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RESEARCH ARTICLE

Absolute chronology and spatial organization of the Early Bronze Age necropolis in Mokrin

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Abstract
The chronology of the Bronze Age in the Carpathian basin is largely based on relative chronologies, i.e. stylistic analysis of ceramic (and other) materials. While the number of radiocarbon dates is generally increasing, certain important sites are still poorly dated. One of the largest necropolises from this period, i.e. Mokrin necropolis, which traditionally belongs to Maros culture, is dated only with 6 radiocarbon dates. Here we synthesize the previous 6 radiocarbon dates with 13 new radiocarbon dates, with two goals in mind: 1) to explore the absolute chronology of the site, specifically to determine its chronological limits; and 2) to test hypotheses about the spatio-temporal organization of the site. Our data show that the chronological limits of the necropolis were most probably between 2073 and 1822 BC. Concerning traditional relative chronologies, none of the previous hypotheses about the internal chronological development of the necropolis is supported by data. Our results suggest that all parts of the necropolis were used relatively simultaneously.

Introduction

Despite a proliferation of new accelerator mass spectrometry radiocarbon (AMS ^{14}C) dates for Bronze Age sites in the Carpathian Basin in the last decade, radiocarbon dating still has not achieved its full potential in this part of Europe. Most researchers rely on relative chronologies established by meticulous stylistic analysis of local archaeological materials, which may or may not be able to fit in with widely used Reinecke or Montelius chronology schemes (O'Shea et al. 2019; Roberts et al. 2013; Staniuk 2021). These relative chronologies are useful in the local or regional analyses but can be notoriously hard to apply to a broader geographical analysis and are confusing for a researcher that encounters them for the first time. General terms like "Early," "Middle" and "Late Bronze Age" are especially disadvantageous, since they are often not contemporaneous across the European continent (Roberts et al. 2013). This mismatch in terminology can only be mended by more calibrated radiocarbon dates which could help the researchers synchronize the cultural developments on both the regional level and across the European continent. New dates also allow for further refinement of the regional chronology and provide an opportunity to recheck the validity of local relative chronologies as well as understanding of the patterns of use, abandonment and reoccupation of sites.

A recent study by Staniuk (2021) has suggested that the Bronze Age cemeteries in the Carpathian Basin show evidence for continuous human presence during the period, unlike settlements where certain shifts in occupation patterns are evident. Chronology of the Maros culture, and Mokrin necropolis in particular (thanks to the wealth of metal and other finds), has been of interest for some time, and various researchers have produced both relative and absolute chronology for the site (Bona 1975;

Gogaltan et al. 2015; O'Shea 1992; O'Shea et al. 2019; Sandor-Chicideanu and Chicideanu 1989; Soroceanu 1975; Primas, 1977; Wagner 2009). When it was first published, M. Girić (1971) divided the ceramic vessels found in the graves into three phases, hypothesizing that the graveyard spread from SE to NW. Soroceanu's (1975) chronological solution was primarily based on the metal findings and comparison of the already grouped ceramic vessels with the ceramics from the Maros settlement in Periam. He suggested there were two phases, the second one with three subphases, and that the necropolis spread from NW to SE. M. Primas (1977) postulated a direction of occupation from SE to NW, having argued that there is no linear chronological sequence, but rather a partially simultaneous occupancy by different kin groups. M. Sandor-Chicideanu and I. Chicideanu (1989) hypothesized that the necropolis developed from a central point, in an almost star-shaped manner, but the groupings they noticed once they had done the seriation, the authors ascribed to social differentiation, and not chronology. Finally, J. Wagner (2009) seriated headdresses found in the graves of women and children (since she hypothesized that those found in the men's graves were not chronologically sensitive), and by using the results of the seriation and the ceramics found on the necropolis, she devised three chronological phases and hypothesized a SE–NW direction of the expansion of the necropolis.

In 1992, J. O'Shea sampled human remains from 6 graves from Mokrin necropolis for radiocarbon dating (1992), thus making Mokrin one of the best dated Maros culture necropolises at the time. The chronology that these dates have provided us with 2100–1800 cal BC, which unfortunately presented us with several issues. Out of 6 dated samples, 4 have returned very similar values (see Table 1) which makes building a chronology for the whole site and explaining how the necropolis was formed very challenging. Additionally, J. O'Shea did not explain his sampling strategy in his 1992 paper, and the dated graves cover a limited area, which precludes spatial analysis and inferences about the spatio-temporal patterns of expansion and use of the necropolis (O'Shea 1992, 1996), as they are located mainly in the western part of the site.

In this paper, we revisited the absolute and relative chronology of the largely explored Mokrin necropolis in Northern Serbia, based on 13 new radiocarbon dates and 6 previously published dates (O'Shea 1992). Besides establishing the chronological limits of this Early Bronze Age necropolis and contributing to the recent effort of establishing more precise regional chronologies (see O'Shea et al. 2019), our goal is to explicitly test the hypotheses about the spatio-temporal development of the necropolis. With this goal in mind, we used all available absolute dates of the site to assess the validity of the two previously suggested hypotheses about the spatial expansion of the necropolis and its relative chronology:

1. The expansion of the necropolis in the SE-NW direction.
2. The radial expansion of the necropolis from the center of the distribution of graves.

In addition to testing these two specific hypotheses about the spatio-temporal development of the necropolis, we also test the general hypothesis that different parts of the necropolis were used at different times—that the necropolis was spatio-temporally structured, i.e. that graves which are close in space are also close in time.

Materials and methods

Mokrin necropolis

Mokrin necropolis is situated in the northern region of Vojvodina in Serbia, near the town of Kikinda, close to the Romanian border (Figure 1). The necropolis belongs to Maros culture—a Bronze Age cultural complex that spans the territory of three modern-day countries—southeastern Hungary, western Romania and northeastern Serbia (Girić 1971; Markova and Ilon 2013; O'Shea 1992). The sites of Maros culture were found along the basins of the Maros (Mures/Moriš) and Tisza rivers. The relative chronology most widely used for the Maros Group was developed by I. Bona's typological analysis of

Table 1. *List of radiocarbon dates for the Mokrin necropolis*

					Results of individual calibration (in years BC)			Results of Bayesian modeling (in years BC)		
Grave no.	Date label	^{14}C age	Reference	Error	Lower 95% CI limit	Upper 95% CI limit	Mean	Lower 95% CI limit	Upper 95% CI limit	Mean
171	BRAMS-5052	3724	This paper	30	2267	2029	2116	2116	1956	2044
208	GrN-14179	3690	O'Shea 1992	30	2197	1975	2081	2113	1952	2031
39	BRAMS-5045	3680	This paper	30	2192	1961	2070	2112	1949	2024
110	GrN-14178	3655	O'Shea 1992	30	2137	1944	2036	2117	1929	2004
227	GrN-14180	3650	O'Shea 1992	35	2139	1925	2029	2111	1899	1998
52	GrN-7977	3650	O'Shea 1992	50	2194	1891	2030	2101	1890	1991
315	MAMS-57899	3616	This paper	26	2112	1892	1978	2032	1898	1972
316	MAMS-57900	3602	This paper	26	2029	1890	1961	2026	1891	1959
163	BRAMS-5051	3599	This paper	30	2035	1831	1958	2027	1888	1956
237	GrN-14181	3595	O'Shea 1992	35	2116	1783	1953	2032	1882	1952
240	BRAMS-5053	3591	This paper	30	2031	1830	1948	2026	1884	1948
59	BRAMS-5050	3575	This paper	30	2026	1779	1925	2025	1827	1931
317	MAMS-57901	3569	This paper	27	2021	1778	1917	2020	1826	1924
318	MAMS-57902	3553	This paper	26	2011	1774	1889	2013	1818	1906
104	BRAMS-5049	3521	This paper	30	1932	1750	1839	1945	1784	1875
82	BRAMS-5047	3521	This paper	30	1932	1750	1839	1945	1784	1875
92	BRAMS-5048	3509	This paper	30	1922	1745	1827	1937	1785	1867
259	GrN-8809	3500	O'Shea 1992	35	1924	1699	1820	1941	1782	1866
279	BRAMS-5054	3476	This paper	30	1887	1694	1802	1921	1775	1856

Figure 1. *Location of the Maros sites (produced using R studio packages; Kahle and Wickham 2013; Slowikowski 2022; Wickham 2016).*

the ceramic vessels from Szőreg necropolis (1975), which established the Maros culture as an Early and Middle Bronze Age culture of the Carpathian Basin. Absolute dates from both settlements and necropolises set the duration of the Maros Group from around 2700 to around 1500 cal BC (Nicodemus et al. 2015; O'Shea 1992; O'Shea et al. 2019).

Having been recognized as an important archaeological site for the study of the Early Bronze Age in Banat, Mokrin necropolis was systematically excavated in the 1960s and 1970s through a joint venture of the National Museum in Kikinda and the Smithsonian Institute. In these campaigns 312 graves, mostly belonging to the Maros group, were excavated and later published in a detailed monograph (Girić 1971). In 2020 The National Museum in Kikinda started a smaller scale excavation campaign focused on the eastern and southeastern parts of the necropolis, with the goal of estimating the number of unexcavated graves and charting the eastern and southeastern borders of the necropolis (Pendić et al. 2022). Since 2020, a total of four campaigns have been undertaken, which uncovered 8 new Maros graves.

The funerary ritual of the Maros group was highly normative on all the known necropolises. The deceased were buried in a flexed position, laid on their side: women were buried on their left side, with head to the south and feet to the north, facing east, and the opposite was true for the men, with only a few exceptions (Girić 1971; Matić 2012). Grave goods assemblages contained mostly ceramic vessels—one-handled and two-handled jugs, bowls and amphorae being the most common types. Bronze jewelry

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is not uncommon (bracelets, hair-rings, head ornaments, needles, etc), but other materials were used as well—animal teeth and bones, river- and sea-shells, kaolin beads, gold, and in one case even a human rib (Girić 1971; O'Shea 1996; Stefanović 2008).

Owing to the relatively good preservation of the skeletal remains, as well as detailed analysis and publication of the grave goods (Girić 1971; O'Shea 1996) and Early Bronze Age chronology, the Mokrin necropolis has been the object of many multidisciplinary studies. Analyses of status, activity, kinship, diet and health have been previously published (Krečković Gavrilović 2022; Pompeani 2020; Porčić and Stefanović 2009; Stefanović 2008; Žegarac et al. 2021).

Materials

To refine the absolute and relative chronology of the site, we collated 6 radiocarbon dates from the old campaign with 13 new dates. As mentioned, J. O'Shea's (1992) sampling strategy was unclear and mainly limited to one part of the necropolis. In contrast, for our new dating campaign, which included graves from both old and new excavations, the main goal was to have good spatial coverage, which we achieved by sampling graves as uniformly as possible from every part of the necropolis (see Figure 3). Additionally, as new radiocarbon dates were obtained during the course of 2020 and 2021 excavation campaigns, four samples from 2021 (graves 315–318) were specifically selected from newly excavated graves, so they are positioned in close proximity to one another. Samples from graves 39, 82, 92, 104, 159, 163, 171, 240 and 279 were sent to Bristol Radiocarbon Accelerator Mass Spectrometry Facility at the University of Bristol, while the samples from graves 315–318 were analyzed in Curt Engelhorn-Centre of Archaeometry in Mannheim, Germany.

Methods

Calibration and Bayesian modeling of radiocarbon dates

We first calibrated all 19 dates individually, making no assumptions about their relationship. In the second step, we applied the Bayesian modeling of dates, assuming that they all belong to a single phase, i.e. that they have been drawn from a temporal interval in which the cemetery was in continuous use. We estimated the start, end and duration of the interval in which the necropolis was in use based on this Bayesian model. The calibration and Bayesian modeling (OxCal code for the model provided in Supplementary file 6) is implemented in the OxCal 4.4.4 (Bronk Ramsey 2009) with the IntCal 2020 calibration curve (Reimer et al. 2020), as well as in the *rcarbon* package (Bevan and Crema 2018; Crema and Bevan 2021) for R (R Core Team 2022). Data for the stable isotopes of nitrogen (^{15}N) and carbon (^{13}C) are available for a sample of 34 individuals buried at Mokrin (Pompeani 2020, 376; Rega 1995, 130), 5 of which were absolutely dated Isotopic values for both elements are within the range which is expected for a diet based on terrestrial resources (for a discussion of diet see Pompeani (2020, 378–382). These results suggest that there was probably no reservoir effect present, so we assumed that no correction was necessary for the individuals which have radiocarbon dates but lack information on stable isotopes.

Testing hypotheses about relative chronology with radiocarbon data

The validity of relative chronological sequence s tested by comparison with absolute dates. In this study, we test two specific relative chronological sequences:

1. The sequence based on the hypothesis of the SE–NW direction of the spatial expansion of the necropolis. If this hypothesis is true, we should expect the graves to be ordered from oldest 8 lowest median BC) graves, in the proximity of SE part of the necropolis, to the youngest (highest median BC) graves, close to the NW part of the cemetery.

2. The sequence based on the hypothesis of the radial spatial expansion of the necropolis from its center (the centroid of x and y coordinates of individual graves). If this hypothesis is true, the oldest dates should be found near the center of the necropolis, and the youngest dates on its outskirts.

We first visually explored the two hypotheses by plotting the median calibrated dates (in years BC) on the site plan, and also by visualizing probability distributions of individual dates in four quadrants of the necropolis. However, as calibrated radiocarbon dates are not point estimates but probability distributions, in order to have a formal method of testing different hypotheses, we calculated a series of Spearman's correlation coefficients between the hypothesized relative chronological sequence of graves (ranks of individual graves in a sequence) and the set of absolute dates with different possible point estimates of calendar dates (see Hamilton and Buchanan 2007; Porčić et al. 2020; Steele 2010). This procedure consists of two steps:

1. In the first step, a single calendar date is sampled for each radiocarbon date according to its calibrated probability distribution, with the calibration performed in the *rcarbon* package (Bevan and Crema 2018; Crema and Bevan 2021) for *R* (R Core Team 2022). The single sampled value is one potential realization of an absolute date of a grave. The end result of this step is a set of potential realizations of absolute dates for the 19 dated graves, based on their radiocarbon determinations.
2. In the next step, we calculate the absolute value of the Spearman's correlation coefficient between the set of potential realizations of absolute dates and the relative chronological ranking of these 19 graves based on the hypothesized spatial dynamics of the expansion of the necropolis. Spearman's correlation coefficient is used as the relationship between the absolute and relative chronology does not have to be linear (Lockyear 2022; Porčić 2023). The result of this step is one possible value of the correlation between the relative and absolute chronology.

We repeated this procedure, i.e. the two steps, 10,000 times (the Monte Carlo technique). The end result of a procedure is a probability distribution of possible correlation coefficient values. We use the same procedure to calculate the associated statistical significance of each correlation coefficient. If most of the correlation coefficients have relatively high absolute values and are statistically significant, this could imply that the proposed relative chronological sequence is accurate in the sense that it captures the chronological signal in the data.

As the ranks of individual graves in hypothesized sequences are coded in such way that lower rank means older age than high rank (e.g. position 1 in sequence is older than position 2), and calendar dates, expressed either in BP or BC terms, are such that higher values mean older age, we expect high negative correlation values if the proposed hypotheses of spatial expansion are correct.

The precision of the sequence is indicated by the value of the correlation coefficient, but this cannot be read at face value. Radiocarbon calibration depends on the shape of the calibration curve in the particular period and the radiocarbon determination is never without error. This means that even if the sequence of graves is perfectly accurate, the correlation between the relative sequence and the associated radiocarbon dates may not be perfect, Due to errors of the radiocarbon measurement and calibration, especially if the temporal interval of interest is relatively narrow. For this reason, we must establish a frame of reference for the empirical distribution of the correlation coefficients by generating the best case scenario distribution of the correlation coefficients. The best case scenario refers to the case when the sequence is completely accurate. We generate 10,000 best case scenarios by randomly sampling 19 absolute dates from the interval between 2077 and 1822 BC, which are the most probable temporal boundaries for the Mokrin necropolis based on the modeling calibration of dates (see Results section, Table 1 and Figure 2). We then back-calibrate these dates to transform them into radiocarbon measurements (each date is associated with a standard error randomly sampled without replacement from the set of empirical dates). Then we apply the Monte Carlo correlation analysis procedure

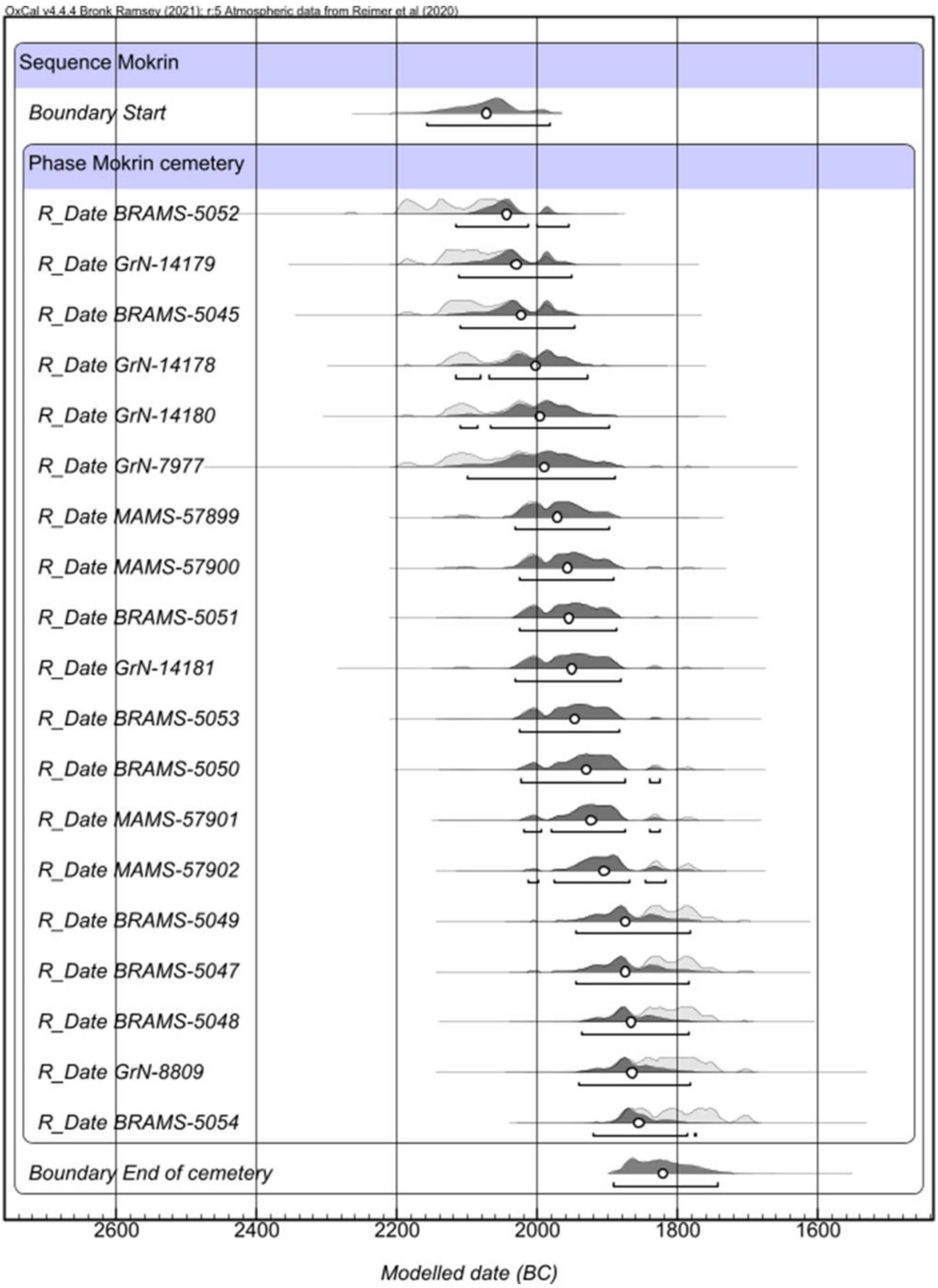

***Figure 2.** Bayesian modeling of radiocarbon dates.*

described above to generate a distribution of correlation coefficient between the relative sequence and the set of radiocarbon dates when the sequence is known and fully accurate. This gives us a frame of reference and enables us to compare the distribution of the empirical correlation coefficients to the distribution of the correlation coefficients when the relative sequence is completely accurate and precise (see Supplementary file 5, Figure 1). For example, we can compare the mean of the empirical distribution to the mean of the best case scenario distribution of correlation coefficients.

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The results of this exercise show that the mean value of the distribution of Spearman's correlation coefficients based on the simulated best case scenarios is 0.75, the median is 0.77, and the 2.5th and 97.5th percentiles are 0.5 and 0.91, respectively. In other words, the expected value of Spearman's correlation coefficient, when the relative chronological sequence is fully accurate and comes from the particular temporal interval is 0.75, and 95% of the correlation coefficients in the best case scenario are between 0.5 and 0.91, with 98.5% of the correlations significant at the 0.05 level (Supplementary file 5: S5; Figure 1). The results of this analysis show that even if the relative chronological sequence was perfectly accurate, we should not expect the correlation between this sequence and radiocarbon dates to be perfect due to errors in radiocarbon measurement and calibration. In the best case scenario, we should expect a correlation of around 0.75 and this is the baseline against which we should compare the empirical correlations.

In order to test the general hypothesis which assumes that different parts of the necropolis were used at different times, we used the Mantel correlation test (Mantel 1967) between spatial and temporal distances of the dated graves. The Mantel correlation is based on calculating Pearson's correlation coefficient between two distance matrices and on the permutation test to calculate the associated p value. If the hypothesis is correct, this correlation should be relatively high and statistically significant, as graves which are close in time should also be close in space. We also apply the Monte Carlo procedure of sampling calendar dates from calibrated distributions in order to calculate temporal distances (Euclidean distances) between pairs of graves and correlate them with spatial Euclidean distances. As a result, we get a distribution of possible correlations between spatial and temporal distances and their associated p values. As the general hypothesis does not specify the direction of the necropolis expansion, we only look at the absolute values of the correlation coefficients between spatial and temporal distances.

Detailed description of the statistical analysis with the *R* (R Core Team 2022) code and the spreadsheet with data used for the analysis can be found in the online Supplementary materials.

Results

The dating and duration of the Mokrin necropolis

Results of the calibration and Bayesian modeling are presented in Table 1 and Figure 2. When dates are calibrated independently, the results suggest that Mokrin necropolis was in use for around 300 years, between 2116 and 1802 BC, based on the means of calibrated distributions of the oldest and the most recent dates in the sample. When Bayesian modeling is applied, i.e. when the dates are modeled as coming from a continuous phase, the estimated start of the necropolis is at 2073 BC (95% CI: 2151–2982 BC), the estimated end is at 1822 BC (95% CI: 1871–1744 BC), and the estimated duration of the the necropolis is 252 years (95% CI: 98–387). The model has a relatively good fit as measured by the OxCal's agreement indices (Amodel = 96.1; Aoverall = 90).

Testing the spatiotemporal hypotheses

Visual exploration of the spatial distribution of medians of calibrated radiocarbon dates shows no clear pattern—both old and young dates are located in different parts of the necropolis—as shown by color gradient and medians of radiocarbon dates (Figure 3). There are certain clusters of younger dates in both southeast and northwest parts of the necropolis, but this pattern is far from straightforward, as there are many exceptions to this trend. When we look at the full probability distributions of individually calibrated radiocarbon dates from different quadrants of the necropolis (Figure 3), again we see no clear spatiotemporal pattern.

The results of the formal statistical analysis using the Monte Carlo resampling approach corroborate the conclusions of the visual analysis. For the SE-NW expansion hypothesis, the mean value of the

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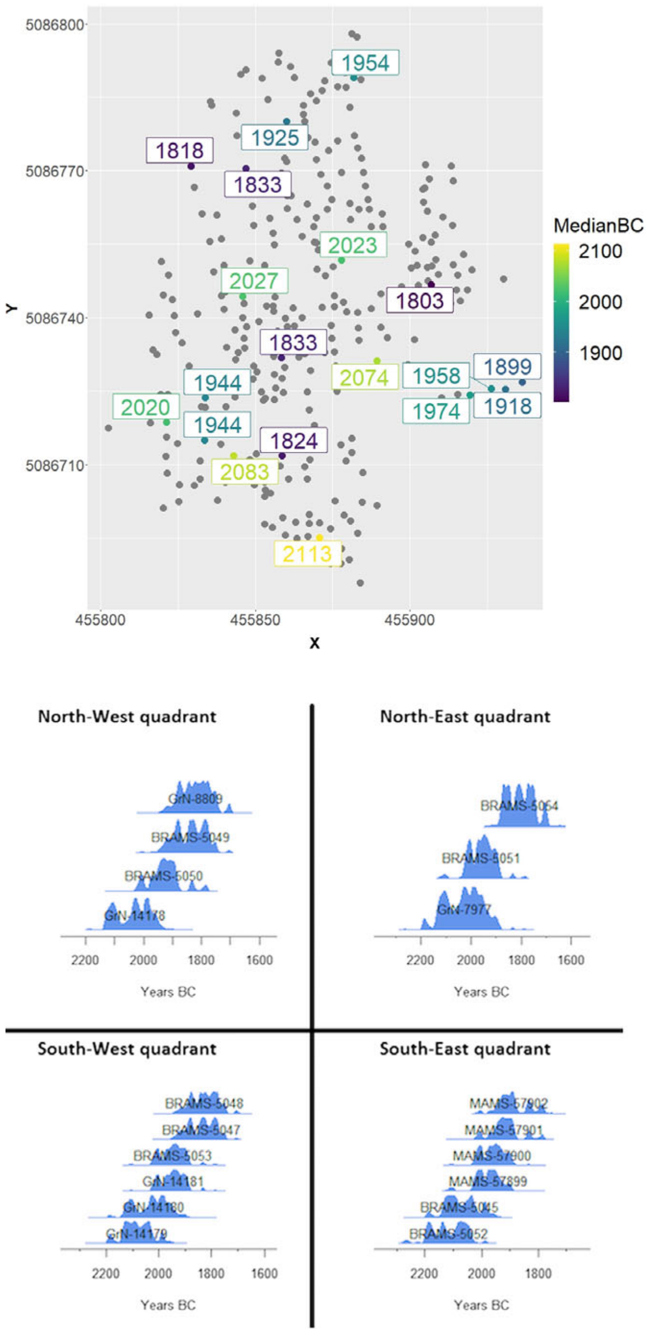

Figure 3. *Upper panel: Plan of the Mokrin necropolis with the value of median shown for radiocarbon dated graves. Note the color gradient as shown in the legend older dates have yellow and bright green colored labels, while younger dates are represented with dark green and blue colors. Lower panel: Calibrated radiocarbon dates in the four spatial quadrants of the Mokrin necropolis.*

Spearman correlation coefficient is –0.1 (2.5th percentile is –0.34; 97.5th percentile is 0.12) with most of the values being negative. 99% of correlation coefficients have associated p values greater than 0.05 (Figure 4, left upper panel). Even though most of the correlation coefficient values are negative, their

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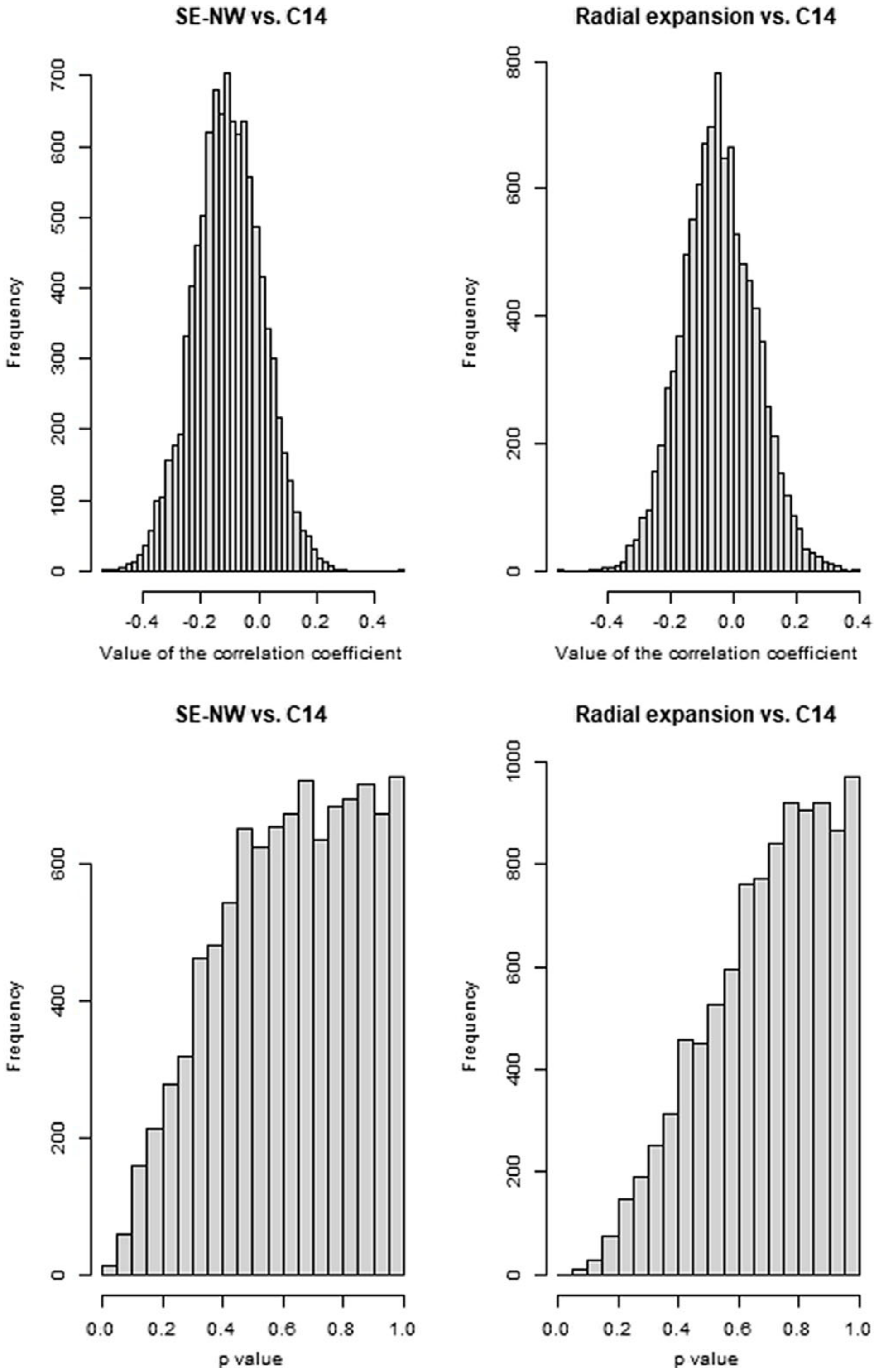

Figure 4. *Distribution of the Spearman correlation coefficients (upper panel) and their associated p values (lower panel) for the correlation between possible combinations of calendar dates and hypothesized relative chronology of the Mokrin necropolis, based on the SE-NW direction of expansion hypothesis (left panel) and the radial expansion hypothesis (right panel).*

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absolute values are rather low, both in absolute terms and compared to the baseline correlations established above (Figure 4, left lower panel). Most of them are not statistically significant at 0.05 level. The hypothesis of the SE-NW expansion is not supported by the radiocarbon data.

For the radial expansion hypothesis, the mean value of the Spearman correlation coefficient is –0.05 (2.5th percentile is –0.27; 97.5th percentile is 0.18). More than 99% of correlation coefficients have associated p values greater than 0.05 (Figure 4, right upper panel). For this hypothesis, the mean correlation is close to zero, and almost none of the correlations are significant at the 0.05 level. This hypothesis is also not supported by the data.

Finally, we present the results of testing the general hypothesis of association between spatial and temporal locations of graves in the necropolis. The mean value of the absolute values of the correlation coefficients between spatial and temporal distances is 0.08 (95th percentile is 0.17; maximum is 0.28), 99.9% of p values are above the 0.05 significance threshold (see Supplementary file 5, Figure S5.2). Therefore, the general hypothesis of spatiotemporal differentiation of the Mokrin cemetery is not true, as there is no significant and strong correlation between spatial and temporal locations of graves.

Discussion and conclusions

In this study, we explored the internal chronological development of the Mokrin necropolis based on absolute and hypothesized relative chronologies. The absolute chronology of the site remains largely unchanged—it was used for ca. 250–300 years, approximately between 2100 and 1800 BC, i.e. in the same interval as most other sites from the late EBA and MBA (Staniuk 2021). Our data also show that all parts of the necropolis were used more or less at all times, i.e. people were simultaneously buried in different parts of the necropolis. The eventual spatiotemporal clustering at smaller spatial scales might be revealed with the increase in the number of radiocarbon dates, but the general pattern seems to be one of relatively simultaneous use. Thus, there is no single and simple spatial direction of the internal chronological development of the necropolis, as previously assumed. The decision of the location for a new interment probably depended on various multifaceted factors. These included spatial dynamics, encompassing the layout and extent of the necropolis, the available space, and the configuration of landscape. Additionally, these decisions might have been influenced by social norms as well, notably the affiliation with a kinship group. The aDNA analysis performed on 24 individuals from Mokrin found a general trend of related individuals being buried close to each other (Žegarac et al. 2021, 10072). Unfortunately, these individuals have not been absolutely dated (save one), therefore a more extensive analysis of the influence of kinship on spatial distribution of graves at Mokrin will have to be explored in the future. Taken together, the preliminary results of the spatial distribution of absolute dates and aDNA analysis suggest the hypothesis that different kinship groups used different parts of the necropolis at the same time. This would mean that kin groups had designated burial areas within the necropolis.

The accuracy and precision of the chronology of Mokrin necropolis can be improved through an increase of the number of dated graves, as well as integration of absolute and relative chronology, based on the seriation of pottery types, which is a work in progress.

Supplementary material. To view supplementary material for this article, please visit https://doi.org/10.1017/RDC.2024.112

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Declaration of competing interests. The authors declare no conflicts or competing interests.

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