distributions of population development in seven micro-regions in Moldova and Ukraine, expressed according to the total area of synchronous settlements. Dark shading indicates the contribution from settlements with known size, while light shading indicates the estimated population from settlements with unknown size parameters.

similar to that seen for ETC migrants to the SBDI and Middle Dnieper regions. The high mobility of the ETC populations led to the first agrarian colonization of this area (*Harper* et al. *forthcoming*), while subsequent WTC populations came in repeated 're-colonizations' that targeted different micro-regions.

In the broader regional context, the beginning of the development of the WTC post-dates the famous Varna I Necropolis (*c.* 4590–4340 cal BC; *Krauß* et al. *2017*), as well as the vast majority of tell settlements of the Kodjadermen-Gumelnița-Karanovo VI (KGK VI) complex. In Romania, two 'collapses' can be perceived: the first at the end of Gumelnița A2 (*c.* 4100 BC) and the second at the end of Gumelnița B (*c.* 3900 BC; *Harper 2016*). The first instance is of particular interest to the expansion of the CTCC, as the territory of the Stoicani-Aldeni variant of the Gumelnița-culture (which previously extended into Romanian Moldavia) was subsumed by the expansion of groups bearing Cucuteni material culture (Cucuteni A4 and AB) at the same time that the WTC was developing and expanding into Ukraine. The later, final extinction of tell settlements in the Danube Valley during Gumelnița B (synchronous with the giant-settlement phenomenon of Tripolye BII and BII) came at a time when European settlement systems, and climatic systems, were in a state of flux. The upland settlements of the subsequent Cernavodă I culture represent a fundamental shift in economic practices and settlement location (*e.g., Anthony 2007; Weninger, Harper 2015*). It is not known whether the gradual collapse of settlement systems associated with the KGK VI complex influenced the massive population increases perceived in the WTC, or whether such divergent patterns are simply representative of regionally variegated responses to changing climate (*Harper 2019; Harper* et al. *2019*).

Conclusions

The results presented in this paper build upon others presented from our project (*Harper* et al. *forthcoming*) in supporting and building upon a syncretic relative chronology established for groups throughout the CTCC. High-resolution AMS dates and Bayesian sequencing support the general principle that ceramic types are highly predictive of the chronological age of settlements. In those situations where some data diverged from relative expectations, such as the sites of Lipchany and Konovka, our results may guide reanalysis and fieldwork in contexts that

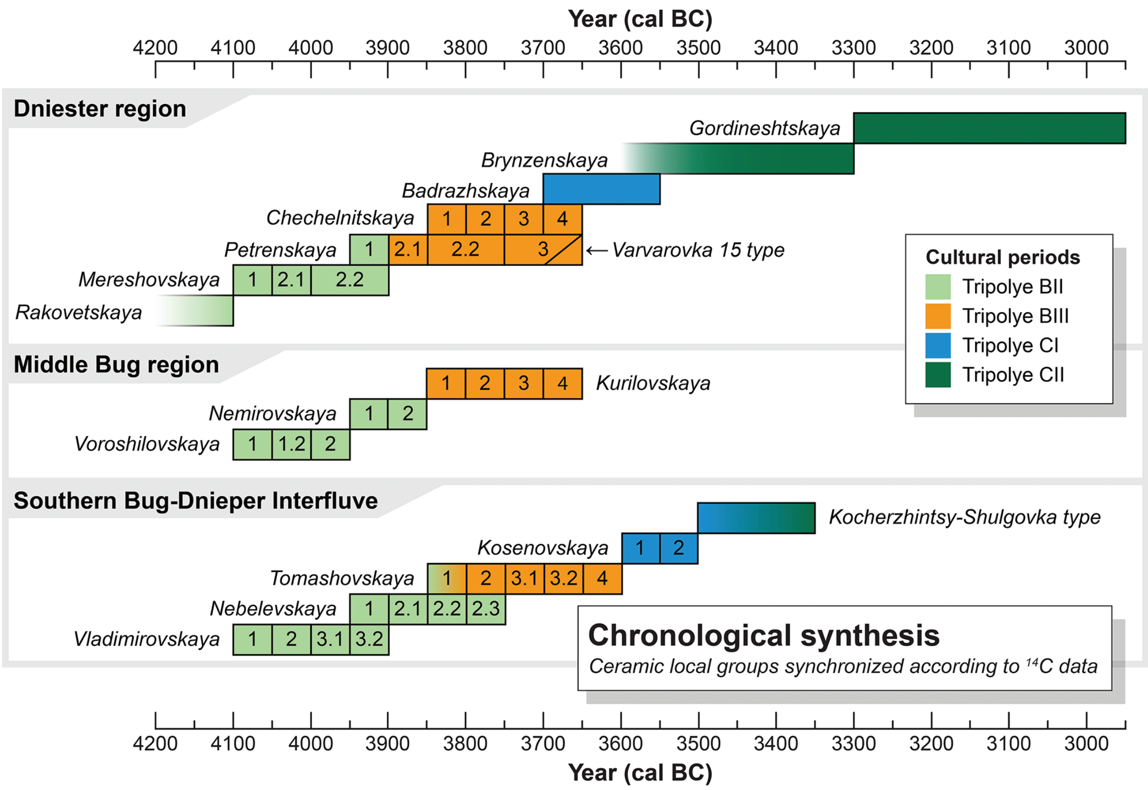

Fig. 7. Our new chronological synthesis for the WTC. Labels in italics beside boxes indicate the names of relevant local groups and site types. Numbers indicate phases and stages. It is important to note the prominent lag times (c. 50–200 years) in the development of Tripolye BIII, CI, and CII when looking west-to-east across the WTC, contradicting the traditional concept of rapidly disseminated cultural horizons.

were traditionally considered to be single-habitation and excavated with the assumption that multiple layers would not be encountered.

Through the creation of a new chronological synthesis, we may hone our existing settlement archaeology data and their derivative models, enabling more precise consideration of the intersection between human settlement, subsistence, climate, and ecology at the north-eastern frontier of 'Old Europe'. We highlight the substantial bias that exists between data in the SBDI and other regions of the WTC, and consider that continued improvement of these datasets should be undertaken with colleagues working in the Dniester region of Ukraine and Prut-Dniester region of Moldova. However, the available data still enable us to explicate the highly targeted and ephemeral nature of Eneolithic settlement, which was characterized by both punctuated settlement and abandonment on the local level and more gradual diffusion of material culture traits on the regional level.

Our dates are important for the delineation of major archaeological phenomena. Important for the consideration of the CTCC as a whole, our Tripolye CII dates from Golyshev reinforce the viewpoint that the transition to the Early Bronze Age was rapid and occurred no later than 2950 cal BC. These results agree with other recent AMS dates from the latest sites of the Tripolye culture and related Terminal Eneolithic contexts, and may put to rest the anomalously young results obtained from conventional ^{14}C dates using liquid scintillation and gas proportional counting methods.

In the case of the SBDI, we provide the first high-resolution dates for the Kosenovskaya local group, establishing a *terminus ante quem* for the giant-settlement phenomenon at *c.* 3500 cal BC. In concordance with our dates from Peshchanoe and Rubanyj Most, as well as consideration of sites AMS-dated by other projects, we confirm the validity of the relative sequence of sites, which proscribes short (at most, *c.* 80-year) habitational periods for most settlement sites. In response to assertions to the contrary, we would continue to assert the importance of considered and scientifically grounded ^{14}C analysis, as well as pottery seriation, that considers the whole cultural and chronological context of these sites.

Supplementary materials are available at http://dx.doi.org/10.4312/dp.48.11.

Author contributions

T. K. Harper and A. Diachenko designed research; T. K. Harper, A. Diachenko, and L. R. Eccles performed analysis; T. K. Harper, A. Diachenko, Y. Y. Rassamakin, D. K. Chernovol, V. A. Shumova, P. Nechitailo, V. V. Chabaniuk, E. V. Tsvek, N. M. Bilas, Y. V. Pohoralskyi, and S. N. Ryzhov contributed data; T. K. Harper created the figures; D. J. Kennett supervised research; T. K. Harper and A. Diachenko wrote the text, with input from S. N. Ryzhov, Y. Y. Rassamakin, L. R. Eccles, and D. J. Kennett.

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