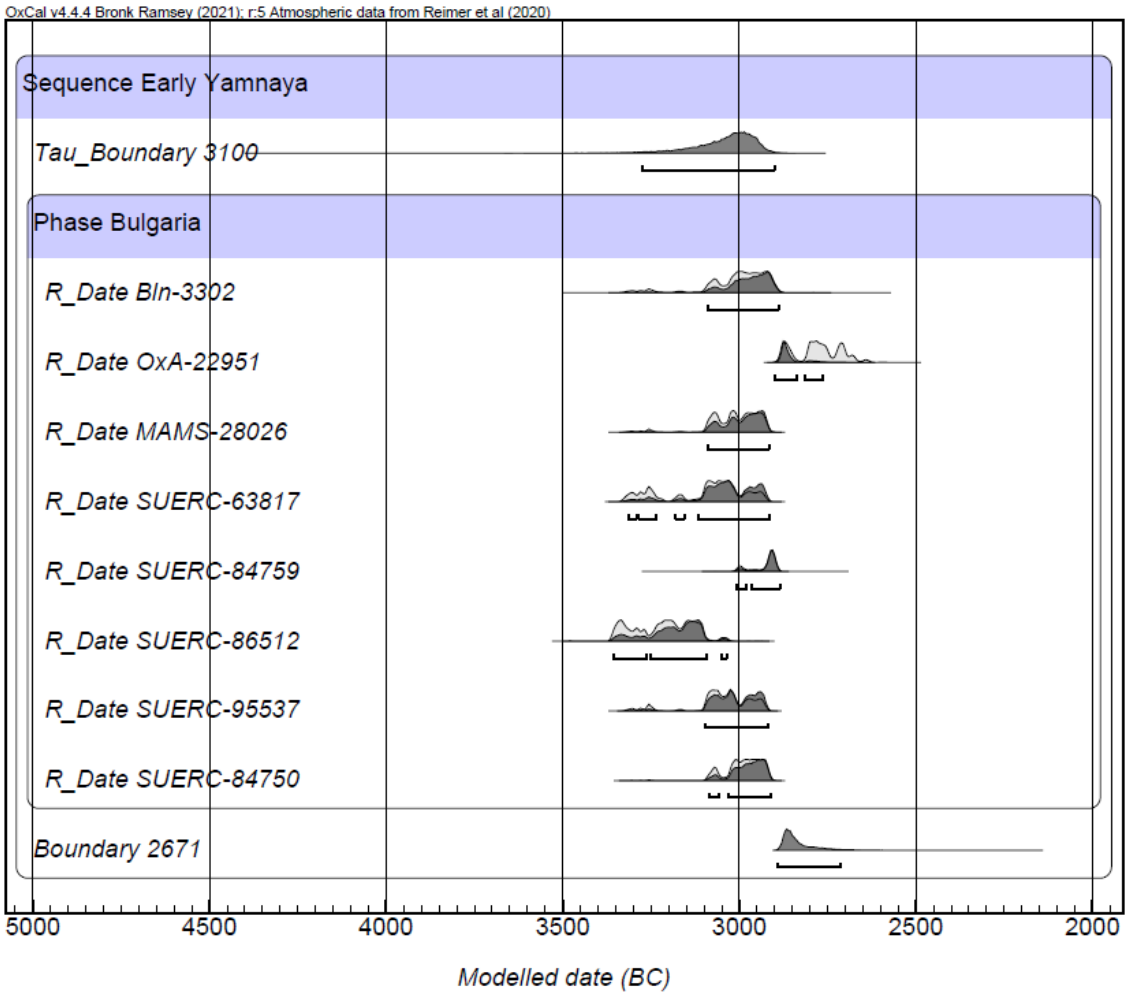
Modelling the Yamnaya Expansion Through Radiocarbon Dates



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Master's Thesis

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November 2021

Tiivistelmä

Tiedekunta: Humanistinen tiedekunta

Koulutusohjelma: Kulttuuriperinnön maisteriohjelma

Opintosuunta: Arkeologia

Tekijä: Alexander Suvorov

Työn nimi: Modelling the Yamnaya Expansion through Radiocarbon Dates

Työn laji: Maisterintutkielma

Kuukausi ja vuosi: Marraskuu 2021

Sivumäärä:170

Avainsanat: jamnaja, radiohiiliajoitus, leviäminen, OxCal, kriging, migraatio, ekspansio

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Säilytyspaikka: Helsingin yliopiston kirjasto

Muita tietoja:

Tiivistelmä:

Maisterintutkielma keskittyy pronssikautiseen Jamnaja-kulttuurin hautauksista kerättyjen radiohiiliajoitusten analysoimiseen erilaisilla menetelmillä. Muun muassa ajoituksia käsitellään OxCal 4.4, CalPal ja ArcGIS ohjelmissa. CalPal:in oiva *Chronology composer*-toiminto järjestää ajoitukset kronologiseen järjestykseen, kun taas OxCal 4.4.-ohjelmassa radiohiiliajoituksia käsitellään tilastollisesti seuraavaa tutkimusvaihetta varten.

Jamnaja-kulttuurin määritelmä on ollut pitkään keskustelun alla. Tutkijat ovat pitkään olleet hyvin eri mieltä siitä, minkälaiset hautaukset kuuluvat Jamnaja-kulttuuriin ja millaisia ne ovat olleet tätä aikaisemmin. Hyvin usein kivikautisia hautauksia luokitellaan jamnajaksi, vaikka niillä ei näyttäisi olevan mitään yhteyksiä siihen. Tutkielmassa on tärkeää rajoittaa jamnaja-kulttuurin määritelmää niin, että tulisi selväksi, mitä hautauksia otetaan mukaan seuraaviin analyyseihin, ja mitä hautauksia jätetään tutkimuksen ulkopuolelle. Työtä varten hautauksia on jaettu neljään ryhmään niiden keskeisten piirteiden perusteella.

Tutkielman varsinainen osuus keskittyy ArcGIS-ohjelman tarjoamaan Kriging interpolointitoimintoihin. Näistä analyysiä varten on valittu Empirical Bayesian Kriging-malli, jonka avulla pystytään seuraamaan muita tuloksia kuin lineaarista ekspansiota. Kyseisessä metodissa arvioidaan tunnettujen pisteiden perusteella, minkälaisia arvoja tuntemattomat pisteet tutkimusalueella saisivat. Metodia yleensä käytetään korkeusmallien rakentamiseen, mutta tässä tapauksessa korkeuden arvot on korvattu radiohiiliajoituksilla. Metodilla suoritetaan kahdenlaista tutkimusta: yhdessä aineistoa on käsitelty laadullisesti, kun taas toisessa ei.

Koska radiohiiliajoitukset yleensä kalibroinnin jälkeen esitetään kahden arvon välinä, ne täytyy analysoida tilastollisesti. OxCal-ohjelman *Tau_Boundary*-funktio mahdollistaa välien pienentämisen, jotta ajoituksien painotettuja ja tavallisia keskiarvoja voidaan käyttää. Metodi perustuu oletettuihin Jamnaja-kulttuurin ilmestymiseen ja loppumiseen.

Radiohiiliajoitukset aiheuttavat kyseisessä analyysissä paljon virhemarginaaleja, joten niiden laatua tulee käsitellä tarkasti. Samalla tavalla kuin hautauksien tilanteessa, ajoitukset on jaettu neljään ryhmään, joissa on huomioitu perinteisen ja AMS-ajoittamisten ero, ”vanhan puun vaikutus”, allaseffekti sekä erilaisten laboratorioiden tuottama tieto. Kiovan laboratorio on pitkään säännöllisesti tuottanut virheellisiä ajoituksia, joten niitä käsitellään tutkielmassa harkiten.

Tulevaisuudessa tutkimusta voi yhdistää sekä isotooppeihin että genetiikkaan. Yhteisellä panoksella Jamnaja-ekspansiosta syntyy täydennetty kuva, jota voidaan käyttää tulkitsemaan 5000 vuoden takaisia tapahtumia. Lisäksi tutkimusta voi laajentaa sisällyttämällä lisää eroavia piirteitä. Kuitenkin kattavaa tietopankkia varten tarvitaan lisää hyvänlaatuisia radiohiiliajoituksia, etenkin Ukrainan alueelta.

Cover picture: Bayesian model of the Bulgarian dataset for the comprehensive model

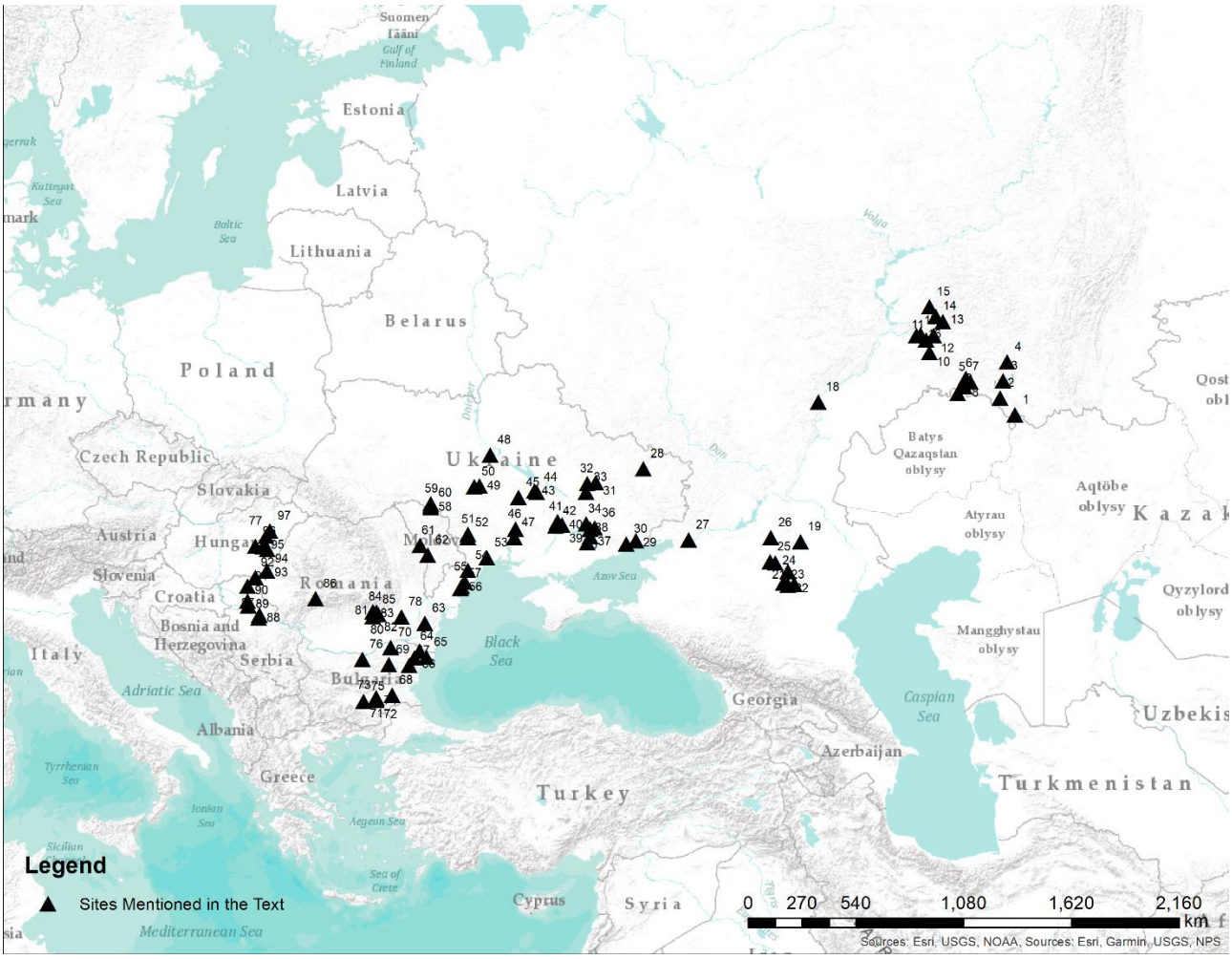
1. Introduction

Figure 1. An Example of a Kurgan. Figure credit: Chernykh & Daragan 2014: Ris. 66.2, 186.

In 1949 Willard Libby developed one of the most used and important methods of dating in archaeology: radiocarbon dating or C14-dating (Libby 1961). Radiocarbon dating is based on measuring the amount of the radioactive isotope of carbon (C14), since it is known that the half-life of the element is 5730 years, i.e. its amount is halved after 5730 years. The C14-ratio is then compared to a calibration curve, which is based on the amount of C14 in the atmosphere (Reimer *et al.* 2020).

Although radiocarbon dating has not been widely used in the past when studying the Yamnaya, a culture of mobile steppe communities that existed at the end of the 4th and during most of the 3rd millennia BC, and spread all the way from the Volga-Ural region to the Tisza river in the west (Map 1), during the last 15-20 years the use of the method has increased. Recent research has enabled more accurate dating of the Yamnaya migration, a hypothesis that has also been reinforced by recent aDNA and isotope studies. This in turn made C14-dating relevant in

archaeology. Before the use of this method in a wider scale, archaeologists mostly relied on the burial rituals in kurgans (Fig. 1), and especially



Map 1. Sites mentioned in the thesis. 1- Tamar-Utkul; 2 – Niznhnyaya Pavlovka; 3 – Pyatiletka V; 4 – Pershin; 5 – Mustaevo V; 6 – IK Shumaevo; 7 – Shumaevo I; 8 – Shumaevo II; 9 – Boldyrevo I; 10 – Lopatino; 11 – Krasnosamarskoe IV; 12 – Kutuluk I; 13 – Poludni II; 14 – Grachevka; 15 – Nizhnyaya Orlyanka; 16 – Skvortsovka; 17 – Podlesnoe I; 18 – Panitskoe 6B; 19 – Chilgir; 20 – Mandjikiny-2; 21 – Mandjikiny-2; 22 – Mu-Sharet I; 23 – Mu-Sharet 4; 24 – Khar-Zukha; 25 – Peschanyi IV; 26 – Peshcanyi V; 27 – Us'man; 28 – Raigorodka; 29 – Volonterivka; 30 – Kremenevka; 31 – Pereschepino; 32 – Minovka; 33 – Mogilev; 34 – Zaporozhye; 35 – Balki; 36 – Tarasova Mogila; 37 – Vinogradnoe; 38 – Starobogdnivka; 39 – Chkalovo; 40 – Verkhnyaya Tarasovka; 41 – Shakhter; 42 – Shakhta 22; 43 – Golovkovka; 44 – Protopopovka; 45 – Sugokleja; 46 – Otradnyi; 47 – Khristoforovka; 48 – Myronivka; 49 – Talyanki; 50 – Dobrovody; 51 - Novogrigorievka; 52 – Revova; 53 – Vapnyarka; 54 – Semenovka; 55 – Liman; 56 – Vishnevoye; 57 – Novoselitsa; 58 – Pidlisivka; 59 – Porohy; 60 – Pridnistryanske; 61 – Petreshti; 62 – Sarateni; 63 – Rahman; 64 – Plachidol; 65 – Poruchik Geshanovo; 66 – Riltsi; 67 – Vetrino; 68 – Boyanovo; 69 – Chudomir; 70 – Belitsa; 71 – Beli Bryag; 72 – Mednikarovo; 73 – Troyanovo; 74 – Ovchartsi, Barrow in the Vineyard; 75 – Merichleri; 76 – Kozlovets; 77 - Balmazújváros-Hortobágy-Árkus-Kettőshalom; 78 – Smeeni; 79 – Targşoru Vechi; 80 – Ariceştii; 81 – Blejoi; 82 – Ariceştii-Rahtivani; 83 – Coada Izvorului; 84 – Nedelea; 85 – Targşoru Nou; 86 – Silvaşu de

Jos; 87 – Vojlovica; 88 – Jabuka; 89 – Sajkas; 90 – Žabalj; 91 – Padej; 92 – Bucova Pusta; 93 – Ketegyhaza-Tőrőkhalom; 94 - Sárrétudvari-Örhalom; 95 - Püspökladany-Kincesdomb; 96 - Kunhegyes-Nagyálláshalom; 97 - Hajdúnánás-Tedej-Lyukashalom

After: Telegin 1977: Ris.1; Rassamakin 1996: Fig.1; Klochko 1999: Fig.1; Klochko & Kruts 1999: Fig.1; Nikolova 1999a: Fig.1, Nikolova 1999b: Fig.1; Subbotin 2000: Ris. 1; Yarovoi 2000: Ris. 1; Govedarica *et al.* 2006: Abb.1; Shishlina 2008: 146; Shishlina *et al.* 2009: Fig.1; Sanzharov & Chernykh 2011: Fig. 1; Shishlina *et al.* 2011; Fig.1, Ivanova 2013: Ris. 1; Morgunova 2013; Morgunova & Khoklova 2013: Fig.1; Rassamakin 2013: Fig. 12; Chernykh & Daragan 2014: Ris. 65; Frînculeasa *et al.* 2015: 2.1., Fig. 2.2.; Kaiser & Winger 2015: Fig.2; Klochko *et al.* 2015a: Fig.1; Klochko *et al.* 2015b: Fig.1; Klochko *et al.* 2015c: Fig.1; Myshkin & Turetskij 2015: Ris 1.1.; Frînculeasa *et al.* 2018: Planşa 11.2; Frînculeasa *et al.* 2019: Planşa XVI; Diaconescu 2020: Fig.8; Koledin *et al.* 2020: Fig.1.; Alexandrov *et al.* 2021: Plate I.

the position of the individual (whether it was supine with flexed knees, crouched on the side, etc.) and the comparison of different cultural features, monuments, and stratigraphy. The approach of the thesis, while containing scientific methods, will remain archaeological and will focus only on archaeological questions at hand. The problems concerning the Indo-European theory will not be discussed here.

Since the dates presented in these and other previous publications (e.g. Gimbutas 1963; Telegin 1977; Telegin 1986) have been revised, it has become clear that a development of burials and monuments (kurgans) belonging to the Yamnaya horizon took place in Eurasia, during 3500-2400 B.C. (Frînculeasa *et al.* 2015: 48). Combined with recent revolutionary discoveries in aDNA studies (Haak *et al*. 2015; Allentoft *et al*. 2015) this has completely changed the understanding of the past in Europe. The role of science is much more important in archaeology now compared to the 1900s, and, according to Kristian Kristiansen (2014) we have entered a Third Science Revolution.

Currently, C14-dating plays an important role in archaeological research. With it, one can for example model migrations and the spread of cultures and traits that come with them. The focus of this thesis is to delve deeper into the radiocarbon dates obtained from various Yamnaya sites and create a better understanding of the events that happened during the period of 3500-2400 B.C. and to study the changes and migration patterns happening at this time. The research questions will mainly focus on interpreting the produced data, from which the following information will be obtained: how and when did the Yamnaya expansion happen? What kind of migration theories can we apply to explain the movement of Yamnaya, or is there a new way to interpret their mobility?

How can one use the methods introduced in the thesis to study the Yamnaya migration and what flaws do the methods have?

2. Theoretical framework

2.1. Definition of the Yamnaya culture: burials and burial rites

Definition of the Yamnaya culture is an important asset in this research, since it affects the choices of burials used for analysis. The general description of the Yamnaya culture is mostly based on the mounds they erected, on their burials and burial rites, which are the only source of information for archaeologists, since Yamnaya communities were mobile, perhaps with a pastoral-like economy, coming from the Pontic-Caspian steppe and did not have any settlements or other types

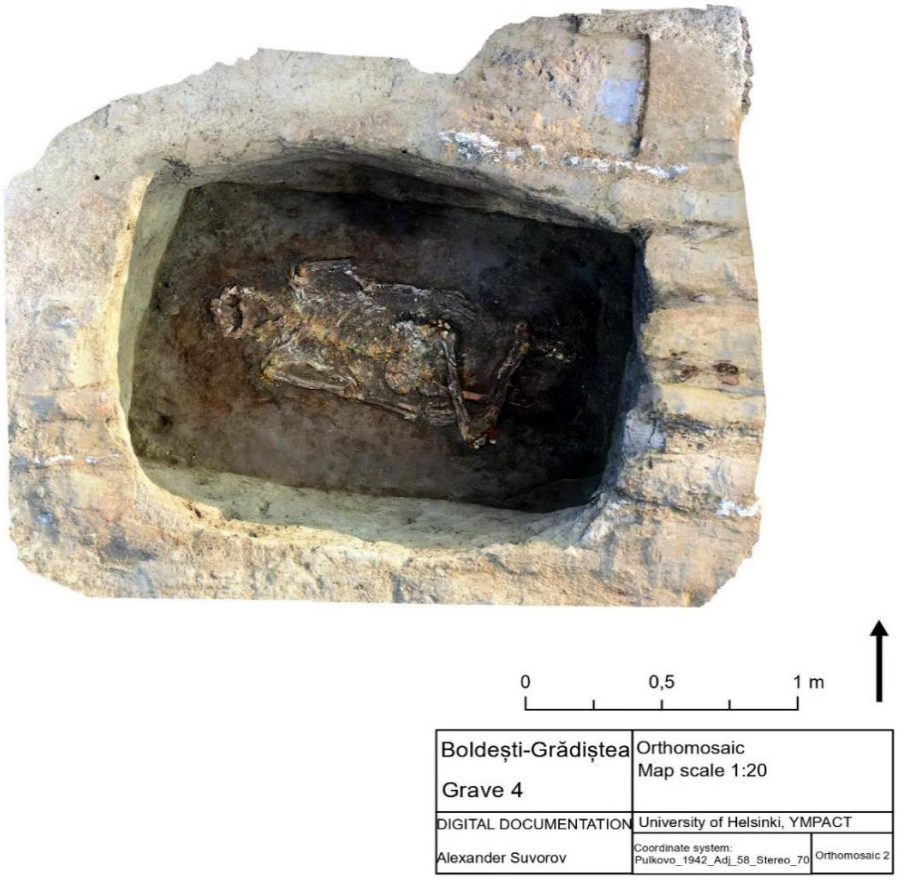


Figure 2. A typical Yamnaya burial from the excavations of Boldești-Grădiștea in 2019 (Grave 4). Orthophoto made by Alexander Suvorov. Photos provided by the *Yamnaya Impact on Prehistoric Europe* ERC-project. Further information: Frînculeasa *et al.* 2020

of sites in the westernmost distribution area (Frînculeasa *et al.* 2015: 47; Kaiser & Winger 2015; Preda-Bălănică *et al.*2020: 97). However, currently some settlement sites are attributed to the Yamnaya culture in the North-Pontic area, for example, Repin, Mikhailovka and Generalka 2 (Kaiser *et al.* 2020; Anthony 2021), although they seem to be more connected with local cultural entities and not to the mobile phenomenon of Yamnaya.

The Yamnaya culture was first defined by the Russian archaeologist V.A. Gorodtsov in his division of the Yamnaya, Katakombnaya and Srubnaya cultures in the 1900s (Gorodtsov 1907), and the description was later developed mainly by Ukrainian and Russian archaeologists (Merpert 1974; Telegin 1977: 5–6). In the former USSR the term "cultural-historical community" was

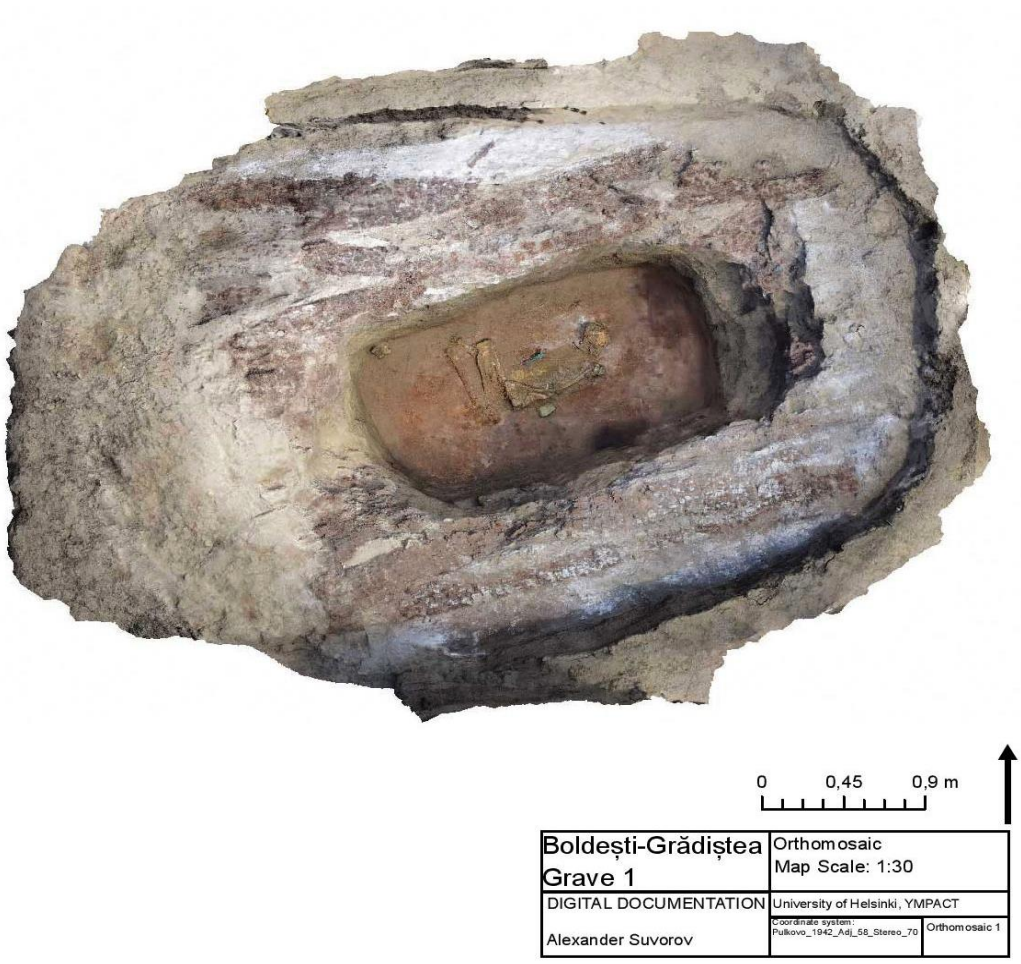


Figure 3. Another Yamnaya grave (Grave 1) from the excavations of Boldești-Grădiștea in 2019, where the individual is laid on the side. Grave goods: a bronze razor-knife, a piece of limestone and a fossil. Orthophoto made by Alexander Suvorov. Photos provided by the *Yamnaya Impact on Prehistoric Europe* ERC-project. Further information: Frînculeasa *et al.* 2020.

developed to prevent confusion over the different traits belonging to the Yamnaya and to recognize that the expansion of the Yamnaya is a widely spread phenomenon that cannot be attributed to a singular culture, but rather a community that shared similarities in burial tradition and existed in the same historical span (Merpert 1974: 54–72; Shaposhnikova 1980). Graves attributed to the Yamnaya culture had also been discovered in various parts of Romania, Bulgaria, Moldova, Hungary, and Serbia (Ecsedy 1979; Panayotov & Dergačov 1984; Panyotov 1989; Motzoi-Chicideanu 2011; Koledin *et al.* 2020). The fact that these burials have been found all the way from the Volga-Ural region and the Pontic-Caspian steppe to areas in Hungary and Serbia, led to different debates related to the spread of the Yamnaya and how we can assign burials and mounds belonging to these people. Currently, Yamnaya graves are usually divided into various styles of burial (Morgunova & Khokhlova 2013: 1289–1294; Morgunova 2014: Table 6, Table 7; Frînculeasa *et al.* 2015: 83).

The most common burial practices are classified by simple pits, sometimes with wooden or stone covers. In the graves, the individual is laid supine with flexed legs at the knees, which can later fall apart or to one of the sides, due to decomposition. These burials usually have few grave goods and the placement of ochre lumps or colouring the individual with ochre is very common (Fig. 2; Frînculeasa *et al.* 2015: 46–47).

Sometimes the deceased can be also laid on the side, the graves are furnished with a variety of grave goods, such as hair-rings, copper knives, awls, pottery, and the pits of these graves become more complex in structure (Fig. 3; Shishlina 2008; Morgunova 2014). The burials will be classified into several categories (table 1). All the Yamnaya burials are placed inside of a kurgan, which was either built on top of a primary burial by the Yamnaya communities themselves or re-used by them after arriving to a territory with already existing kurgans of local origin (Frînculeasa *et al.* 2015: 80–86). In this study, burials belonging to the class A will be automatically picked for studying. For the graves in the other classes, several statistical analyses will be performed. Their trait differencies will be carefully examined, and based on the results they might be selected for further modelling, where possible.

CLASS A	CLASS B	CLASS C	CLASS D
- Supine, with flexed legs - E or W orientation - Ochre - (Rectangular pits) covered with wood or other organic materials - (Few grave goods)	One trait is different or missing from class A	Two traits differing from class A	Three or more traits different from class A

Table 1. Classification of Yamnaya burials according to the burial styles attributed to the Yamnaya culture

The dating of the Yamnaya is problematic since scholars are still debating over its definition. The earliest dates coming from Yamnaya contexts seem to be currently placed at around 3300-3100 BC (Wang *et al.* 2019; Anthony 2021), whereas some specialists tend to introduce a lower chronology starting from 3000 BC (Rassamakin 2013; Anthony 2021). Some Russian scholars have dated the earliest Yamnaya to 3800 BC (Morgunova & Khoklova 2013: 1290–1293).

The discrepancies of the dates depend on the definition of the Yamnaya, which varies in different regions according to the burial rituals and grave goods. The traits described above are similar in all the burials that are associated with the Yamnaya. However, in many cases earlier burials found in Russia and the Ukraine can include more grave goods and the pits can differ in construction (Telegin & Mallory 1994; Klejn *et al.* 2017: 4). Moreover, the term 'Yamnaya', or as it has been translated into English as the Pit-Grave culture and juxtaposed with the term Ochre-Grave culture, adds to the confusion.

Since the term includes the word "pit", or *яма* in Russian, sometimes burials that are clearly of local origin and had appeared before the Yamnaya period, are usually combined with the Yamnaya graves under a single cultural unity (Dani & Nepper 2006; Alexandrov & Kaiser 2016). This issue has been addressed in many papers and continues to be one of the problems contributing to the debate on the subject (Frînculeasa *et al.* 2015; Kaiser & Winger 2015; Dani 2020). As an example, the graves in Sárrétudvari-Őrhalom have been analyzed with strontium and oxygen isotopes, which indicate a clear local origin for some of the graves (Gerling *et al.* 2012).

The use of the term 'Ochre Grave Culture' may also be counterproductive, especially when considering a large area. This is because ochre was used in burials associated with other local Eneolithic cultures like the Kvityana culture (Anthony 2007: 271) in the Ukraine and even in the Stone Age communities in Scandinavia and Finland (Ahola 2017: 97–98). These terms then describe only a part of the burial ritual, and do not consider the whole interior and the position of the deceased, which is now regarded as one of the most defining and important traits (Frînculeasa *et al.* 2015: Fig. 17, 82–83; Heyd 2019). This in turn makes it more complicated to assign the burials to a specific tradition or culture. Moreover, some of the burials belonging to earlier cultures attributed to the Eneolithic, also share many similar traits with the Yamnaya burials, like the Suvorovo-Novodanilovka or Skelya, which makes the definition even more unclear (Rassamakin 1999). In the end, the definition of Yamnaya is based on distinguishing of Yamnaya burials from earlier Eneolithic ones.

Moreover, in some cases it is not clear, whether certain burials should be considered belonging to the Yamnaya culture or a different cultural entity. Mainly these debates happen around the Repin culture that is either considered a variant of the Yamnaya (Morgunova 2014), or a separate culture (Rassamakin 1999; Rassamakin 2013). The burials in this culture are found under burial mounds, the deceased is laid on the back with flexed legs at the knees and ochre is used in large amounts. However, the burials still retain some Eneolithic characteristics (Anthony 2021). The appearance of supine burials with flexed legs indicates that changes in burial rites were happening and the Yamnaya burial graves were starting to spread. The burials of the Repin culture are usually located next to settlements that were likely seasonal (Morgunova 2013: 9). The radiocarbon dates for these burials are also quite early (ranging from 3800 calBC to 3100 calBC), which may either indicate the influence of the reservoir effect, meaning that the carbon mitigated

in marine organisms could have been consumed by humans and other terrestrial organisms (Ascough *et al.* 2005). The local culture was most likely influenced by the Yamnaya communities coming from another place. Moreover, the Repin-style pottery disappears from Yamnaya burials completely, which could indicate the Repin culture being a separate entity (Rassamakin 2013).

This thesis will focus on the "classic" definition of Yamnaya that is based on the burials belonging to class A (table 1), and the terms 'Pit-Grave culture' and 'Ochre Grave Culture' will not be used, since they include wider cultural entities tied to a similar burial type. The inventory of the graves and the orientation of the deceased will not be necessarily a defining factor since it can vary in different regions. The burials of the Repin stage will be excluded and viewed as belonging to a separate cultural identity. Main reason for this division is the context of the burials, which have many local Eneolithic traits, like pottery, present (Rassamakin 1999). Moreover, the Repin culture is mostly associated with a sedentary way of life, and this does not correspond with the mobile lifestyle of Yamnaya communities.

2.2. Migration theories and their application in the study of Yamnaya culture

The migration theories applied to explain the Yamnaya expansion have deep roots in history. The notion of a cultural entity coming from the east to the west had already been developed in the 1960s by Marija Gimbutas (Gimbutas 1963; Gimbutas 1970). Her research focused on the migrations of the so-called 'Kurgan culture', which invaded Europe in three distinct waves. This theory has been later revised by other western scholars, namely J.P. Mallory and D. Anthony (Anthony 1986; Mallory 1997). This day, the migrations are a topic for debate once more, especially since the studies conducted by Haak *et al.* (2015) but also other geneticist teams suggest a migration happening in Europe based on aDNA-studies. Different sciences, like isotope studies, continue to support the idea of migrations and are constantly revealing new information about mobility and migrations (Gerling *et al* 2012; Gerling 2015).

In the case of Yamnaya, it is unclear, how and when the expansion happened exactly. The debates have mostly concentrated on the character of the migration, which is sometimes thought of as a full-scale violent invasion (Kristiansen *et al.* 2017; Bátora 2021). This idea was quickly

picked up by many scientific journals (for example Gibbons 2017 for Science Magazine), and now the Yamnaya people are known as the most violent and murderous group to ever exist. However, most of the presented ideas are based on singular cases with non-extensive research with the use of applied sciences and on the generalization of the results and are not visible in archaeological contexts (Vander Linden 2016; Heyd 2017), which in turn creates potentially false and misleading information.

The theories of violent Yamnaya people invading and destroying the local population indicate that the migration happened in a single wave and thus raising the question of whether Marija Gimbutas' initial theory was right. However, there is yet to be an indication of whether the migration happened in a wave (or waves), or whether there are other explanations for these events. David Anthony raised this question already in the 1990s (Anthony 1986; Anthony 1990), and these same possibilities are being developed even today. Before assessing migrations, their conditions and the nature need to be considered. What kind of events could have enacted the migration? Anthony points out that migrations are driven by different factors (like climate, food intake, resources etc.), and the question that should be asked is not how we can study migrations, but rather what could have influenced them and how they happened.

Currently it is obvious that a migration happened (Kristiansen *et al.* 2017; Heyd 2019), but we do not know how it proceeded. Migrations are a combination of different push-and-pull factors, which seem to have an influence on a large territory. However, the nature of the migrations is somewhat unclear. Was it a large-scale migration, or a series of smaller groups with similar identities and traditions moving around? To identify the migrants, we must look at several factors and try to differentiate between the local cultures affected by the migration and the migrants affected by the local societies (Furholt 2018; Furholt 2021). We also need to try to understand the interactions between different communities and not only rely on scientific data. The migration was not necessarily violent, but the expansion could have been rather peaceful, with ideas being exchanged and social networking happening between various groups on a certain territory (Harrison & Heyd 2007; Heyd 2019: 217 –218).

Through the study of interactions and different cultural traits we will be able to distinguish the migration events, whether it was individuals moving or whether certain cultural ideas were exchanged between different societies, as it has been suggested (Harrison & Heyd 2007; Kulcsár

& Szeverényi 2013). With the help of radiocarbon dating we will be able to conduct research on what kind of migrations happened: short- or long distance, whether the communities were taking "leaps" like in the game of leapfrog, or if individuals travelled in single waves or whether a whole community arrived on a territory in a single or multiple waves, whether the people who migrated ever returned back from where they came from (return migration), or whether there was any migration happening at all (Wendrich & Barnard 2008; Anthony 2021).

In this thesis, the major emphasis will be placed on how we can use radiocarbon dates to model the Yamnaya migration. By using different methods, it is possible to create a model that will show a prediction of points in space that in turn will explain the possible spread of the Yamnaya. The study will enable a possibility to combine the models based on radiocarbon dates with different migration theories, and in the end, it will show, which theory does the model fit best. The initial hypothesis is that the Yamnaya migration happened from the east to the west (namely from the Caucasus steppes and the Volga-Ural region to regions like Romania, Hungary, Serbia, Bulgaria), and it was a single, continuous event. The burials spread chronologically one after another from a region to the next. The methods that will be used in the thesis and will be discussed in the next chapter, will rely on this hypothesis and either prove or disprove it, or, a new theory about the Yamnaya expansion could emerge as a result of this thesis.

3. Methods

3.1. Research history and background

Modelling of radiocarbon dates has been recently conducted in various cases. Some of them were used to explain for example the spread of Neolithic farming from Anatolia to Europe (Bocquet-Appel *et al.* 2009). This study was later elaborated on with the addition of several new factors and information (Brami 2014; Brami & Zanotti 2015). In this study, different geospatial methods were used to model the 2000-year lag that happened in the spread of agriculture and to explain, why this could have happened. In the study, methods, such as kriging interpolation and Bayesian modelling were used to predict the distribution of points in space and time (Bronk Ramsey 2009; Bayliss 2009; Racimo *et al.* 2020). The method will be explained and discussed more thoroughly in the last subchapter. The potential of the research provided in relation to the expansion of Neolithic

farming opens a new door for modelling other expansions and migrations by using known data from radiocarbon dates.

Another similar study has also been conducted in Mongolia during the Bronze Age (Taylor *et al.* 2019). In the study Empirical Bayesian kriging was applied to model the chronology of the Bronze Age cultures on the territory of Mongolia. Moreover, the method explains the dynamics of the populations and how the different monuments belonging to different cultures spread accordingly to chronology. This study is useful comparing to the thesis, since it models pastoralist communities in the Bronze Age, which can be compared in its similarities with the Yamnaya culture that also has these same traits.

After reflecting upon the different studies produced in relation of modelling radiocarbon dates by using kriging interpolation and Bayesian modelling methods, one could conclude that a similar study could well be applied to model the migration of the Yamnaya. Radiocarbon dates for the Yamnaya culture have been collected intensely over the past 15-20 years, and they have become an important asset in analyzing Yamnaya in comparison to local cultures and to establish a relative chronology in different regions (Rassamakin & Nikolova 2008; Morgunova 2014; Alexandrov 2020; Dani 2020; Diaconescu 2020). The dates have been extensively used to understand the origins of the Yamnaya and the transition from local burial traditions and cultures to Yamnaya burial styles and social structures (Rassamakin 2013; Horváth *et al.* 2013).

Only recently attempts have been made to analyze radiocarbon dates from an archaeological perspective and to understand the migration and dynamics of the Yamnaya culture (Anthony 2021). However, rarely the whole area of the Yamnaya phenomenon is considered. The studies in various cases only consider certain areas, where the Yamnaya graves had been documented (Anthony 2007; Frînculeasa *et al.* 2015; Diaconescu 2020; Alexandrov 2020), and these studies are not connected to a wider context of the whole area, where the Yamnaya had potentially existed. The knowledge that we have from the radiocarbon dates could be applied to understand the spread of the Yamnaya culture, and not only tie it to a regional context. This is the key point of this thesis, to use the radiocarbon dates available to model the migration of the Yamnaya culture and to understand how and when the migration was happening.

3.2. Gathering the data and choosing the burials for research

Radiocarbon dates had been collected in different regions at a different pace and intensity. In the USSR the dates had already been analyzed in the 1970s (Telegin 1977). However, they were inaccurate, since they were not properly calibrated (adjusted to various nuclear events happening in the 1950s) and thus yielded dates, such as 2000-1800 calBC for the Yamnaya burials, which currently does not represent the actual period of existence for the Yamnaya. After calibration techniques were revised, the dates had been marginally pushed back and they have constantly become more precise (Klochko 1999; Klochko & Kruts 1999). However, some of the dates yield problems, which had been addressed in different papers, and new publications with re-calibrated and checked dates are published continuously (Chernykh & Orlovskaya 2004; Rassamakin & Nikolova 2008; Chernykh & Orlovskaya 2011; Alexandrov 2020).

The dates used for the thesis come from these kinds of publications, where a table with the dates has been introduced. In the cases of Romania, Hungary, Serbia and Bulgaria, the dates have been published on multiple occasions (Frînculeasa *et al.* 2015; Ailincai *et al* 2016; Koledin *et al.* 2020; Alexandrov 2020), and, since the publications are very recent, it is also not difficult to revise the contexts of the burials. The dates from Bulgaria have also been kindly provided by Professor Stefan Alexandrov, which helped fill in some of the gaps in this country. In this thesis, the description of various Yamnaya burials is given, and to model the initial migration patterns of these people and to distinguish between the migrants and the locals, we need to investigate the Yamnaya burials associated with class A (Table 1). However, other burials will also be analyzed according to their traits, and further modelling will be provided. This will help distinguish between the various changes happening in time. Some key aspects will include notions of whether we can see a certain trait appearing on a specific territory or in a specific time gap. That is why for all the published radiocarbon dates the context of the burials the samples belong to need to be analyzed. Most of the contexts in regions, such as Hungary and Bulgaria, for example, had been presented over the years in various monographs and publications (Ecsedy 1979; Panayotov 1989).

However, in the countries of Ukraine and Russia, and especially on the territory of the Ukraine, most of the contexts of excavated burials with radiocarbon dates are difficult to find or are completely lost. Some of these are only published in paper format, and to read and analyze them it would require travelling to Kiev, Moscow, and other cities to find the reports of the

excavations. In the case of the "Akkembyetskiy kurgan" the excavation reports are lost, so we do not know the contexts for these graves (Szmyt & Chernyakov 1999). The contexts are also not presented in many publications and thus must be sought out from various sources. Some of the reports have been published in digital form (e.g. Subbotin *et al.* 2017) and were relatively easy to find. Moreover, some of the contexts that were impossible to track with methods at hand are compensated with newer dates from various sites, for example the ones at Yampil (Klochko *et al.* 2015a; Klochko *et al.* 2015b; Klochko *et al.* 2015c).

Currently, the information with contexts and radiocarbon dates have been found for sites in Russia, the Ukraine, Moldova, Bulgaria, Romania, Hungary, and Serbia. All the burials that fit the description of a class A Yamnaya burial (i.e. supine with flexed legs, simple pits with ochre, individuals oriented for east to west or the other way around, wooden or stone covers and few grave goods), yielded a total of dates. The sites and burials used for the research, with their sources and all the necessary information about the samples and recalibrated dates are displayed in the supplementary tables 1, 2.

3.3. Mapping of the sites with ArcMap

After the information about the burials had been filled into the table, they should be mapped to perform geostatistical analysis. The sites were gathered from maps presented in different publications. Unfortunately, there is no map, where the Yamnaya sites from all the regions assessed in this thesis would be collected, so one had to be made manually. Different maps were scaled according to their region by using the *Georeference* tool in the ArcMap 10.8 programme. This adds a degree of uncertainty, since the control points do not represent the actual locations and since the maps have been drawn in different coordinate systems and in different styles (see for example, McEachern & Niessen 2009; Wieczorek *et al.* 2010). However, since the framework of the thesis is concentrated on a large-scale event and considers a distance equal to 4000 kilometers (measured with the *Measuring tool* in ArcMap 10.8.), the errors of the locations of the sites are minimized.

After the maps have been geo-referred, a point shapefile was created for placing the sites on a background map, provided by OpenStreetMap. The WGS 1984 Web Mercator (auxiliary sphere) projected coordinate systems, in which the unit of measurement equals to 1 meter, was used to unite the maps in a single system with linear units of measurement, so that the geospatial

analysis would be easier. The points were then added according to their locations with the *Editor* tool. In the attribute table of the shapefile, the name of the site, the uncalibrated date, the country, and the sample codes were added. The attribute table was then joined with the .txt version of the Excel, where the radiocarbon dates were collected, by using the sample codes. The information in the Excel contains the weighted mean value and the median of the dates modelled in OxCal to get numeric information for the points on the map. The reason for using a single number and statistically analyzing the dataset is explained in the next subchapters.

3.4. Calibration of the radiocarbon dates

As it has been mentioned, radiocarbon dating has become an important tool to try to understand the different relations between cultures and events that had happened in the past. The method has been developed over the years, and many problems concerning its precision have been noticed and resolved since its appearance. Notably, the calibration of the dates produced from samples has been the main point in revising previous studies and progressing towards an accurate set of dates (Clark & Renfrew 1973; Bronk Ramsey 2009; Wood 2009). Radiocarbon dating revolutionized the perception of archaeology since it enabled the distribution of different cultures and discoveries and made it possible to analyze them in time. However, the first dates produced by this method were not accurate because they were not calibrated at first (Telegin 1977). The calibration process was introduced later in the 1970s (Clark & Renfrew 1973) and was developed further in the 1990s (Kovalyukh & Nazarov 1999; Wood 2009). Today, radiocarbon dating is becoming even more accurate, and different problems, for example, old wood effect and reservoir effect, related to it are now being brought up and resolved (Olsen *et al.* 2013; Shishlina *et al.* 2014).

Calibration of dates acquired from samples is necessary to produce a correct range of dates, during which the event in questions happened. When samples are analyzed the dates are first acquired as a number before present (BP), because as a result of human activity like the use of atomic bombs and the release of industrial greenhouse gases have affected the radiocarbon ratio in the atmosphere, causing the calculations produce older dates and to be presented before the year 1950 (Gillespie 1984). Thus, the calculated amount of carbon in a sample is then compared to an atmospheric curve and the date is presented in a range and expressed in calBC or calAD, indicating the real dataset. In this thesis, the dates will be mostly calibrated with the OxCal 4.4. programme

(Bronk Ramsey 2020), which is available online, and the IntCal20 atmospheric curve will be used for calibration (Reimer *et al.* 2020). The calibrated dates can be viewed in the Supplementary table 3.

3.5. Bayesian modelling of the dates

After the dates had been calibrated, a statistical analysis of the dates was performed. The analysis was conducted with the *Tau_Boundary* function in OxCal 4.4. (Bronk Ramsey 2009; Bronk Ramsey 2020). The *Tau_Boundary* command was used to allow some overspill in the boundaries of the set dates. Since there is no conclusion on when the Yamnaya culture first appeared, different date caps were used in the analysis. For the dates from the Ukraine and Russia the cap was set at 3300 calBC, and for other regions the highest median value of the date range with some room for overspill (for example, 2954 for Hungary; see supplementary figures 1-9). The dates used for the thesis were divided according to modern geographical borders, and as a result 6: Russia, The Ukraine and Moldova, Romania, Hungary, Bulgaria, Serbia. Moldova and the Ukraine were combined for this purpose, since Moldova is a rather small region and it only yielded 3 dates from 2 sites, so it seemed reasonable to combine it with a larger region. The *Tau_Boundary* function does not limit the first appearance of Yamnaya in a region to a certain year, but rather allows the range to go beyond the set limit.

The *Boundary* function then narrows down the range of the dates according to the set parameters, thus allowing to statistically calculate a more accurate starting date for a site. This does not mean that an exact date for the appearance of a certain site or burial is introduced, but it is a more probable one than it would be without statistical calculation (Brami & Zanotti 2015). From the narrowed ranges, two numbers were added to the existing excel table: the median of the new range and also the weighted mean value, which is a number that is compared to the whole number of dates and weighted against them (examples of the use of the weighted mean value Qi 1998; Polezzi 2006).

Both the weighted mean value and the median will be analyzed and viewed during the thesis. They will be compared to each other on which one is more reliable, and which provides more accurate data that we can relate to existing migration theories. Both numbers have been gathered from the OxCal programme and used in the interpolation kriging analysis, which will be explained in more detail in later chapter.

3.6. CalPal and BarCharts

Another way to establish the chronology of the sites is to make chronological barcharts, which place the dates in the order of age. The bar charts were produced with CalPal, a programme developed for the construction of archaeological chronologies (Weninger & Jöris 2006). The programme was kindly provided by Professor Bernhard Weninger from the University of Cologne. The sites, collected in an excel-file, were then imported into the programme, and the bar charts were produced for a chronological sequence of the sites, to see which site comes before which, and whether some visible patterns could be seen from the data. An example of a barchart can be observed in chapter 4, where several barcharts were created to illustrate the chronology of burials from different classes.

This method will also be used to compare burials within the categories (table 1) created especially for this thesis. This will help in understanding the possible changes happening in the evolution of burial tradition. For example, we could analyze which traits differ and during which time gaps can these variations be noted. Also, the disappearance and the appearance of certain traits could be discovered with this method. CalPal should ultimately be a very useful tool for statistical analysis of the burials and for understanding the processes that were happening with the changes in the burial tradition.

3.7. Kriging interpolation

Interpolation is a geostatistical method, which creates continuous surfaces based on certain point-measurements in space (Holopainen *et al.* 2015). It analyses the data and predicts the values of nearby spaces based on the data that is provided (Johnston *et al.* 2001). Various semivariogramme models could be applied for the kriging methods, for example, exponential or linear, and kriging then assumes that points are spread according to the model set. Kriging is a common tool used to predict surfaces based on height inputs and to create Digital Elevation models (Bernardes *et al.* 2006).

In the case of the thesis, similar procedures as in Brami & Zanotti 2015 will be used, and Empirical Bayesian Kriging will be utilized instead of ordinary kriging. The Z-point will describe the radiocarbon dates instead of elevation, and both weighted mean values and medians produced

from the Bayesian modelling will be tested to see what kind of predictions of dates the method will produce. The same analyses will be conducted for the comprehensive and audited dataset, with the exclusion of some dates. The criteria for the comprehensive and the audited dataset will be discussed in the next chapters.

4. Analysis of the data

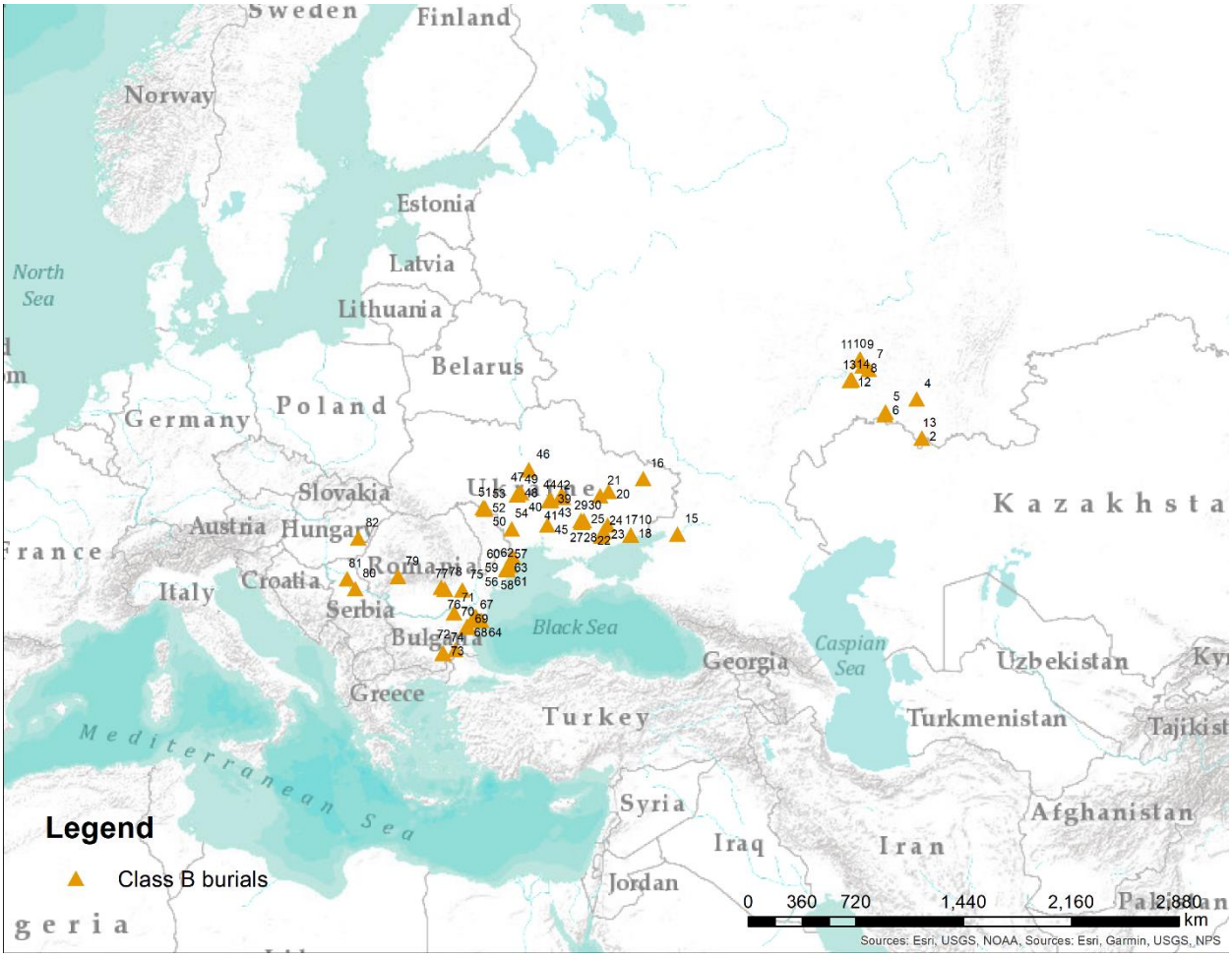
4.1. Basic statistical analysis of the burials: examining the traits of class B burials

Map 2. Class A burials. 1 – Shumaevo II mound 6, gr.6; 2 – Kutuluk I mound 4, gr. 1; 3 - Mandjikiny-1 mound 3, gr.2; 4 – Peschanyi IV mound 11, gr. 4; 5 – Peschanyi IV mound 11, gr. 5; 6 – Kremenevka mound 6, gr. 6; 7 – Verkhnyaya Tarasovka mound 17, gr. 3; 8 – Golovkokva mound 7, gr. 4; 9 – Myronivka mound 7, gr. 2; 10 – Dobrovody mound 2, gr.4; 11 – Khristoforovka mound 1, gr.11; 12 – Revova mound 3, gr.16; 13 – Pridnistryanske mound 4, gr.4; 14 – Pridnistryanske mound 4, gr. 8; 15 – Sarateni mound 1, gr. 4; 16 – Sarateni mound 1, gr.5; 17 – Vishnevoye mound 17, gr.4; 18 – Smeeni mound 1, gr. 5; 19 – Rahman mound 1, gr.1; 20 - Ariçeştii IV, gr.2; 21 - Targşoru Vechi mound 1, gr.9; 22 – Ariceştii-Rahtivani mound 1, gr.1; 23 – Blejoi IV, gr. 1; 24 – Coada Izvorului mound 1, gr. 3; 25 – Târgşoru Nou mound 1,

gr.2; 26 – Riltsi mound 260, gr. 1; 27 – Chudomir mound 1, gr. 5; 28 – Kozlovets mound 1, gr. 1; 29 – Merichleri mound 1, gr. 6; 30 – Sajkas "Ciganska Humka", gr. 1; 31 – Zabalj "Medisova Humka", gr.1; 32 – Padej, "Humka u Barnahatu", gr.1; 33 – Bucova Pusta IV; 34 – Ketegyhaza-Törökhalom mound 3, gr.4; 35 – Kunhegyes-Nagyallashalom gr.14; 36 – Kunhegyes-Nagyallashalom, gr.18; 37 - Balmazújváros-Hortobágy-Kettöshalom; 38 - Hajdúnánás-Tedej-Lyukashalom

Since the burials have been divided into several categories (Table 1, Supplementary table 1.), they must be statistically analyzed. This will reveal new information on which kind of traits appear during a certain time, and perhaps on which territories. We can place the different classes on a map to further examine the sites based on the traits that they possess or miss. Some often-recurring traits will be looked at more carefully, and they will be modelled with ArcGIS, if possible. Burials from class A will be automatically treated as Yamnaya burials since they fulfill the needed criteria. There are in total 45 published dates from 38 burials belonging to class A burials, for which contexts could be identified (Map 3). These graves possess all the traits that are characteristic of Yamnaya: the individuals are laid supine with flexed legs head to the east or west; there are wooden covers on top of the pits or organic mats underneath the skeleton; ochre is strewn around or can be found as lumps; the individual may also be painted with ochre. This is not the most numerous category, as most other burials seem to slightly differ from this set classification. Class A inhumations seem to peak at around 2900 calBC, with the earliest one appearing in several spots (Sărăteni in Moldova, Yampil region and Kutuluk in Russia) (fig.4)

Class B burials is the most numerous group, and it includes in total 82 burials (Map 3). Out of those, 46 burials (or roughly 56%) have a different orientation than that of defined in class A. The deviations in the orientation are usually quite small, either slightly to the north or to the south. However, sometimes even untraditional orientations, like from north to south, can be seen (for example, Golovkovka mound 14, grave 4). These displacements seem to be mostly found in Ukraine and in Russia, which could well be due to fact that there is a greater number of burials concentrated on these territories compared to other parts. The dates of the burials seem to be mostly later compared to those of class A burials, however, in some cases graves with a deviating orientation are older (Semenovka mound 14, grave 2, for example), which could be because of old-wood effect influencing the results.



Map 3. Class B Burials. 1 – Tamar-Utkul VII mound 1, gr.1; 2 – Tamar-Utkul VII mound 4, gr.9; 3 – Tamar-Utkul VIII mound 8, gr.1; 4 – Pershin mound 1, gr.4; 5 – IK Shumaevo mound 2, gr.2; 6 – Shumaevo I mound 3, gr.6; 7 – Poludni I mound 2, gr.7; 8 – Grachevka II mound 5, gr.2; 9 – Nizhnyaya Orlyanka mound 1, gr. 4; 10 – Niznhyaya Orlyanka mound 1, gr. 5; 11 – Nizhnyaya Orlyanka mound 4, gr. 2; 12 – Podlesnoe I mound 3, gr. 3; 13 – Podlesnoe I mound 3, gr. 4; 14 – Skvortsovka nmound 9, gr.1; 15 – Us'man mound 1, gr. 13; 16 – Raigorodka mound 1, gr. 9; 17 – Kremenevka mound 6, gr. 8; 18 – Kremenevka mound 6, gr. 4; 19 – Kremenevka mound 6, gr. 7; 20 – Pereschepino mound 1, gr. 13; 21 – Mogilev "Brilyuvata Mogila", gr. 12; 22 – Tarasova Mogila mound 1, gr.11; 23 – Vinogradnoe mound 24, gr.20; 24 – Starobogdanivka mound 1, gr. 6; 25 – Verkhnyaya Tarasovka mound 9, gr. 11; 26 – Chkalovo mound 11, gr. 8; 27 – Chkalovo mound 11, gr. 9; 28 – Chkalovo mound 11, gr. 11; 29 – Shakhter mound 29, gr. 12; 30 – Shakhter mound 29, gr. 11; 31 – Golovkovka mound 5, gr. 5; 32 – Golovkovka mound 6, gr. 8; 33 – Golovkovka mound 6, gr. 9; 34 – Golovkovka mound 6, gr. 11; 35 – Golovkovka mound 11, gr. 5; 36 – Golovkovka mound 12, gr. 3; 37 – Golovkovka mound 14, gr. 4; 38 – Golovkovka mound 14, gr. 7; 39 – Sugokleja mound 1, gr. 5; 40 – Sugokleja mound 1, gr. 8; 41 – Sugokleja mound 1, gr. 14; 42 – Sugokleja mound 1, gr. 16; 43 - Sugokleja mound 1, gr. 20; 44 – Sugokleja mound 1, gr. 24; 45 – Otradnyi mound 1, gr. 21; 46 – Myronivka mound 1, gr. 8; 47 – Talyanky mound 4, gr. 1; 48 – Dobrovody mound 2, gr. 3; 49 – Dobrovody mound 1, gr. 2; 50 – Pidlisivka mound 1, gr. 1A; 51 – Porohy mound 3A, gr. 11; 52 – Pridnistryanske mound 4, gr. 3, 53 – Pridnistryanske mound 4, gr. 6; 54 – Novogrigorievka "Lyubasha", gr. 8, 55 – Semenovka mound 14, 2; 56 – Liman mound 2, gr. 2; 57 – Novoselitsa mound 19, gr. 7; 58 – Novoselitsa mound 19, gr. 11, 59 – Novoselitsa mound 19, gr. 16; 60 – Novoselitsa mound 19, gr. 19; 61 – Novoselitsa mound 20, gr. 8; 62 – Novoselitsa mound 20, gr. 9; 63 – Vishnevoye mound 17,

gr. 17; 64 – Vishnevoye mound 17, gr. 38; 65 – Poruchik Geshanovo mound 1, gr. 3; 66 – Plachidol mound 1, gr. 1; 67 – Riltsi mound 264, gr. 4 68 – Vetrino-1 mound 34, gr.2; 69 - Vetrino-2 mound 7, gr.2; 70 – Vetrino-3 mound 1, gr.8; 71 – Belitsa mound 1, gr. 1; 72 - Boyanovo "Lozianska Mogila", gr. 14; 73 – Mednikarovo mound 2, gr.1; 74 – Troyanovo Chernyova Mogila, gr. 4; 75 – Smeeni mound 1, gr. 18; 76 – Targşoru Vechi mound 1, gr. 2A; 77 – Targşoru Vechi mound 1, gr. 10; 78 – Nedelea mound 2, gr. 1; 79 – Silvaşu de Jos mound 4, gr. 1; 80 - Zabalj "Medisova Humka" gr. 4; 82 – Jabuka "Tri Humke" gr. 1; 82 – Püspökladany-Kincesdomb

The second most common deviating trait is the position of the deceased. Most of these individuals are crouched on either side, but some with an unclear position are also present. These burials are also clearly more numerous in Ukraine and Russia, which is also due to the bias in the number of graves. What comes to the dating of these burials, they clearly seem to be later than class A burials, with the earliest one being grave 1 from mound 8 at Tamar-Utkul VIII (Morgunova 2014: 36–40).

The tradition of supine burials with flexed legs seems to continue with the ones described here. What is clear though, is that crouched burials are appearing much later than the ones, in which the individual is supine with flexed legs. However, there is no indication that one is more preferred than the other, but rather that the ways the individual was laid were contemporary with each other after around 2900 BC. Perhaps, the Yamnaya started to incorporate some local traditions into their burial customs, or they decided to change the ritual according to changes in their social structure or religion. Svitlana Ivanova has pointed out that the choice of position is strongly related with social status, and one can see a hierarchical influence in the position of the individual and the grave (Ivanova 2007: 69–70). However, in many cases the funerary equipment and the structures of the crouched burials are much richer and more complex than of those with individuals that are supine with flexed legs (for example, in Boldești-Grădiștea Frînculeasa *et al.* 2020). This contradicts with Ivanova's theory if we assume that equipment is associated with social status.

Ochre is missing only from a handful of graves, which could have several reasons. Firstly, the ochre was so rare, or it was not in the original context of the pit (or in the fill, for example), so that it seemed unnecessary to record its presence. Moreover, some of the burials are disturbed by animal holes, which could mean that ochre was not preserved (for example, Alexandrov *et al.* 2021: 6). There is also a possibility that ochre was simply not used, which would indicate a major change in the burial tradition.

While analyzing the appearance of certain traits, one must note that some of the dates for these burials are just an estimation of a year, when these burials were constructed. As discussed in chapter 3.4, the gaps for radiocarbon dates have been minimized to extract median and weighted mean values for the burials. But this does not ultimately mean that traits disappear during a certain period, or that the position changes exactly during the dates expressed in figures 4-7. These are just predictions that could prove to be wrong if radiocarbon dating would become even more accurate. However, some dates can be certainly excluded from further studies. An example of such would be Starobogdanivka mound 1, grave 6, which displays an unusually high date (median 3509). This indicates that this date has either been influenced by the old-wood effect or that it was contaminated while being analyzed in the Kiev laboratory.

From the BarCharts produced by CalPal (Weninger & Jöris 2006; figs. 4 & 5), one can see that most of the type A and B burials peak around 2800-2600 calBC, while some of the oldest burials appear already around 3600 calBC. The appearance of Yamnaya burials in this case is slightly flawed, as already expressed in previous chapters. The CalPal BarCharts are introduced here to present a picture of the chronology of all the burials used in the analysis, to see, if one can determine a starting age of burials, belonging to different groups. If we are to believe the dates during these analysis, type A and B burials are appearing simultaneously throughout the suggested timeline for Yamnaya. Different traits are, however, introduced slightly later than the appearance of class A burials, which would indicate a change in the traditional burial custom during 2800 BC. At the same time, the Yamnaya seem to be maintaining the traditional style as well, incorporating it along with some changes for other burials.

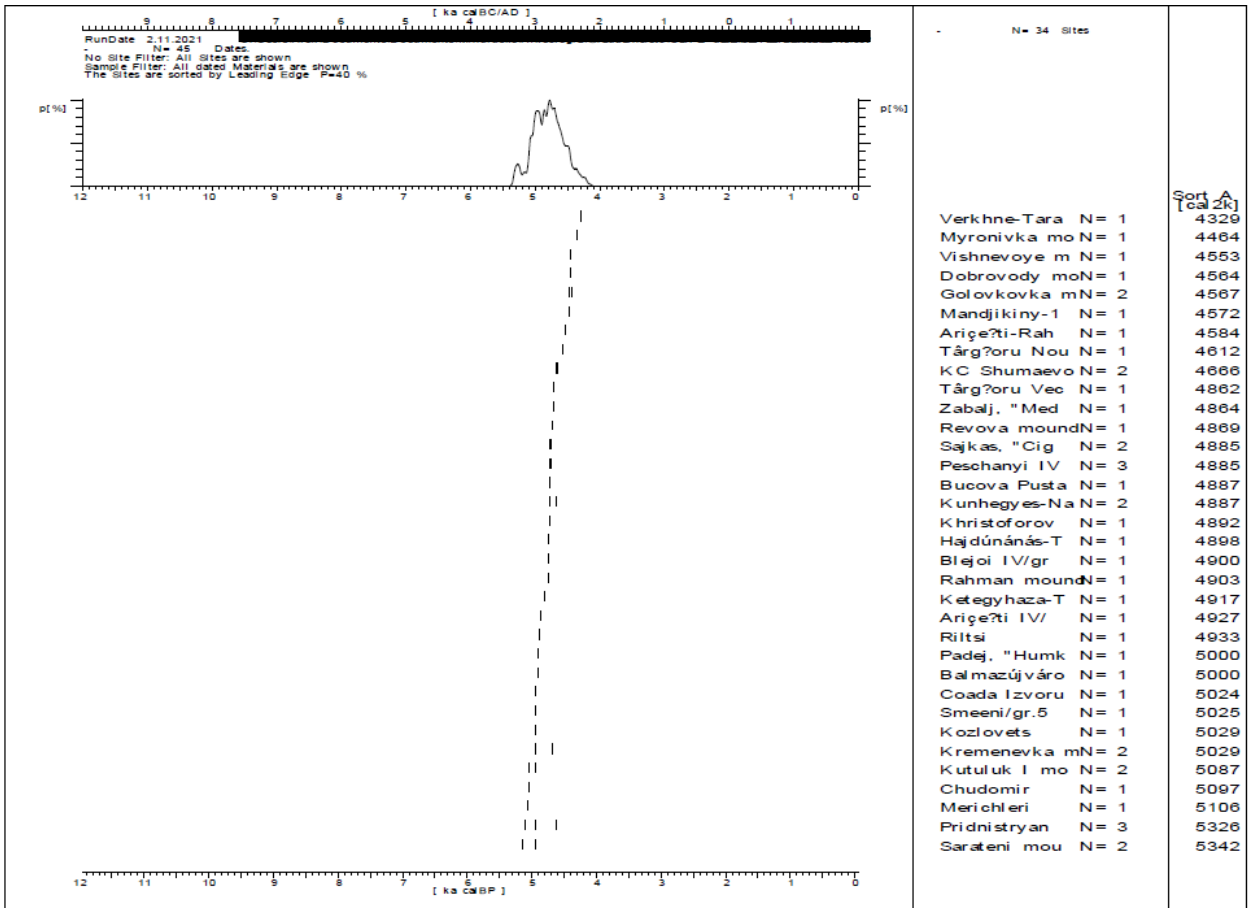


Figure 4. Chronological order of class A burials. Created with CalPal (Weninger & Jöris 2006).

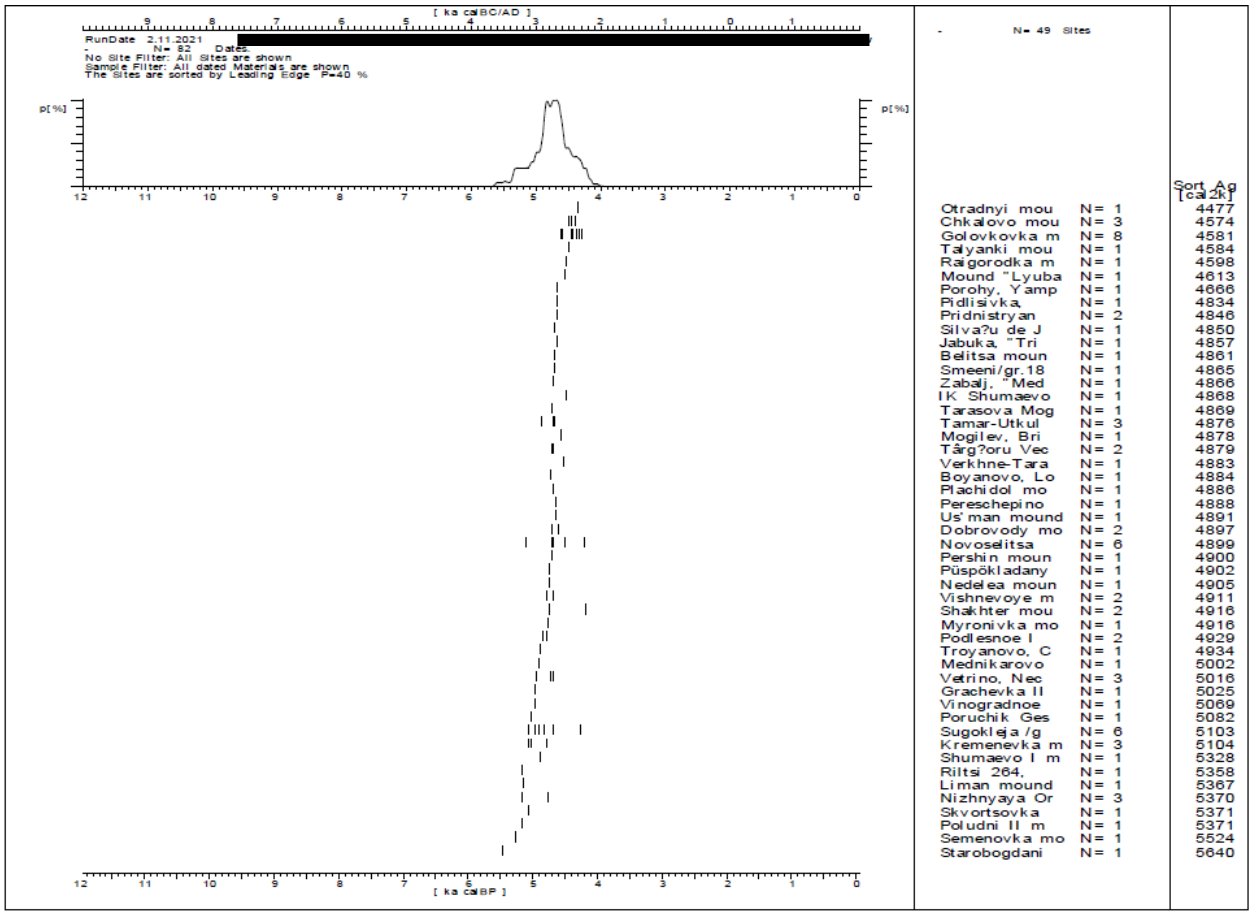


Figure 5. Chronology of class B burials. Created with CalPal (Weninger & Jöris 2006).

4.3. Basic statistical analysis of the burials: examining the traits of class C burials

Map 4. Class C burials. 1 – Tamar-Utkul VII mound 8, gr.4; 2 – Tamar-Utkul VIII mound 4, gr.1; 3 - Pyatiletka V mound 5, gr.2; 4 – Boldyrevo mound 1, gr.1; 5 – Mustaevo mound 1, gr.1; 6 – Mustaevo V, mound 9, gr.2; 7 – Skvortsovka mound 7, gr.1; 8 – Skvortsovka mound 8; gr.1, 9 – Grachevka I mound 1, gr.2; 10 – Krasnosamarskoe IV mound 1, gr.3; 11 - Grachevka II mound 5, gr.1; 12 – Lopatino I mound 35, gr. 1; 13 - Raigorodka mound 1, gr.10; 14 – Volonterovka mound 1, gr.3; 15 – Kremenevka mound 6, gr.6; 16 – Pereschepino mound 1, gr.7; 17 – Minovka mound 1, gr.3; 18 – Zaporozhye mound 1, gr.4; 19 – Balki mound 1, gr.40; 20 – Balki mound 1, gr. 57; 21 – Shakhter mound 29, gr.19; 22 – Shakhta 22 mound 2, gr.9; 23 – Protopopovka mound 1, gr.3; 24 – Protopopovka mound 1, gr.4; 25 – Golovkovka mound 5, gr.3; 26 – Golovkokva mound 14, gr.2; 27 – Golovkovka mound 14, gr.9; 28 – Otradnyi mound 1, gr.17; 29 – Otradnyi mound 1, gr.22; 30 – Otradnyi mound 26, gr.9; 31 – Myronivka mound 3, gr. 1; 32 – Myronivka mound 2, gr.3; 33 – Myronivka mound 2, gr.4; 34 – Talyanky mound 4, gr.2; 35 – Talyanky mound 4, gr. 3; 36 – Dobrovody mound 2, gr. 6; 37 - Dobrovody mound 2, gr.10; 38 – Pidlisivka mound 1, gr. 11; 39 – Vapnyarka mound 4, gr.18; 40 – Semenovka mound 11, gr.6; 41 – Semenovka mound 11, gr. 7; 42 – Vishnevoye mound 17, gr. 36; 43 – Vishnevoye mound 17, gr. 37; 44 – Rahman mound 1, gr. 5; 45 – Smeeni mound 1, gr. 15; 46 – Smeeni mound 1, gr. 16; 47 - Blejoi III, gr. 1; 48 – Vetrino-1 mound 34, gr. 3; 49 – Vetrino-1 mound 34, gr.4; 50 – Vetrino-3 mound 1, gr. 4; 51 – Vetrino-3 mound 1, gr. 5; 52 –

Vetrino-3 mound 1, gr. 1; 53 – Vetrino-3 mound 1, gr. 3; 54 - Poruchik Geshanovo mound 1, gr.1; 55 – Ovchartsi Barrow in the vineyard, gr. 3;; 56 – Beli Bryag mound 5, gr. 3/2; 57 - Sarretudvari Örhalom mound 1, gr.9; 58 - Sarretudvari Örhalom mound 1, gr. 10

Class C consists of 58 or 59 (Map 4) burials, and they mostly seem to be present in the Ukraine. Although, the number is biased due to the larger number of burials, which are in this area. Vojlovica "Rafineria Nafte" mound grave 1 is included in class C in Supplementary table 1 but has been left out of the analysis due to the unclear indications of ochre. Since there is no mention of ochre in the articles, we cannot be sure, whether it should be included in class D instead. Blejoi III gr. 1 has been analyzed in both class C and class D since the position of the deceased is unclear. It seems that the individual is slightly crouched, although the torso could have also been laying on the back (Frînculeasa *et al.* 2017: 37).

The most dominating deviating factor is yet again the orientation of the individuals (46 out of 58 burials, or around 79%). About half of the total (33, or 60%) contain individuals in crouched or slightly crouched positions, while in some burials the position is unclear. One deceased in Mustaevo V mound 1, grave 1, is laid on the stomach, which in general is a very unusual position for the dead in Yamnaya burials (Morgunova 2014: 36–37; Frînculeasa *et al.* 2015). 27 of the burials possess both deviating factors (crouched on either left or right side with a different orientation than east to west or west to east). Compared to style B burials, crouched individuals seem to appear as early as 3109 BC, which would mean that crouched burials already existed at the same time as type A burials. However, this date had been obtained from the Semenovka barrow 11, gr. 6 from a wood sample and analyzed in the Kiev laboratory. There are potential flaws in this date, as the sample could have been influenced by the old-wood effect. The date is also unreliable due to the difficulties emanating from the analysis of the samples by the Kiev laboratory.

Once again, the orientation seems to be the most dominating difference in class C burials. The deviations are again very small, and they do not seem to be affected by the region these burials were constructed in. We cannot be sure, why ochre or organics are not present in some of the class C burials. Either these elements were simply omitted during the construction of the graves, or they were not recorded during excavation or they have not been preserved. Anyhow, one must consider these traits when assessing the burials, as they could also be an indication of changes happening in the burial style.

Class C burials seem to have a wide range of dates from 3200s to 2300s BC, which would indicate that these changes were contemporary with the class A burials, although class C burials seem to have 2 peaks at 2800 calBC and 2400 calBC (fig. 6). In this case these could be some local traits getting mixed with the Yamnaya burial styles. This result could also be obtained, if burials were disturbed by robbers or animals, and archaeologists were not able to retrieve all information from these graves. However, one must be careful, when analyzing these dates, because most of the burials have been dated in the Kiev laboratory, which has been consistently producing dates that are too early (Goslar *et al.* 2015). Moreover, some of these dates have most likely been affected by old-wood effect (like Semenovka mound 11, grave 6). The second peak for this class seems to be flawed, since it represents the dates obtained from the Kiev laboratory, which, as expressed earlier, are unreliable.

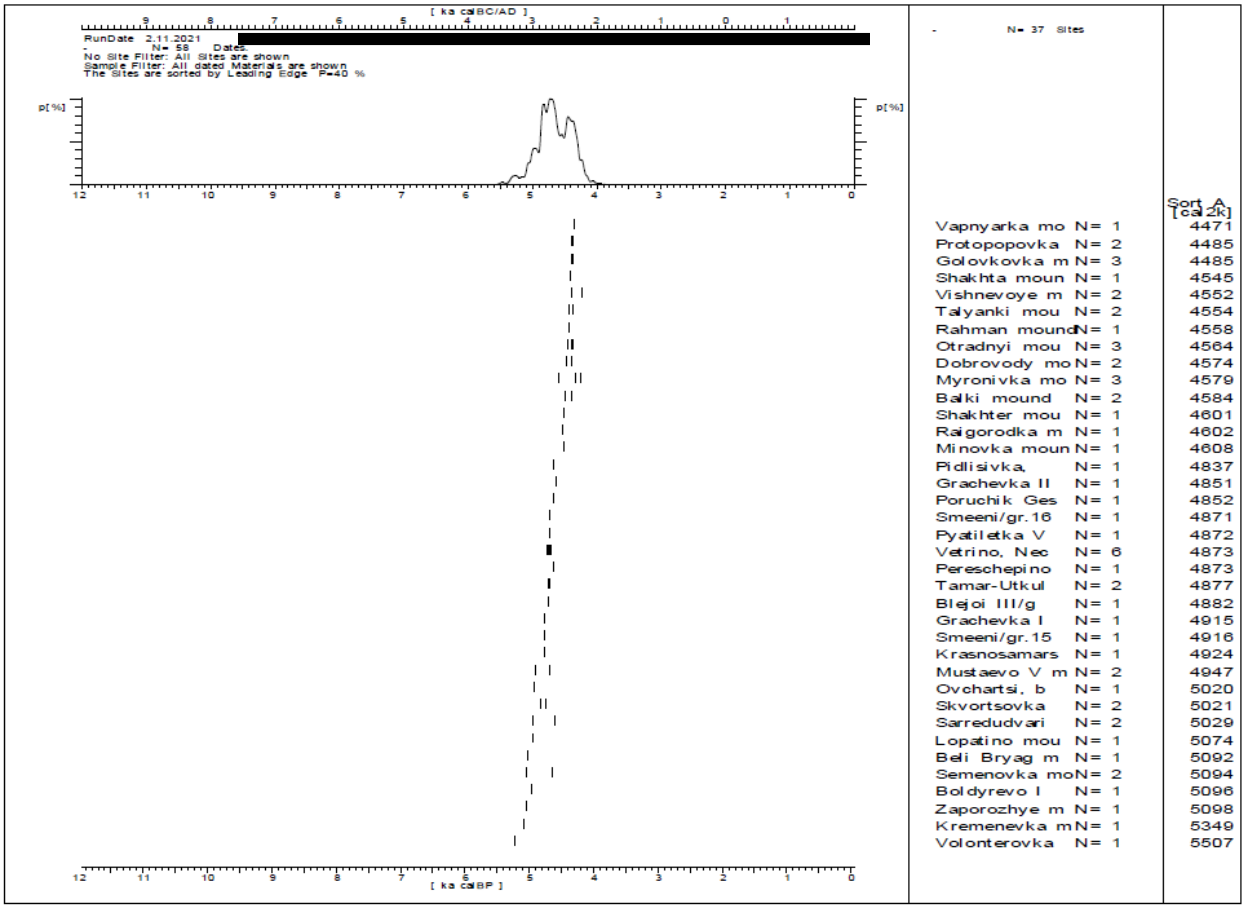
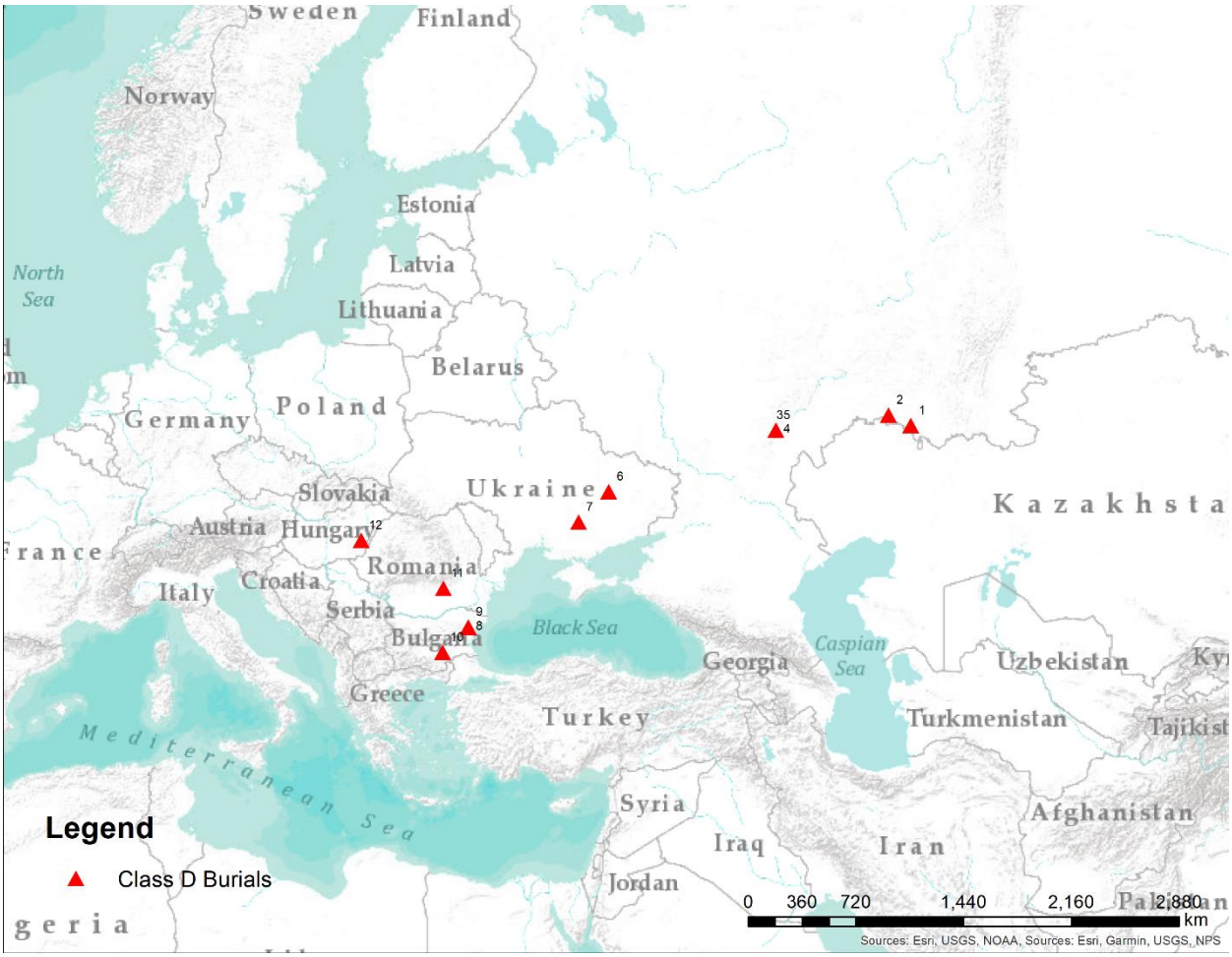


Figure 6. Chronology of type C burials. Produced in CalPal (Weninger & Jöris 2006).

4.4 Basic statistical analysis of the burials: examining the traits of class D burials

Class D contains the least burials (only 12), and most of them seem to be in Russia. This is once again due to the bias in the number of sites. These burials are missing all the traits that could be recognized in class A burials. One could say that these burials would be the farthest away in their classification from a Yamnaya burial, although in publications they have been assigned to this cultural entity.



Map 5. Class D Burials. 1 - Nizhnyaya Pavlovka V mound 1, gr. 2; 2 - Mustaevo mound 8, gr.2; 3 – Panitskoe 6B, gr.6, ind.2; 4 - Panitskoe 6B, gr.6, ind.1; 5 – Panitskoe 6B, gr. 7; 6 - Pereschepino mound 1, gr.6; 7 – Shakhta 22 mound 2, gr.6; 8 – Vetrino-3 mound 1, gr.7; 9 – Vetrino-3 mound 1, gr.9; 10 – Beli Bryag mound 5, gr. 3/1; 11 - Blejoi III, gr.1; 12 - Sarretudvari Örhalom, gr.4

From Map 5 one can see that class D burials are located all the way from the Orenburg region in Russia to sites in Romania and Hungary. An explanation as to why these burials are

defined as Yamnaya could be related to the stratigraphy of the mounds (Mimokhod 2009: 49–52, Morgunova 2014). Some of the burials, like in Panitskoe 6B, gr. 7 are poorly preserved, which makes attribution difficult. Moreover, they have been dated with radiocarbon, and based on the stratigraphy and results from radiocarbon they have been assigned to the Yamnaya culture (Mimokhod 2009). In this case, however, we cannot be certain if these graves really belong to the Yamnaya culture, as we do not see any traits that are specific to their burial custom. These could well be local burials that have been constructed using influences from the Yamnaya or local tradition that adopted some of the Yamnaya traits. As mentioned above, most of these graves are badly preserved, which means that we cannot classify these burials into a category, as we do not know whether the graves had organics or ochre, or whether the burials were in a certain position. However, in the burials that still have an indication of how the individual was laid, the deceased were mostly crouched (7 out of 12 burials). Blejoi III, grave 1 has been added to list D as well, since it is unclear, whether the burial is supine or if it is crouched. Therefore, it has been analyzed twice in the class C and in class D, to see, what kind of outcome it creates for both burials. The crouched burials, as in the case of type B, are clearly later than the supine burials of A type. This has also been observed stratigraphically as well (for example, Frînculeasa *et al.* 2017: 74–77).

While analyzing the radiocarbon dates and the location of the map, one cannot find any significant connections to a spread of a new burial tradition or changes in the Yamnaya custom. The burials seem to appear steadily in almost every part of the territory of Yamnaya influence in certain time periods. The type D burials have a peak of around 2800 calBC (fig. 7), which corresponds to the existence of type A and type B burials as well. What is clear, is that the burials from Hungary and Romania are clearly younger compared to those situated in Russia. If we would assume that these burials indeed belong to the Yamnaya culture, we could potentially identify a direction that they were moving from. The dates in the Ukraine seem to be misleading (for example, Shakhta 22 mound 2, gr. 6 being too young to be considered belonging to Yamnaya, with a median of 2384 calBC), so the situation there is becoming more unclear.

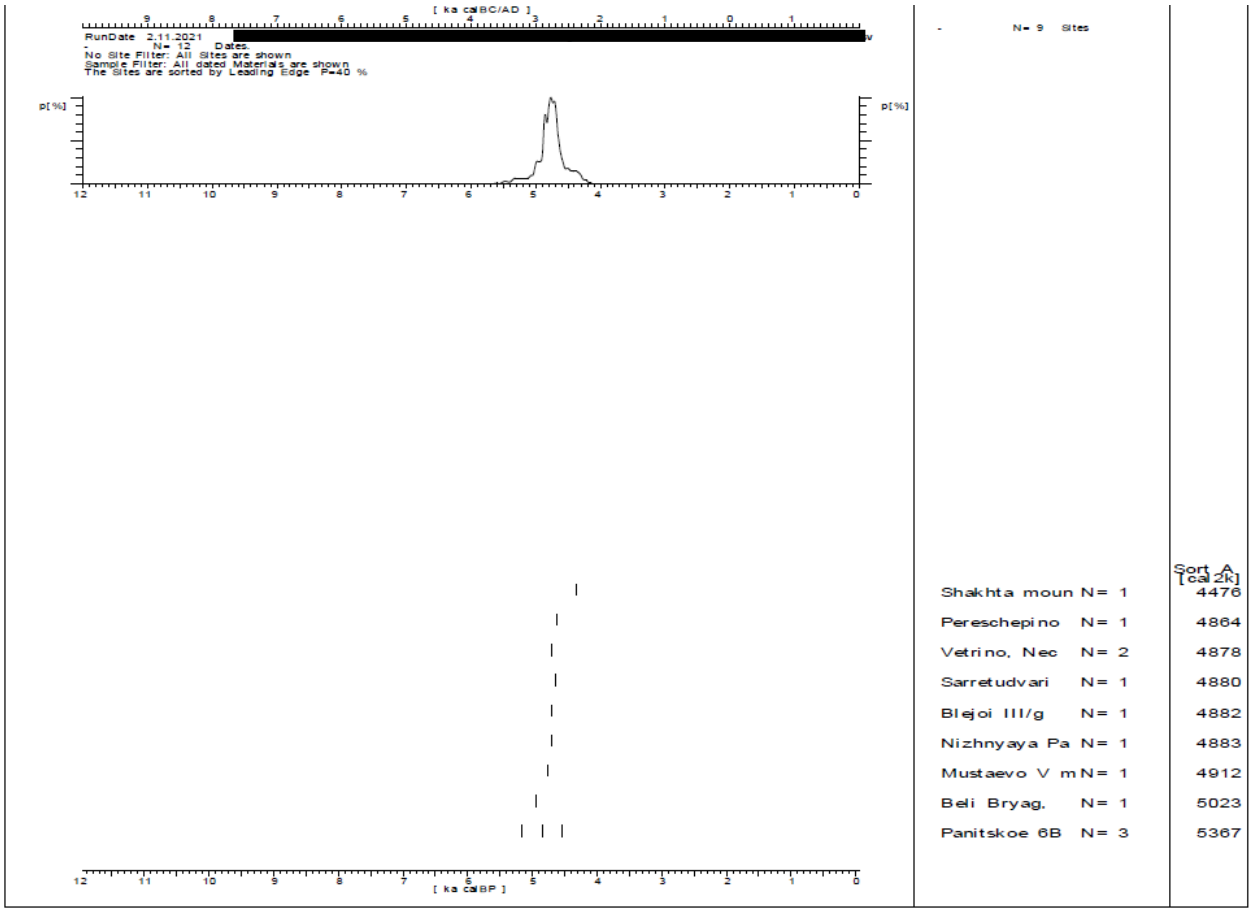


Figure 7. Chronology of type D burials. Produced in CalPal (Weninger & Jöris 2006).

4.5 General conclusions about changes in traits

In chapter 4, a brief overview of all burials from different classes has been given. Some simple statistical analyses have been provided to give an understanding of how these classes are spread on the map and which traits are most commonly missing. Unfortunately, with the situation related to the Kiev laboratory dates and the traits steadily missing from burials on every territory and throughout the whole period of the Yamnaya culture, one cannot say for sure, if the customs changes in a certain time gap. However, what is clear, is that crouched burials appear much later compared to the supine burials of type A. Both seem to be appearing steadily after, and it does not seem that one variant of placing the deceased is taking over the other, but both are used on all territories.

The BarCharts also indicate that graves of C type seem to peak slightly later than the rest of the groups. The second peak in fig. 6, however, is clearly flawed, as it is too young to be considered true. This is due to most of the dates in the C group had been analyzed in the Kiev laboratory, which has produced consistently erroneous late dates, influencing the general perspective of the appearance, and spread of the Yamnaya culture. Here, the BarCharts have been provided to give a general overview of the sites and how they had been originally dated. These graphs also provide an overview on the problem that researchers are currently facing, with too few dates being correct and reliable. Although the Kiev dates are included, the BarCharts give a good general summary of the chronology of various sites and how they are situated in the graph among other locations analyzed in this study.

Overall, it seems that the practices typical for Yamnaya graves are preserved in type A burials, which extend on the entire duration of the culture. However, at the same time graves that have differences in the burial ritual exist at the same time and they deviate from the standard ritual in all regions and during all time phases. This could be explained by interactions with the local communities or a local specialization of the ritual. Orientation and the position are altered the most, while organics and ochre pose some problems, since we cannot know for sure, whether they are being left out of the burials intentionally, if they have not been recorded in the reports or if they had been destroyed by animals and grave robbers. In relation to orientation, it could be possible that the Yamnaya were burying their deceased using a certain landmark or movements of celestial objects. Slight deviations from the traditional east to west, or west to east orientation could be due to seasonal changes. These ideas have recently been expressed by K. Wentink (2020), and the same thought could also be applied to Yamnaya.

Some of the graves had been identified as Yamnaya based on the stratigraphy of the kurgan and their radiocarbon dates. However, their relation to this cultural entity is unclear, as they do not possess any of the traits characteristic to the Yamnaya culture. For example, Sarredudvari Örhalom gr.4 (Dani & Nepper 2006) and Vetrino graves could well be local burials. Alexandrov *et al.* 2021 have assigned some of the Vetrino graves as to belonging to local Eneolithic cultures, mainly to the Usatovo culture (Alexandrov *et al.* 2021: 12–13), although many of them seem to have a lot of similar characteristics to the type A burials (except the position), like for example, feature 2 from Vetrino-2 mound 7. Usatovo and Yamnaya horizons seem to appear simultaneously and have

similar characteristics, but the Usatovo culture has a close connection to the Tripolye settlements. David Anthony suggests that Yamnaya moved past the Usatovo territory into the Danube valley, establishing their livelihoods there (Anthony 2007: 361). This could indicate that perhaps these cultures had a close connection to each other, and possibly were influencing each other's burial customs and social structures. However, this theory is contradicted by Igor Manzura, who states using radiocarbon data that the Usatovo culture existed in the middle of the 4th Millenium BC and only lasted for about 250-300 years (Manzura 2020: 75–76). This would imply that the Usatovo culture would have seized to exist way before the Yamnaya appeared in the Ukraine and Bulgaria

Here, the claimed Usatovo burials have been included in various categories, which are based on the definition of the Yamnaya culture. For example, Vetrino-2 mound 7, gr. 1 has been assigned to Usatovo, although in the thesis it has been classified as to belonging to B category. Is this a local grave displaying traditions of the Usatovo burial ritual, or a Yamnaya one influenced by the already existing local burial customs of the late 4th millennium BC with roots in the north-west Pontic steppe? One cannot know for sure, and these kinds of problems need further examining, before making any certain claims over the cultural association of the burials.

5. Analyzing the radiocarbon dates

5.1 Analyzing the comprehensive dataset

The aim of the thesis is to create 2 models with Empirical Baeysian Kriging, with which one could compare the reliability of the obtained radiocarbon dates. For this, a full-scale quality assessment will be made, especially for the audited dataset. Some of the outliers and dates that exceed the mark of 3500 BC had been eliminated prior to creating the Kriging model. The date of 3500 BC was established based on Rassamakin 2013 and Wang *et al.* 2019, which cap the first appearance to Yamnaya to 3000BC and 3300BC respectively. The date ranges below 3500 are realistic, as they do not imply that the dated objects or samples belong to 3500 BC, but rather that they are younger than that. Dates over 3500 BC, however, are not realistic anymore since there are no agreements on an earlier start to Yamnaya than 3500 (Anthony 2021; Szmyt 2021). The boundary for the end of the Yamnaya culture had been set to 2400, as it transitions to the Catacomb culture during that time (Kaiser 2019). This boundary is not a definitive end of the Yamnaya culture, but rather a suggestion of a date, to which we can attribute the gradual disappearance of Yamnaya

graves and the appearance of Catacomb culture graves in its stead in certain regions. The boundaries help distinguish the definitive Yamnaya graves from the Eneolithic graves and create a framework for the analysis of the thesis.

When reflecting upon chapter 4, one can notice that it is difficult to trace the disappearance or the change of a certain trait in Yamnaya burials on a chronological or a regional scale. However, the most visible difference, which can be related to time, is the altering of the position of the deceased. Chronologically, crouched burials appear almost a century later than supine burials, and they also peak at around 2700 calBC (fig. 8), whereas supine burials are more numerous during 2900-2800 calBC (fig. 9). This is the reason why applying Empirical Bayseian Kriging to supine burials would make more sense if one was to look at the initial migration of the Yamnaya communities.

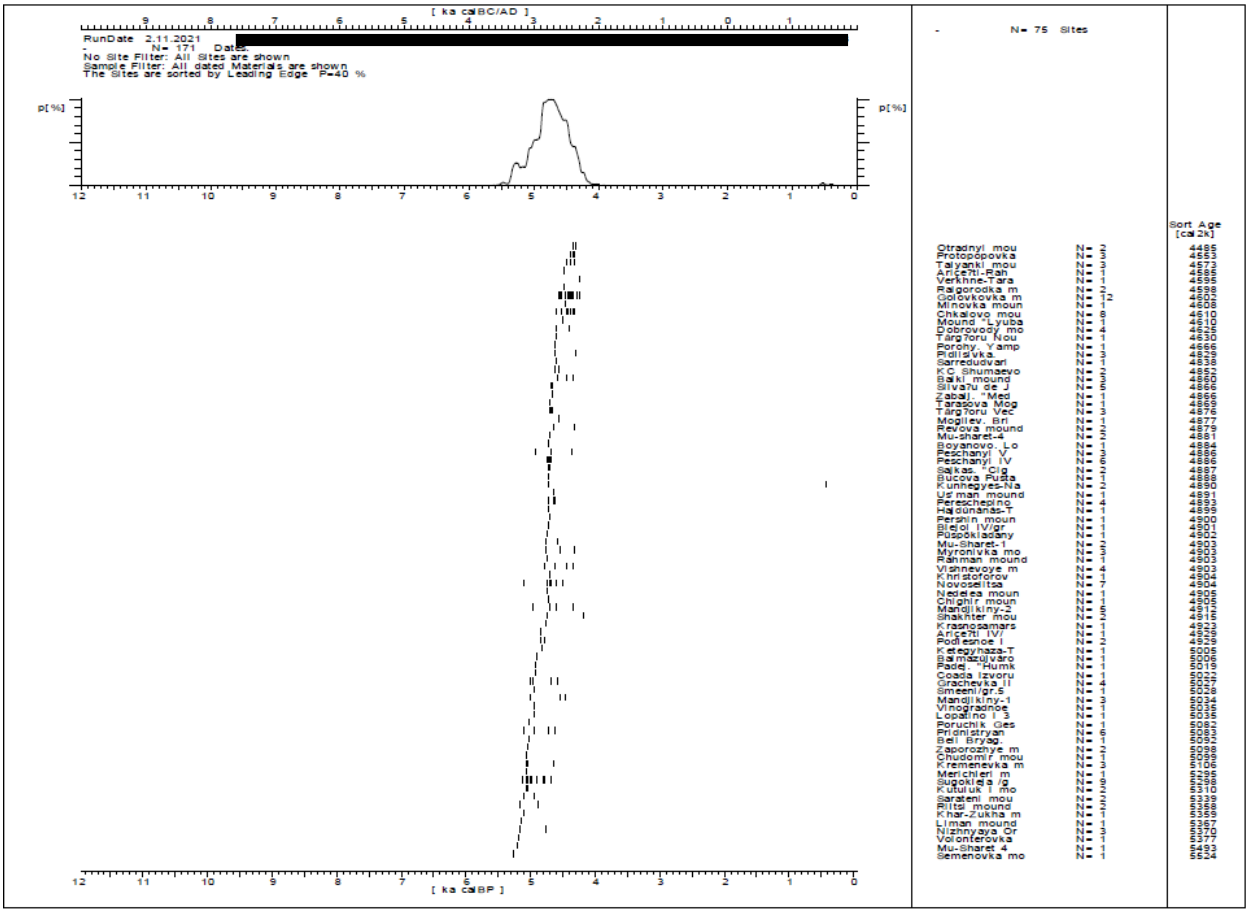


Figure 8. BarChart of supine burials.

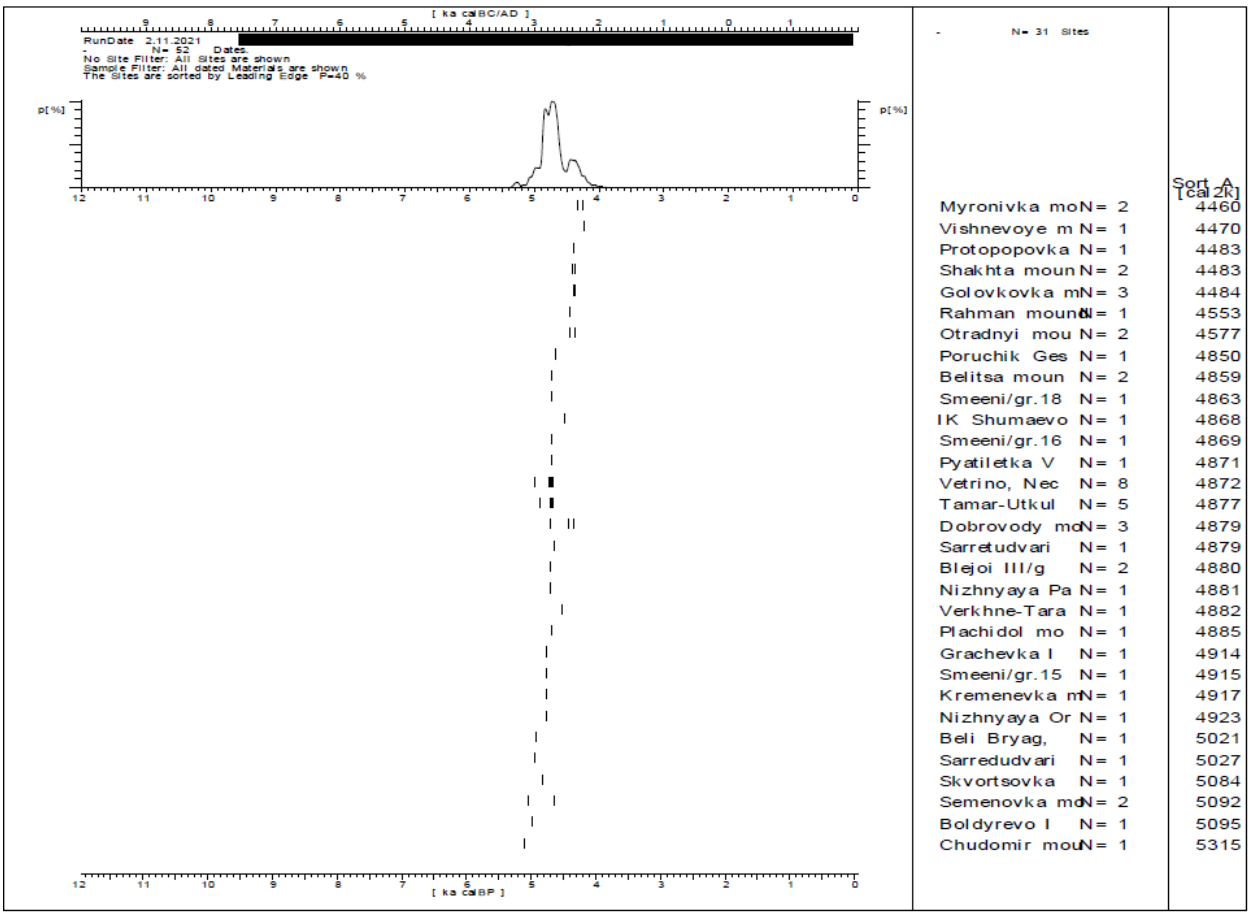
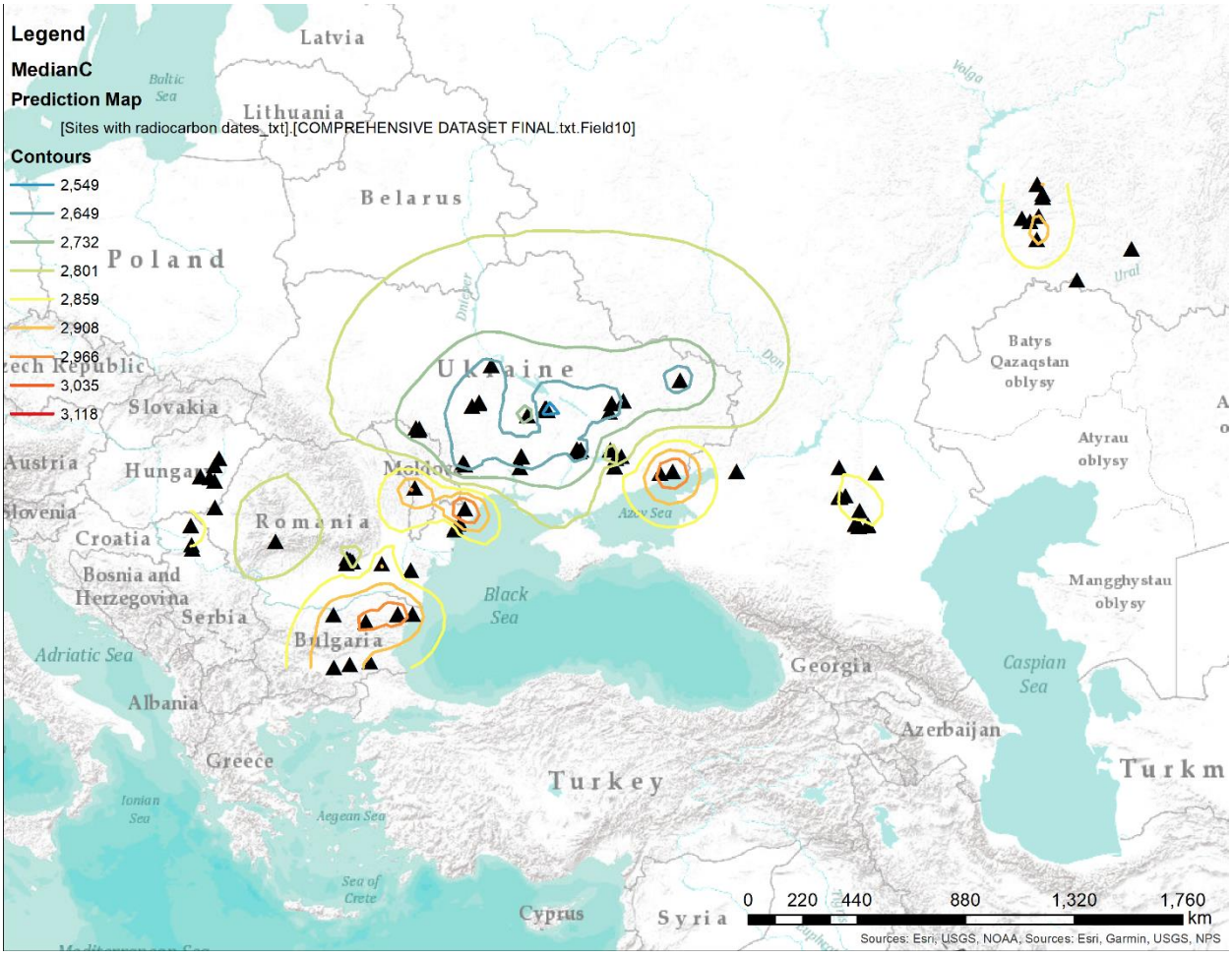


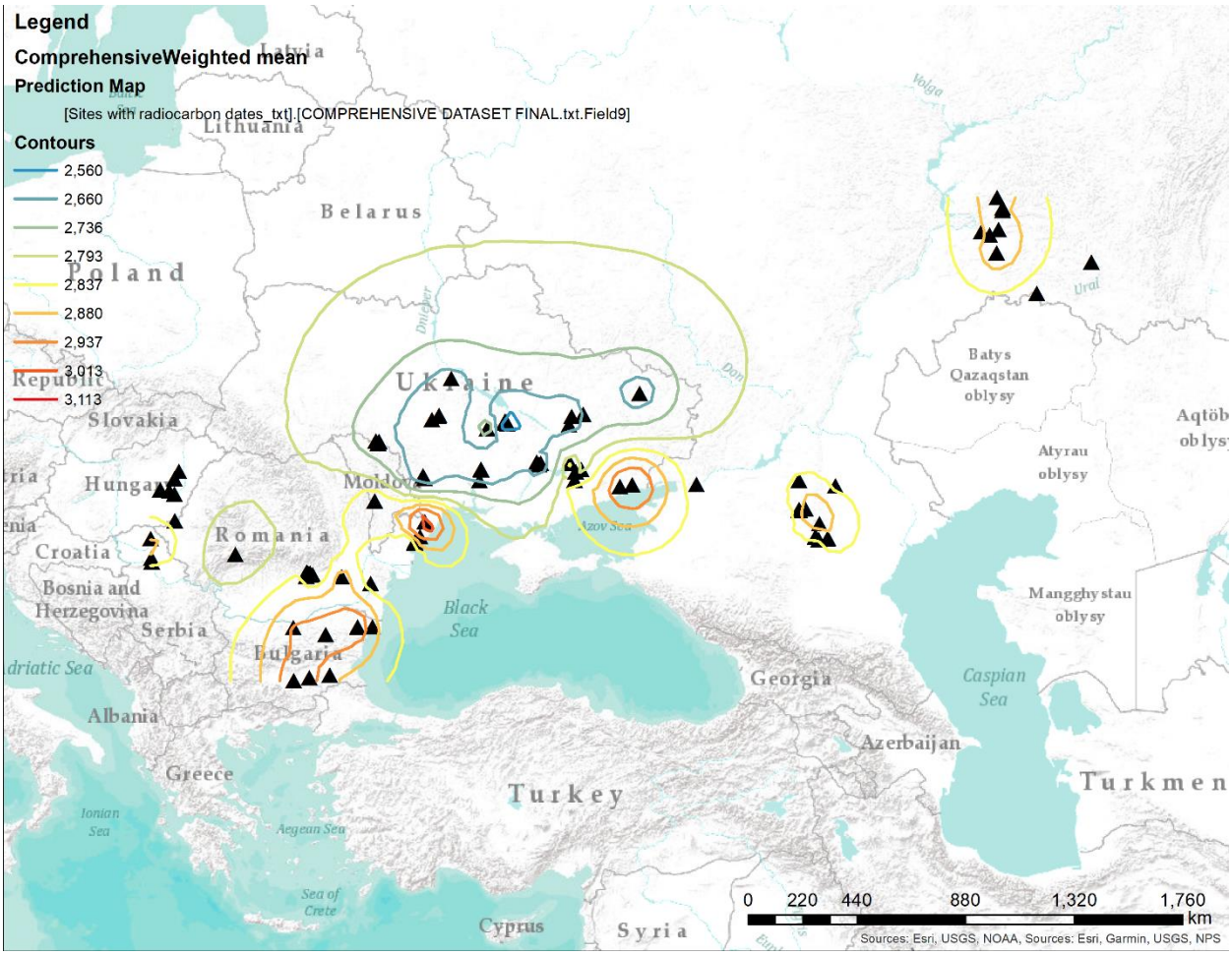
Figure 9. BarChart of crouched burials.

Based on these observations the following maps were created (Maps 6 and 7). One of them displays the spread prediction based on median values, extracted from the OxCal analysis, while weighted mean values were used in the creation of the second map. A total of 129 dates were used from 97 sites. Those dates that are marked in red are outliers given by the OxCal 4.4 (Bronk Ramsey 2021) programme (accordance with set parameters is under 60%), and they will be eliminated from further analyses (Supplementary tables 5 and 6). The dates have been analyzed with the *Tau_Boundary*-function according to their location on the territories of the modern countries. Moreover, the limits were set according to the highest and lowest dates in some countries (Romania) with some overspill gaps, while in other countries (Russia and Ukraine) the limit had been set to the assumed starting and ending dates of Yamnaya (i.e. 3300 and 2600). The dates will become outliers within these limits if they do not have the required accordance with the other values.

As a result, the given weighted mean values and proposed medians were gathered into an excel from the OxCal programme. These values serve as the main factors for the Kriging analysis. Since the basis for them is different, the maps differ slightly, but some similarities can be found while analyzing both. The dates in the comprehensive dataset have not been quality controlled, which means that the results produced by the Kriging analysis are very biased. One must consider aspects like old-wood effect, reservoir effect, contamination, and false results from certain labs, which all affect how the expansion is presented. Some sites have also a set of dates, from which the oldest one was taken to keep the consistency in the dataset. This methodology was also followed by Brami and Zanotti (2015) in their analysis of the spread of farming during the Neolithic period.



Map 6. Isochrones produced by Empirical Bayesian Kriging using median values provided by OxCal. Dates used have not been quality controlled.



Map 7. Isochrones produced by Empirical Bayesian Kriging using the weighted mean value provided by OxCal. Dates used have not been quality controlled.

The maps 6 and 7 show slight differences in the distribution of the isochrones. Firstly, the dates differ slightly: the date distribution posed by the weighted mean value is older compared to those provided by the median value. Moreover, the supposed centers, where older dates are presented, are shown more clearly when using the weighted median values. What is clear, is that the oldest dates are concentrated around the Volga-Ural region, Caucasus, Volonterivka and Kremenivka, Semenovka and the Moldovan mounds and in Bulgaria. Some of these dates, however, are most likely false and do not represent the origins of the Yamnaya culture. In the case of Semenovka and Moldova, old-wood effect is most likely affecting the samples, while in Bulgaria the possibility of the reservoir effect producing older dates should not be excluded. Dates for Volonterivka and Kremenivka are both produced by the Kiev laboratory, which is not reliable, as discussed throughout the thesis.

The most interesting aspect of both maps, however, is how the dates inside of Ukraine are modelled. There is a clear consistency in the dates becoming younger and younger the more one moves inside of the territory. This is explained by the fact that most of the dates collected for the Ukraine are produced in the Kiev laboratory. The samples are clearly analyzed incorrectly. For example, if Yamnaya moved in from the east, as has been suggested by many researchers, it would be impossible that they did not erect mounds in the Ukraine while they were moving to the west. With the dates being younger than assumed initially, the Kriging creates a sinkhole in the middle of the territory, where Yamnaya are known to have had influence. Therefore, analyzing the original path of the Yamnaya expansion is becoming difficult, we are missing a huge chunk of data, which would clarify the relation between the chronologies in Russia and in Romania, Bulgaria, Moldova, Hungary, and Serbia.

Another aspect which is clear from the produced maps, is that the dates in Romania, Hungary and Serbia are clearly younger compared to sites in Moldova, Semenovka and Russia. This could be explained by the Yamnaya moving into these territories much later, and this could in turn indicate the direction of the expansion. However, from this map the nature of the spread is still unclear. The isochrones have very small gaps between each other (some isochrones differing only by some decades), which indicates a very rapid, explosive expansion. This has also been suggested by David Anthony (2021). The next step would be to find out, what could have caused such a fast expansion. The problem here lies in how we perceive Yamnaya: whether it is the people moving in and replacing the local population completely, or whether the locals are adopting the Yamnaya burial style and integrating it with their own. One can expect that this process did not happen in the same manner everywhere and that different scenarios involving a whole range of events, violent and peaceful, were happening in different regions. However, to confirm this we need more genetic and high-quality radiocarbon data, especially from the Ukraine.

5.2 Categories for the audited dataset

Some of the dates had been excluded from the comprehensive dataset, meaning that certain quality assessment had been conducted already. However, the comprehensive dataset includes all the dates one could find from various sources. These dates are subject to all effects (like old-wood effect, reservoir effect), contamination and discrepancies that various laboratories might produce.

These notions will only be considered when assessing the audited dataset. A total of 129 dates were gathered for the comprehensive dataset (Supplementary table 5). Most of the samples were taken from human bone or wood.

The dates for the audited dataset were assessed according to quality divisions specially devised for the thesis (table 2). First, the uncertainty had been limited to ±60, so that gaps in radiocarbon date ranges are as small as possible for the data to be as reliable as possible. After that the dates were sorted into categories based on qualities. Quality A includes all dates that have been produced by AMS, since they are the most reliable ones and undergo a large amount of pretreatment for the sample to dating to be accurate (Brock *et al.* 2010). Samples from wood and human bones, which had been discovered in the context of the burials, are also included in this division. Quality B and Quality C are equal, as they consider different effects affecting the dates. Quality B has wood samples that fall in the proposed timeframe of the Yamnaya culture, but which could potentially show signs of old-wood effect influencing the dating. Quality C, on the other hand, considers the reservoir effect, which could be visible in some of the human bones. The reservoir effect is not widely studied in relation to the Yamnaya culture, but at least some of the samples gathered from the Caucasian steppes could be showing some signs of it (Shishlina 2008; Shishlina *et al.* 2014).

Quality D includes all the dates that clearly do not belong to the proposed period of the Yamnaya culture and dates that are not reliable. A problem rises especially when dates produced by the laboratory in Kiev are considered. Several studies analyzing the quality of Kiev lab dates have been conducted to determine the reliability of these dates. The results of the Kiev lab dates are usually scattered and do not correlate neither with the dates produced by other laboratories (like Oxford or Poznán) nor with the cultural contexts and the periods of certain cultures (Goslar *et al.* 2015). Thus, the dates from the Kiev laboratory pose a problem in assessing the audited dataset for the Yamnaya culture. The dates have been (at least partly) included in the audited dataset but reducing them completely from the analysis brings the total of high-quality dates to around 52 (Supplementary table 6), which is nearly not enough for analysis, especially since these dates are scattered in Romania, Hungary, Serbia, Bulgaria, and Russia, leaving a large gap in spatial data in Ukraine. This means that for spatial analysis, the Kiev dates that are somewhat

reliable must be used for Empirical Bayesian Kriging to get a correlation between Russia and the sites to the west of Ukraine.

Table 2. Quality criteria for the radiocarbon dates.

Quality A	Quality B	Quality C	Quality D
Criteria: AMS-dating, samples from the context (wood, human bone)	Criteria: samples from wood, which might have been affected by the old-wood effect, making the dates older than they are. Carbonated wood	Criteria: human bones from graves. Reservoir effect might be affecting the dates (if the humans consumed large amounts of fish).	Dates affected by contamination or producing discrepancies when re-assessed between various labs. Dates produced by the Kiev laboratory

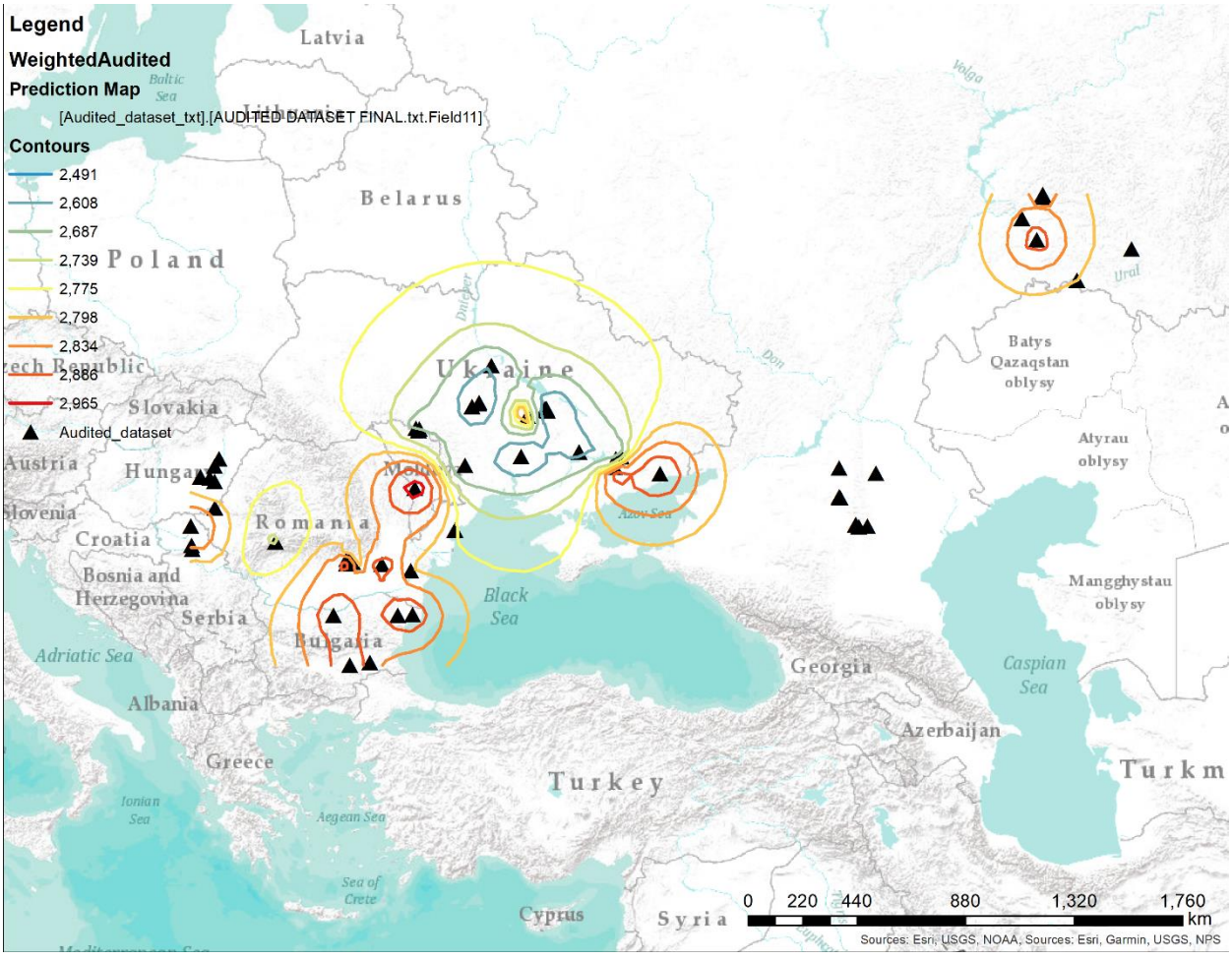
5.3 Analyzing the audited dataset

After discarding the dates that did not fill up the criteria proposed in subchapter 5.2, the dataset was left with a total of 52 dates. Some additional dates from the Kiev laboratory were added to create a correlation between the sites in Russia and countries to the west of the Ukraine. This means that most of the dates in the audited dataset are unreliable, but one can look past that in the analysis, since the main conclusions are derived from the samples analyzed by high-quality technology.

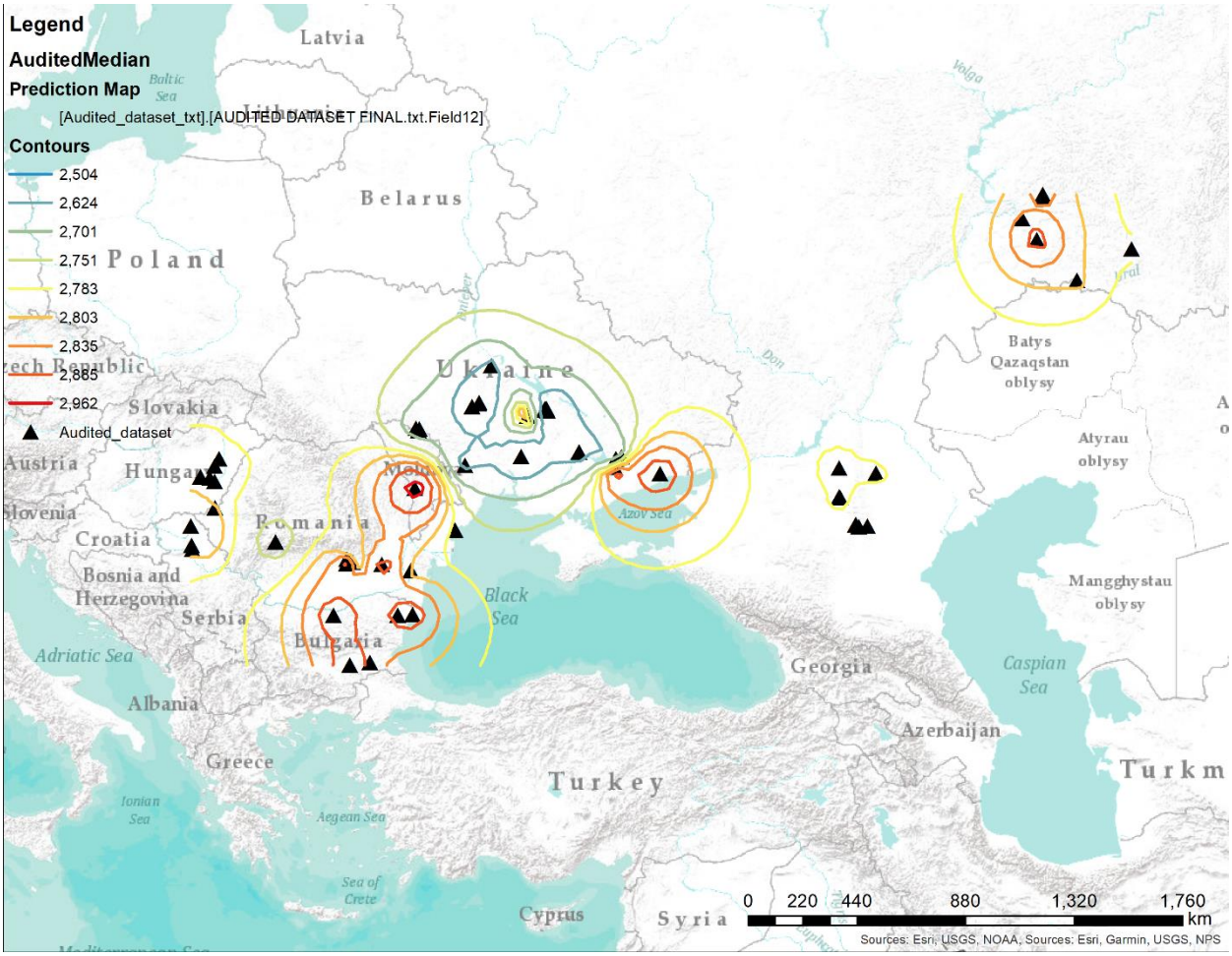
Most of the usable dates are produced from sites situated in Russia, Romania, Hungary, Bulgaria, and Serbia. There are a total of 8 dates, which are gathered from the Yampil region on the border of the Ukraine, and some older sites like Tarasova Mogila and Vinogradnoe. These dates possessed the criteria expressed in table 2: they do not seem to be affected by reservoir or old-wood effect, they were not produced by the Kiev laboratory and they were not contaminated and seem to correlate with the assumed chronology of Yamnaya. Some of the dates used for the comprehensive dataset were excluded, even though they were produced in laboratories with high-quality technology. These include dates from Merichleri, Riltsi 264 and Chudomir in Bulgaria, and Mandjikiny-2 11, gr.3. The dates from Bulgaria are clearly way too old and do not correlate with the dates produced in Romania, since the Yamnaya had to first come through

Romania to Bulgaria. This could be explained by the reservoir effect. The date from the Russian site of Mandjikiny had been gathered from a pin made of animal. While animal bones are a more reliable source for radiocarbon dates, the pin poses a problem with dating, as we do not know how long it had been used before it was deposited in the burial (Shishlina *et al.* 2014: 114).

The same procedure with analyzing the dates in OxCal with the *Tau_Boundary*-function was conducted, and outliers were eliminated from further analyses. The weighted mean value and the median proposed by the programme were recorded in Excel and used with the points in ArcGIS by transforming the data into a .txt file and joining it with the dataset in the GIS-programme. Empricial Bayesian Kriging was once again used, and both the median and the weighted mean value were used to create maps 8 and 9.



Map 8. Prediction made by Empirical Bayesian Kriging. The weighted mean value from the audited dataset was utilized for this map. Dates used in this map have been quality controlled.



Map 9. Prediction made by Empirical Bayesian Kriging. The median value from the audited dataset was utilized for this map. The dates used for this map have been quality controlled

The maps show a completely different expansion trend compared to the comprehensive dataset. What is interesting, is that the Moldovan dates are very old compared to all the others. The map models a spread from these kurgans to the west. This could be either due to the Yamnaya burial ritual arriving to Moldova at the same time as it started to spread in the Volga-Ural region, or the dates are false and display old-wood effect. A similar problem can be observed with the proposed center around the sites of Volonterivka and Kremenivka in southeastern Ukraine. Unfortunately, the dates there had been produced by the Kiev laboratory, so a starting center there could potentially be false.

The modelled datasets also show a small center in the middle of the Ukraine, where the burials are predicted to have been constructed before 2800 calBC. This center seems to come from some of the better-quality dates from this territory. What is clear is that based on this center the dates in Ukraine should be younger compared to those in Volga-Ural region. This could indicate the potential direction of the Yamnaya expansion. Considering the dates to the west of the Ukraine, which are also younger than those from the Volga-Ural region, it is possible to propose that the Yamnaya were moving in from the east, with an originating point possibly situated along the Volga. Looking at the isochrones, the possible starting date for the Yamnaya expansion could be around 3100-3000 calBC, after which the expansion proceeded in a very fast and explosive way all the way across Ukraine to Hungary and Serbia.

From both maps it is possible to see that the expansion happened rapidly. The difference between the isochrones is spectacularly small, which means that in a matter of 200 years the Yamnaya had already expanded on the whole territory considered in the thesis. If the deceased in the burials analyzed here are all coming from the eastern parts of the North-Pontic steppes, this would mean that a huge mass of people were involved in the expansion. However, such a rapid expansion would be impossible if we assume that the amount of people involved in the expansion was small. This would mean that a more viable explanation would be that the local population were integrating and adopting the Yamnaya burial style. However, ifthe local population adopt it willingly or whether Yamnaya were imposing it on the locals is a mystery. It is possible that either the Yamnaya burial style came together with an ideology or religion that was attractive to the people, or that the Yamnaya people had some sort of dominating influence over the locals. However, since there is no archaeological record of violence happening during this period, this could suggest that the adoption of the Yamnaya burial ritual happened peacefully without any further conflicts between the locals and the migrants.

This theory needs further proof from the genetic side of research. If some of the locals were buried using the Yamnaya ritual, it would show in genetic data. This kind of research would give more insight into the processes that really happened during this period. There are already some examples (Beli Bryag, mound 5, gr.3, which is also integrated into this study), where some aspects of the Yamnaya ritual are visible, yet the ancestry of these individuals is local (Mathieson *et al.* 2018: Supplementary table 1). What is clear now, based on the

radiocarbon and archaeological data, is that the Yamnaya expansion was fast and explosive. Such speed could be explained by the locals adopting the Yamnaya burial style one way or another. The explosiveness of the expansion is derived from the number of people involved in it and considering how fast the spread happened and how many burials we observe, it would require populations of immense sizes. The general direction of the expansion is clearly from east to west, but the nature of the expansion is difficult to find out. The more probable suggestion would be that some of the people migrated into different parts of the steppe. They settled in some centers and the influence of the culture started to take root and spread among the locals. The idea of the centers comes from the fact that if the Yamnaya ideology had originated in the Volga-Ural region around 3100-3000 calBC and if we see Yamnaya burials already appearing around 2965 in Romania and Bulgaria according to the isochrones, the influence should also be coming from various places simultaneously. The distance is way too long for only one center of origin to be considered, which is why multiple starting points for the Yamnaya expansion could possibly be identified. However, to identify some clear centers we need more dates from the Ukraine that are accurate and produced with high-quality AMS technology. Moreover, the reservoir effect should be also studied, at least in some of the Bulgarian dates, because the dataset is getting obscured by all these problems explained in the thesis.

5.4 Conclusions for the results of the comprehensive dataset

The analysis of the comprehensive dataset does not unfortunately give any reliable information. However, we can identify some problems that are affecting the data, like the inconsistency produced by the Kiev laboratory dates and some uncertainties in the Bulgarian dates. One can also see that the expansion is clearly happening very rapidly, which can help with speculation over possible ways, how such an explosive expansion can take place. The most probable answer is that the locals are adopting the Yamnaya burial style, either due to it being attractive or due to the Yamnaya ideology being imposed on the locals. Certainly, there are also people moving deeper into the steppes, but the possibility of the deceased in the mounds to be only migrants does not seem plausible. It would require a huge amount of people to be able to spread so explosively in a narrow period, which leads to the conclusion that smaller groups of people possibly moved into different territories, and their lifestyle then was spread to other inhabitants.

What is also clear from the comprehensive dataset is that we need more high-quality AMS dates, especially from the Ukrainian mounds. However, before such dates are collected, archaeologists must clearly define, which burials are being classified as Yamnaya. Currently the inconsistency in the theoretical framework is causing confusion over this aspect. This in turn is a cornerstone for misleading and potentially false theories that must be revised over and over, once new data is starting to pour in. Once we know, which burials are clearly Yamnaya and especially, which ones are the earliest Yamnaya in a specific mound according to stratigraphy and the position of the deceased, a clear picture of the expansion based on radiocarbon dates can be constructed. To broaden the understanding of the events that happened 5000 years ago, researchers must also integrate other study fields, like isotope geochemistry and genetics.

Isotope geochemistry could be a very useful tool in further research, as scholars clearly need to examine the reservoir effect in closer detail. This is especially true, as there have been concerns raised about the dates being older than they are supposed to be already (Shishlina *et al.* 2014). We can also observe reservoir effect possibly taking place in the newer Bulgarian dates, however needs further investigations.

5.5 Conclusions for the results of the audited dataset

What comes to the audited dataset, while still being incomplete and full of uncertainties, it provides a clearer picture of the general direction and some insight into how the expansion possibly happened. It seems that the oldest dates are coming from the Volga-Ural region, which could be the original starting point for the Yamnaya burial style. The models provide some other centers, but one must treat them with caution, as in the case of Volonterivka and Kremenivka the dates are produced in the Kiev laboratory, while the mounds of Semenevka in Ukraine and Sărăteni in Moldova could be false due to old-wood effect taking place.

In the audited dataset the Romanian and Bulgarian dates are intact with each other, and they are older than those in Hungary and Serbia, while being younger than dates from Volga-Ural region, which means that the general direction of the expansions is east to west. The nature of the expansion is a matter of speculation, as again the gaps between the isochrones are very narrow, which indicates a very rapid and explosive expansion of the Yamnaya burialritual. This, however, cannot be explained just by the people moving to the west, as it would require an immense number of individuals for so many burials to be constructed in such a short period of

time. Therefore, the more plausible explanation for such a fast spread could be the local people playing a role in the events. Either the locals willingly adopted the burial style and the underlying beliefs, thinking of it as a better way to respect their deceased, or it was imposed on them by the migrants in a dominative way. However, since we do not have any archaeological proof for violence during this period, the first variant seems more likely.

To explain the expansion better, scholars need to integrate genetics into the study. If we find local ancestry in clearly defined Yamnaya burials, this could open a new door in the long debate over the nature of the expansion. Moreover, we could reconstruct the direction of the expansion with new dates from the Ukrainian samples, since the current ones are proving to be consistently incorrect, obscuring our understanding of the expansion and how it proceeded and which direction.

6. Conclusions and Further Research Opportunities

The questions raised in the thesis concerned the clear definition for the Yamnaya, analyzing the variations withing their burial style, reconstructing the chronology for the expansion using various methods and creating models that are statistically as correct as possible with the data currently available. All these questions have been answered in the thesis on some level, but some uncertainties remain. Unfortunately, more data is needed to create the most accurate picture of the Yamnaya expansion as possible and different fields of studies need to be included. More radiocarbon dates, especially from the Ukraine, more genetic data to prove locals being involved in the events and more insight into the reservoir effect are still required. These could be the next steps taken in the future research concerning the topic of the thesis.

What is clear from the analyses provided in the thesis, is that we need a consistent definition for the Yamnaya culture. Currently, the scholars are merging local burial styles with the Yamnaya one, which affects the understanding of the expansion, its origination center, and the period, during which it evolved. The definition used in this thesis is based on several factors and therefore by revising these aspects we can include and exclude burials using the traits in them. Not only does it make analyzing burials easier, but it also helps with creating various chronologies for the groups presented in the thesis. From the statistical analysis provided in chapter 4, we can see that supine burials appear earlier than crouched ones, which helps with

identifying the earliest graves. The other traits expressed in Table 1 seem to slightly deviate in burials during the whole chronology of Yamnaya, and there is no clear change in the burial ritual. Moreover, what comes to ochre and organic material, is that they are easily destroyed by grave robbers and animals, and identifying these traits is difficult and sometimes impossible for archaeologists. Sometimes, ochre is even failed to be registered in the final reports, as it could have mostly been in the fill or there was so few of it that it did not seem necessary for the archaeologists to document it. This complicates further the identification and classification of burials. Although, when creating bar charts for classes C and D, it looks like these groups peak at a different time compared to burials belonging to groups A and B, which might be an indication of the burials style changing. No regional or chronological patterns, however, were identified.

After completing the statistical analysis for the 4 groups created for the thesis, it was clear that the more plausible way to analyze the Yamnaya expansion is through supine burials of categories A and B, since they appear earlier than crouched ones. This conclusion was used as a basis for the comprehensive and the audited models, presented in chapter 5. While the comprehensive dataset gives an indication to the problems we are facing with radiocarbon dating of the Yamnaya burials and provides an insight to the speed at which the expansion happened, the audited dataset shows a possible direction and helps with the speculation over the nature of the expansion. The conclusion from both models is that the expansion was a rapid and explosive event. Moreover, both models show the inconsistency of the dates provided by the Kiev laboratory. The dates are clearly too young, which is why we need more radiocarbon samples from burials in this territory. These new samples should be analyzed with high-quality AMS technology in different laboratories independently to provide a more secure dataset.

The comprehensive dataset provided insights into various effects that are influencing the reliability of the samples. First, the reservoir effect should be studied consistently, while analyzing the dates. Reservoir effect has been a topic raised recently in relation to the dates from the Caucasus region, and from the dataset of the thesis it seems that the samples taken from Bulgaria should be revised as well. In some samples the old-wood effect can also be possibly observed, like the dates coming from the burials of Sărăteni in Moldova. Once these possible influencing factors are revised, we should get a clearer chronology of the expansion.

The audited dataset creates a model with several observations that answer questions posed in the thesis. First, the originating place of the Yamnaya burial ritual. In the models it is visible that the oldest dates, which are reliable for the most part, are coming from the Volga-Ural region. In the thesis this location is proposed as one of the more probable starting points for the Yamnaya expansion. However, considering the speed of the expansion there are most likely multiple centers, to which the Yamnaya communities migrated. From these places the burials style started to spread into many directions. If compared to some models that have been explained in subchapter 2.2, it seems that the original idea of a wave sweeping over Europe, expressed by Gimbutas, does not correlate with the radiocarbon data, since a wave radiocarbon dates would be consistently younger as one travels from east to west. However, the dates seem to be very close to each other, only differing in some decades. Instead, one could think of possible leapfrog events (Anthony 1990: 902–903). Some center that could potentially be visible in maps 8 and 9 are situated around Moldova and Romania, somewhere in eastern and middle parts of the Ukraine. From these initial leapfrogging events, the ritual started to spread rapidly across the whole territory. However, the centers provided here are hard to pinpoint exactly, because we do not possess clear radiocarbon data from the Ukraine. With new dates from this territory, it would be possible to identify these centers in the future.

Since it would be impossible for so many people to move the distance of more than 4000 kilometers in such a short period of time as proposed by the models, the more likely explanation for the speed of the expansion is that the locals are using the burial style as well, either due to its attractiveness and possible role as some sort of a higher ideology, or due to the Yamnaya people imposing their lifestyle and the ideology on the locals forcefully. There are no records of violent conflicts between the locals and the Yamnaya communities and this does not support the latter proposal, which is why the locals were most likely adopting the burial ritual willingly. However, further proof for this theory is needed from the genetical side, as we would require Yamnaya burials with local ancestry to be present.

The models explained here give a starting picture for the expansion of the Yamnaya culture. Combining this with data from other relevant fields, like genetics and isotope geochemistry, will broaden our perspective of the events happening 5000 years ago. The next steps for the results of the thesis are to revise some dates for reservoir and old-wood effect,

gather new dates in Ukraine and include additional information from genetic analysis. Another possibility is to compare the models provided with simulations of different expansional patterns. This would clarify how exactly the Yamnaya burial style spread across the territory and on which communities it had an influence. Combining all the results provided by the study fields expressed above would create a complete picture of the Yamnaya expansion, which we could then use to interpret the events happening 5000 years ago.

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SUPPLEMENTARY MATERIAL

SUPPLEMENTARY TABLE 1. Classification of the burials used for the thesis.

CLASS	**NAME OF THE SITE (mound/burial)**	**COUNTRY THE MENTIONED SITE IS SITUATED IN**
B, N-S Orientation	Târgşoru Vechi mound/gr. 2a	Romania
A	Târgşoru Vechi mound/gr. 9	Romania

B, no ochre	Târgşoru Vechi mound/gr. 10a	Romania
A	Ariçeşti IV/gr.2	Romania
A	Smeeni/gr.5	Romania
C, slightly crouched, SSE-NNW	Smeeni/gr.15	Romania
C, slightly crouched, no organics	Smeeni/gr.16	Romania
B, (slightly) crouched	Smeeni/gr.18	Romania
D, no ochre, crouched? , SW-NE	Blejoi III/gr.1	Romania
A	Blejoi IV/gr.1	Romania
A	Ariçeşti-Rahtivani mound 1/gr.1	Romania
A	Coada Izvorului/ gr.3	Romania
A	Rahman mound 1/ gr.1	Romania
C, crouched, orientation NW-SE	Rahman mound 2/ gr.5	Romania
B, no ochre	Silvaşu de Jos mound 3/gr. 1	Romania
B, no ochre	Silvaşu de Jos mound 4/gr. 1	Romania
B, no ochre	Silvaşu de Jos mound 4/gr. 1	Romania
B, no ochre	Silvaşu de Jos mound 4/gr. 1	Romania
B, no ochre	Silvaşu de Jos mound 4/gr. 1	Romania
B, no ochre	Nedelea mound 2/gr.1	Romania
A	Târgşoru Nou/ gr.2	Romania
A	Bucova Pusta/ Hügel IV	Romania
A	Ketegyhaza-Törökhalom mound 3/gr.4	Hungary

A	Kunhegyes-Nagyallashalom/ gr.14	Hungary
A	Kunhegyes-Nagyallashalom/ gr.18	Hungary
B, no ochre	Püspökladany-Kincesdomb/ gr.1	Hungary
A	Balmazújváros-Hortobágy-Árkus-Kettőshalom/	Hungary
A	Hajdúnánás-Tedej-Lyukashalom	Hungary
D, crouched, no ochre, no organics	Sarredudvari Örhalom gr.4	Hungary
C, orientation N-S and no ochre	Sarredudvari Örhalom gr.9	Hungary
C, crouched, no ochre	Sarredudvari Örhalom gr.10	Hungary
C, orientation NNE-SSW, slightly crouched	Poruchik Geshanovo mound 1/gr.1	Bulgaria
B, orientation SW-NE	Poruchik Geshanovo mound 1/gr.3	Bulgaria
B, slightly crouched	Plachidol mound 1/ gr. 1	Bulgaria
B, orientation SW-NE	Boyanovo, Lozianska Mogila/gr.14	Bulgaria
B, position unclear	Vetrino, Necropolis 1, barrow 34, f. 2	Bulgaria
C, orientation SSE-WNW, crouched on the right side	Vetrino, Necropolis 1, barrow 34, f. 3	Bulgaria
C, orientation SSE-WNW, crouched on the right side	Vetrino, Necropolis 1, barrow 34, f. 4	Bulgaria

B, crouched on the right side	Vetrino, Necropolis2, barrow 7, f. 1	Bulgaria
D, position unclear, organics unclear, orientation unclear	Vetrino, Necropolis 2, barrow 7, f. 6	Bulgaria
C, crouched on the right side, SE-NW orientation	Vetrino, Necropolis 3, barrow 1, f. 4	Bulgaria
C, crouched on the right side, orientation NE-SW	Vetrino, Necropolis 3, barrow 1, f. 5	Bulgaria
C, crouched on the right side, orientation NE-SW	Vetrino, Necropolis 3, barrow 1, f. 1	Bulgaria
C, slighly crouched on the right side, orientation NE-SW	Vetrino, Necropolis 3, barrow 1, f. 3	Bulgaria
D, slighly crouched on the right side, SE-NW, no ochre, no organiccs	Vetrino, Necropolis 3, barrow 1, f. 7	Bulgaria
B, crouched/position unclear	Vetrino, Necropolis 3, barrow 1, f. 8	Bulgaria
D, SE-NW, position unclear, no ochre	Vetrino, Necropolis 3, barrow 1, f. 9	Bulgaria
D, no ochre, crouched, no organics	Beli Bryag, gr. 3/1	Bulgaria
C, no ochre, no organics	Beli Bryag, gr. 3/2	Bulgaria
B, organics missing	Mednikarovo mound 2, gr.1	Bulgaria
B, no organics	Chernyova Mogila, gr. 4	Bulgaria
A	Merichleri mound 1, gr. 6	Bulgaria
A	Riltsi mound 260, gr. 1	Bulgaria
B, SW-NE orientation	Riltsi mound 264, gr. 4	Bulgaria
B, crouched on the right side	Belitsa mound 1, gr. 1	Bulgaria
A	Chudomir mound 1, gr.5	Bulgaria
C, no organics, no ochre	Ovchartsi, barrow in the vineyard gr. 3	Bulgaria

A	Kozlovets mound 1, gr. 1	Bulgaria
A	Sajkas, "Ciganska humka"/gr.1	Serbia
A	Sajkas, "Ciganska humka"/gr.1	Serbia
A	Zabalj, "Medisova humka" / gr.1	Serbia
B, position unclear	Zabalj, "Medisova humka" / gr.4	Serbia
A	Padej, "Humka u Barnahatu"/ gr.2	Serbia
B, slightly crouched	Jabuka, "Tri Humke"/ gr.1	Serbia
C, orientation Sw-NE, sligthly crouched	Vojlovica, "Rafineria nafte"/ gr.1	Serbia
A	Sarateni mound 1/ gr.4	Moldova
A	Sarateni mound 1/ gr.5	Moldova
C	Petreshti mound 1/ gr.8	Moldova
B, no ochre	Pereschepino mound 1/gr.13	Ukraine
C, SW-NE, no ohcre	Minovka mound 1/gr.3	Ukraine
Not enough information	Mogilev mound 1/gr.6	Ukraine
Position (supine)? and orientation unclear, B?	Mogilev, Brilyuvata/ gr.5	Ukraine
Position and orientation unclear, B?	Mogilev, Brilyuvata/ gr.5	Ukraine
B, no ochre	Mogilev, Brilyuvata mogila/ gr.12	Ukraine
D, orientation SW-NE, no ochre, position unclear	Pereschepino mound 1/gr.6	Ukraine

C, SW-NE, ochre unclear	Pereschepino mound 1/ gr.7	Ukraine
C, SW-NE, ochre unclear	Pereschepino mound 1/ gr.7	Ukraine
B, ochre unclear	Pereschepino mound 1/ gr.13	Ukraine
C, orientation unclear, no ochre	Zaporozhye mound /gr.14	Ukraine
C, orientation south, no ochre	Balki mound 1/ gr. 40	Ukraine
C, orientation south, no ochre	Balki mound 1/ gr. 40	Ukraine
C, orientation south, no ochre	Balki mound 1/ gr. 57	Ukraine
B, crouched on the left side	Verkhne-Tarasovka mound 9, gr.18	Ukraine
A	Verkhne-Tarasovka mound 17, gr.3	Ukraine
C, orientation, no ochre	Khristoforovka mound 1/ gr.1	Ukraine
A	Khristoforovka mound 1/ gr.11	Ukraine
B, orientation SW-NE	Chkalovo mound 11/ gr.8	Ukraine
B, orientation NE-SW	Chkalovo mound 11/ gr.9	Ukraine
B, orientation NE-SW	Chkalovo mound 11/ gr.9	Ukraine
B, orientation NE-SW	Chkalovo mound 11/ gr.9	Ukraine
B, SW-NE	Chkalovo mound 11/ gr.11	Ukraine
B, SW-NE	Chkalovo mound 11/ gr.11	Ukraine
B, SW-NE	Chkalovo mound 11/ gr.11	Ukraine
B, SW-NE	Chkalovo mound 11/ gr.11	Ukraine

D, no organics, N-S, crouched on the side	Shakhta mound 2/ gr.6	Ukraine
D, no organics, N-S, crouched on the side	Shakhta mound 2/ gr.6	Ukraine
C, NE-SW, crouched on the left side	Shakhta mound 2/ gr.9	Ukraine
C, NE-SW, crouched on the left side	Shakhta mound 2/ gr.9	Ukraine
B, SW-NE	Golovkovka mound 3/ gr.1	Ukraine
C, crouched on the right side, NE-SW	Golovkovka mound 5/ gr.3	Ukraine
C, crouched on the right side, NE-SW	Golovkovka mound 5/ gr.3	Ukraine
B, SW-NE	Golovkovka mound 5/ gr.5	Ukraine
B, SW-NE	Golovkovka mound 5/ gr.5	Ukraine
B, SW-NE	Golovkovka mound 6/ gr.8	Ukraine
B, SW-NE	Golovkovka mound 6/ gr.8	Ukraine
B, SW-NE	Golovkovka mound 6/ gr.9	Ukraine
B, SW-NE	Golovkovka mound 6/ gr.11	Ukraine
A	Golovkovka mound 7/ gr.4	Ukraine
A	Golovkovka mound 7/ gr.4	Ukraine
B, SW-NE	Golovkovka mound 11/ gr.5	Ukraine

B, SW-NE	Golovkovka mound 11/ gr.5	Ukraine
B, NE-SW	Golovkovka mound 12/ gr.3	Ukraine
C, crouched on the left side, NW-SE	Golovkovka mound 14/ gr.2	Ukraine
D, N-S, crouched on the side, no ochre	Golovkovka mound 14/ gr.3	Ukraine
B, N-S	Golovkovka mound 14/ gr.4	Ukraine
B, SW-NE	Golovkovka mound 14/ gr.7	Ukraine
C, NE-SW, crouched on the left side	Golovkovka mound 14/ gr.9	Ukraine
B, NW- SE	Protopopovka mound 1/ gr.2	Ukraine
C, SW-NE, no ochre	Protopopovka mound 1/ gr.3	Ukraine
C, SW-NE, no ochre	Protopopovka mound 1/ gr.3	Ukraine
C, crouched on the left side, SW-NE	Protopopovka mound 1/ gr.4	Ukraine
C, crouched on the left side, SW-NE	Protopopovka mound 1/ gr.4	Ukraine
B, NE-SW	Talyanki mound 4/ gr.1	Ukraine
C, no ochre, orientation NE-SW	Talyanki mound 4/ gr.2	Ukraine
C, no ochre, orientation NE-SW	Talyanki mound 4/ gr.3	Ukraine
D, slightly crouched, no ochre, NE-SW	Talyanki mound 4/ gr.4	Ukraine
B, SW-NE	Myronivka mound 1/ gr.8	Ukraine

C, N-S, crouched on the left side	Myronivka mound 2/ gr.3	Ukraine
C, no organics, crouched on the left side	Myronivka mound 2/ gr.4	Ukraine
C, no ochre, SW-NE	Myronivka mound 3/ gr.1	Ukraine
A	Myronivka mound 7/ gr.2	Ukraine
C, NE-SW, slightly crouched on the left side	Otradnyi mound 1/gr. 17	Ukraine
B, NE-SW	Otradnyi mound 1/gr. 21	Ukraine
C, NE-SW, slightly crouched on the right side	Otradnyi mound 1/gr. 22	Ukraine
C, no ochre, SW-NE	Otradnyi mound 26/gr. 9	Ukraine
B, N-S	Revova mound 3/gr.7	Ukraine
A	Revova mound 3/ gr. 16	Ukraine
B, SW-NE	Mound "Lyubasha" / gr.8	Ukraine
B, no ochre?	Vinogradnoe mound 24/ gr. 20	Ukraine
C, position unclear, SE-NW	Volonterovka mound 1/ gr.3	Ukraine
B, SE-NW	Volonterovka mound 1/ gr.4	Ukraine
B, position crouched on the side	Kremenevka mound 6/ gr.4	Ukraine
A	Kremenevka mound 6/ gr. 6	Ukraine
A	Kremenevka mound 6/ gr. 6	Ukraine
B, position on the back	Kremenevka mound 6/ gr.7	Ukraine
B, position on the back	Kremenevka mound 6/ gr.7	Ukraine

B, no ochre	Kremenevka mound 6/ gr. 8	Ukraine
C, no ochre, position unclear	Kremenevka mound 6/ gr.9	Ukraine
B, SW-NE	Shakhter mound 29/ gr. 11	Ukraine
B, NE-SW	Shakhter mound 29/ gr. 12	Ukraine
C, no ochre, NW-SE	Shakhter mound 29/ gr. 19	Ukraine
B, N-S	Sugokleja /gr.5	Ukraine
B, SW-NE	Sugokleja /gr.8	Ukraine
B, SW-NE	Sugokleja /gr.8	Ukraine
B, SW-NE	Sugokleja /gr.8	Ukraine
B, SW-NE	Sugokleja /gr.8	Ukraine
B, NE-SW	Sugokleja /gr.14	Ukraine
B, slightly crouched	Sugokleja /gr.16	Ukraine
B, SW-NE	Sugokleja /gr.20	Ukraine
B, SW-NE	Sugokleja /gr.20	Ukraine
B, NW-SE	Sugokleja /gr.24	Ukraine
A	Vishnevoye mound 17/ gr.4	Ukraine
B, orientation supine (legs unclear)	Vishnevoye mound 17/ gr.17	Ukraine
C, N-S, no ochre	Vishnevoye mound 17/ gr.36	Ukraine
C, crouched on the right side, NNW-SSE	Vishnevoye mound 17/ gr.37	Ukraine
B, NNW-SSE orientation	Vishnevoye mound 17/ gr. 38	Ukraine
B, NNW-SSE orientation	Vishnevoye mound 17/ gr. 38	Ukraine
B, SE-NW	Tarasova Mogila/ gr.11	Ukraine

B, SWW-NEE orientation	Raigorodka mound 1/ gr.9	Ukraine
C, SWW-NE, no ochre	Raigorodka mound 1/ gr.10	Ukraine
B, orientation is unsecure	Liman mound 2/ gr.2	Ukraine
C, WNW-ESE, crouched on the left side with a slight turn on the back	Semenovka mound 11/ gr.6	Ukraine
C, SW-NE, crouched on the left side with a slight turn on the back,	Semenovka mound 14/ gr.7	Ukraine
B, ESE-SWS	Semenovka mound 14/ gr.2	Ukraine
B, SSW-NNE	Novoselitsa mound 19/ gr. 7	Ukraine
B, NNW-SSE	Novoselitsa mound 19/ gr. 11	Ukraine
B, NE-SW	Novoselitsa mound 19/ gr. 16	Ukraine
B, SEE-NWW	Novoselitsa mound 19/ gr. 19	Ukraine
B, SEE-NWW	Novoselitsa mound 19/ gr. 19	Ukraine
B, NNE-SSW	Novoselitsa mound 20/ gr.8	Ukraine
B, NNE-SSW	Novoselitsa mound 20/ gr.8	Ukraine
B, SSW-NNE	Novoselitsa mound 20/ gr.9	Ukraine
B, crouched on the left side	Dobrovody mound 1/ gr. 2	Ukraine
C, NE-SW, crouched on the left side	Dobrovody mound 1/ gr. 6	Ukraine
B, WSW-ENE	Dobrovody mound 2/ gr. 3	Ukraine
A	Dobrovody mound 2/ gr. 4	Ukraine

C, Crouched on the left side, SE-NW	Dobrovody mound 2/ gr. 6	Ukraine
C, crouched on the right side, SSE-NNW	Dobrovody mound 2/ gr. 10	Ukraine
B, NE-SW	Starobogdanivka mound 1/ gr.6	Ukraine
C, S-N, no organics	Vapnyarka mound 4/ gr. 18	Ukraine
B, SW- NE	Pidlisivka, Yampil mound 1/ gr. 1A	Ukraine
B, SW- NE	Pidlisivka, Yampil mound 1/ gr. 1A	Ukraine
C, no ochre, NW-SE	Pidlisivka, Yampil mound 1/ gr. 11	Ukraine
B, N-S	Porohy, Yampil mound 3A/ gr. 11	Ukraine
B, SW-NE	Pridnistryanske mound 4/ gr. 3	Ukraine
A	Pridnistryanske mound 4/ gr. 4	Ukraine
A	Pridnistryanske mound 4/ gr. 4	Ukraine
B, SW-NE	Pridnistryanske mound 4/ gr. 6	Ukraine
B, SW-NE	Pridnistryanske mound 4/ gr. 6	Ukraine
A	Pridnistryanske mound 4/ gr. 8	Ukraine
C, on the stomach, no ochre	Mustaevo V mound 1/gr.1	Russia
C, on the stomach, no ochre	Mustaevo V mound 1/gr.1	Russia
C, on the stomach, no ochre	Mustaevo V mound 1/gr.1	Russia

D, only skull, NE-SW, no ochre	Mustaevo V mound 8/ gr.2	Russia
D, only skull, NE-SW, no ochre	Mustaevo V mound 8/ gr.2	Russia
C, no ochre, position unclear	Mustaevo V mound 9/ gr.2	Russia
C, no ochre, position unclear	Mustaevo V mound 9/ gr.2	Russia
C, crouched on the right side, NE-SW	Skvortsovka mound 7/ gr.1	Russia
C, orientation of the pit: SW-NE, position unclear	Skvortsovka mound 8/ gr.1	Russia
B, position unclear	Skvortsovka mound 9/ gr.1	Russia
B, orientation SE-NW	Pershin mound 1/ gr.4	Russia
B, both individuals crouched	IK Shumaevo mound 2/2	Russia
B, both individuals crouched	IK Shumaevo mound 2/2	Russia
B, both individuals crouched	IK Shumaevo mound 2/2	Russia
B, both individuals crouched	IK Shumaevo mound 2/2	Russia
A	KC Shumaevo II mound 6/ gr.6	Russia
A	KC Shumaevo II mound 6/ gr.6	Russia
B	Shumaevo I mound 3/ gr.6	Russia
A	Kutuluk I mound 4/ gr. 1	Russia
A	Kutuluk I mound 4/ gr. 1	Russia
B, no ochre?	Us'man mound 1/ gr. 13	Russia
B, NE-SW	Nizhnyaya Orlyanka I mound 4/ gr.2	Russia

B, slighlty turned to the right	Nizhnyaya Orlyanka I mound 1/ gr.4	Russia
B, NE-SW	Nizhnyaya Orlyanka I mound 1/ gr.5	Russia
B? based on picture	Poludni II mound 2/ gr. 7	Russia
C, crouched on the left, NE-SW	Grachevka I mound 1/gr. 2	Russia
C, organics unclear, NE-SW	Grachevka II mound 5/gr.1	Russia
C, organics unclear, NE-SW	Grachevka II mound 5/ gr.1	Russia
B, NE-SW	Grachevka II mound 5/ gr.2 (primary)	Russia
B, NE-SW	Grachevka II mound 5/ gr.2 (primary)	Russia
D, no organics, no ochre, NW-SE	Panitskoe 6B/ gr.6., ind. 2	Russia
D, no organics, no ochre, NW-SE	Panitskoe 6B/ gr.6., ind. 1	Russia
D, no ochre, SW-NE, poisition unclear	Panitskoe 6B/ gr. 7	Russia
B, SE-NW	Podlesnoe I mound 3/gr. 3	Russia
B, NE-SW	Podlesnoe I mound 3/gr. 4	Russia
C, organics unclear, NE-SW	Krasnosamarskoe IV mound 1/ gr. 3	Russia
C, crouched on the right side, no ochre	Boldyrevo I mound 1/ gr.1	Russia
C, crouched on the right side, no ochre	Boldyrevo I mound 1/ gr.1	Russia
B, crouched on the right side	Tamar-Utkul VII mound 1/ gr.1	Russia
B, crouched on the right side	Tamar-Utkul VII mound 4/ gr.9	Russia

C, crouched on the right side, no ochre	Tamar-Utkul VII mound 8/ gr.4	Russia
C, crouched on the right side, no ochre	Tamar-Utkul VIII mound 4/ gr.1	Russia
B, crouched on the right side	Tamar-Utkul VIII mound 8/ gr.1	Russia
C, crouched on the right side, NE-SW	Pyatiletka V mound 5/gr. 2	Russia
D, SE-NW, crouched on the right side, no ochre	Nizhnyaya Pavlovka V 1/2	Russia
not enough information	Mu-Sharet-1 mound 5/ gr. 3	Russia
not enough information	Mu-Sharet-1 mound 5/ gr. 3	Russia
not enough information	Mu-Sharet 4 mound 12/gr.1	Russia
not enough information	Mu-sharet-4 mound 11/ gr.3	Russia
not enough information	Mu-sharet-4 mound 1/ gr.3	Russia
A	Mandjikiny-1 mound 3/ gr.2	Russia
not enough information	Mandjikiny-1 mound 14/ gr.10	Russia
not enough information	Mandjikiny-1 mound 14/ gr.12	Russia
B, slightly SE-NW	Mandjikiny-2 mound 11/ gr. 2	Russia
B, slightly SE-NW	Mandjikiny-2 mound 11/ gr. 2	Russia

not enough information	Mandjikiny-2 mound 11/ gr. 3	Russia
not enough information	Mandjikiny-2 mound 11/ gr. 3	Russia
not enough information	Mandjikiny-2 mound 11/ gr. 3	Russia
not enough information	Peschanyi V mound 1/ gr.3	Russia
not enough information	Peschanyi V mound 15/ gr.6	Russia
not enough information	Peschanyi V mound 15/ gr.6	Russia
not enough information	Khar-Zukha mound 2/ gr,3	Russia
not enough information	Chighir mound 2/ gr.3	Russia
A	Peschanyi IV mound 11/gr. 4	Russia
A	Peschanyi IV mound 11/gr. 4	Russia
A	Peschanyi IV mound 13/gr. 5	Russia
B, SW-NE	Peschanyi IV mound 13/gr.6	Russia
B, SW-NE	Peschanyi IV mound 13/gr.6	Russia
B, no ochre	Peschanyi IV mound 16/gr.4	Russia
C, organics unclear, NE-SW	Lopatino I 35/1	Russia

SUPPLEMENTARY TABLE 2. Radiocarbon sample codes, material used for dating and the date in BP.

NAME OF THE SITE (mound/burial)	COUNTRY THE MENTIONED SITE IS SITUATED IN	SAMPLE CODE	MATERIAL	DATE (BP)
Târgşoru Vechi mound/gr. 2a	Romania	DeA-10666	Human bone	4176±32
Târgşoru Vechi mound/gr. 9	Romania	DeA-10667	Human bone	4123±33
Târgşoru Vechi mound/gr. 10a	Romania	DeA-10668	Human bone	4140±33
Ariçeşti IV/gr.2	Romania	DeA-2797.1.1	Human bone	4287±38

Smeeni/gr.5	Romania	DeA-8817	Human bone	4357±35
Smeeni/gr.15	Romania	DeA-7739	Human bone	4240±54
Smeeni/gr.16	Romania	DeA-7737	Human bone	4142±30
Smeeni/gr.18	Romania	DeA-7735	Human bone	4126±31
Blejoi III/gr.1	Romania	DeA-8813	Human bone	4174±33
Blejoi IV/gr.1	Romania	DeA-16952	Human bone	4212±29
Ariçeşti-Rahtivani mound 1/gr.1	Romania	DeA-7738	Human bone	4018±32
Coada Izvorului/ gr.3	Romania	DeA 14449	Human bone	4353±28
Rahman mound 1/ gr.1	Romania	Poz-46583	Wood	4220±35
Rahman mound 2/ gr.5	Romania	Poz-65968	Human bone	3950±35
Silvașu de Jos mound 3/gr. 1	Romania	Poz 78170	Human bone	4130±35
Silvașu de Jos mound 4/gr. 1	Romania	Poz-56765	Carbonated wood	4135±30
Silvașu de Jos mound 4/gr. 1	Romania	RoAMS 5E	Carbonated wood	4147±31
Silvașu de Jos mound 4/gr. 1	Romania	Poz-53778	Human bone	4115±30
Silvașu de Jos mound 4/gr. 1	Romania	RoAMS 5C	Human tooth	4104±25
Nedelea mound 2/gr.1	Romania	?1	Human bone	4225±37
Târgşoru Nou/ gr.2	Romania	?2	Human bone	4037±43

Bucova Pusta/ Hügel IV	Romania	Poz-66988	Human bone	4190±35
Ketegyhaza-Törökhalom mound 3/gr.4	Hungary	Bln-609	Human bone	4265±80
Kunhegyes-Nagyallashalom/ gr.14	Hungary	Poz-39454	Human bone	4075±35
Kunhegyes-Nagyallashalom/ gr.18	Hungary	poz-39456	Human bone	4195±35
Püspökladany-Kincesdomb/ gr.1	Hungary	Poz-42724	Human bone	4215±35
Balmazújváros-Hortobágy-Árkus-Kettőshalom/	Hungary	Poz-38461	Human bone	4320±35
Hajdúnánás-Tedej-Lyukashalom	Hungary	Poz-31405	Human bone	4210±35
Sarredudvari Örhalom gr.4	Hungary	deb-7182	Human bone	4135±60
Sarredudvari Örhalom gr.9	Hungary	deb-6871	Human bone	4060±50
Sarredudvari Örhalom gr.10	Hungary	deb-6639	Human bone	4350±40
Poruchik Geshanovo mound 1/gr.1	Bulgaria	Bln-3301	Human bone	4080±50

Poruchik Geshanovo mound 1/gr.3	Bulgaria	Bln-3302	Human bone	4360±50
Plachidol mound 1/ gr. 1	Bulgaria	Bln-2501	Human bone	4170±50
Boyanovo, Lozianska Mogila/gr.14	Bulgaria	OxA-22951	Human bone	4186±27
Vetrino, Necropolis 1, barrow 34, f. 2	Bulgaria	SUERC-95534	Human bone	4184±24
Vetrino, Necropolis 1, barrow 34, f. 3	Bulgaria	SUERC-95535	Human bone	4138±22
Vetrino, Necropolis 1, barrow 34, f. 4	Bulgaria	SUERC-95536	Human bone	4176±24
Vetrino, Necropolis2, barrow 7, f. 1	Bulgaria	SUERC-95544	Human bone	4372±23
Vetrino, Necropolis 2, barrow 7, f. 6	Bulgaria	SUERC-95545	Human bone	4145±22
Vetrino, Necropolis 3, barrow 1, f. 4	Bulgaria	SUERC-97444	Human bone	4127±30
Vetrino, Necropolis 3, barrow 1, f. 5	Bulgaria	SUERC-97448	Human bone	4154±27

Vetrino, Necropolis 3, barrow 1, f. 1	Bulgaria	SUERC-97442	Human bone	4117±25
Vetrino, Necropolis 3, barrow 1, f. 3	Bulgaria	SUERC-97443	Human bone	4158±29
Vetrino, Necropolis 3, barrow 1, f. 7	Bulgaria	SUERC-97450	Human bone	4158±25
Vetrino, Necropolis 3, barrow 1, f. 8	Bulgaria	SUERC-97451	Human bone	4142±29
Vetrino, Necropolis 3, barrow 1, f. 9	Bulgaria	SUERC-97452	Human bone	4172±27
Beli Bryag, gr. 3/1	Bulgaria	MAMS-28025	Human bone	4360±27
Beli Bryag, gr. 3/2	Bulgaria	MAMS-28026	Human bone	4397±27
Mednikarovo mound 2, gr.1	Bulgaria	MAMS-26934	Human bone	4333±20
Chernyova Mogila, gr. 4	Bulgaria	MAMS-28031	Human bone	4308±28
Merichleri mound 1, gr. 6	Bulgaria	SUERC-63817	Human bone	4428±33
Riltsi mound 260, gr. 1	Bulgaria	SUERC-84759	Human bone	4314±26
Riltsi mound 264, gr. 4	Bulgaria	SUERC-86512	Human bone	4520±34

Belitsa mound 1, gr. 1	Bulgaria	SUERC-84760	Human bone	4123±26
Chudomir mound 1, gr.5	Bulgaria	SUERC-95537	Human bone	4414±25
Ovchartsi, barrow in the vineyard gr. 3	Bulgaria	SUERC-63829	Human bone	4342±33
Kozlovets mound 1, gr. 1	Bulgaria	SUERC-84750	Human bone	4380±26
Sajkas, "Ciganska humka"/gr.1	Serbia	Poz-88657	Wood	4170±40
Sajkas, "Ciganska humka"/gr.1	Serbia	Poz-88664	Human bone	4195±35
Zabalj, "Medisova humka" / gr.1	Serbia	Poz-100501	Human bone	4125±35
Zabalj, "Medisova humka" / gr.4	Serbia	Poz-100500	Human bone	4130±30
Padej, "Humka u Barnahatu"/ gr.2	Serbia	Bln-2219	Wood	4320±50
Jabuka, "Tri Humke"/ gr.1	Serbia	Poz-93213	Human bone	4100±40
Vojlovica, "Rafineria nafte"/ gr.1	Serbia	Poz-88701	Human bone	4290±35

Sarateni mound 1/ gr.4	Moldova	Lu-2476	Wood	4480±50
Sarateni mound 1/ gr.5	Moldova	Lu-2459	Wood	4360±30
Petreshti mound 1/ gr.8	Moldova	Lu-2474	Wood	4530±50
Pereschepino mound 1/gr.13	Ukraine	Ki-9980	Wood	4150±70
Minovka mound 1/gr.3	Ukraine	Ki-421	Wood	3970±80
Mogilev mound 1/gr.6	Ukraine	Ki-491	Wood	3940±120
Mogilev, Brilyuvata/ gr.5	Ukraine	Le-?	Wood	3830±120
Mogilev, Brilyuvata/ gr.5	Ukraine	Ki-522	Wood	4530±130
Mogilev, Brilyuvata mogila/ gr.12	Ukraine	Ki-494	Wood	4080±100
Pereschepino mound 1/gr.6	Ukraine	Ki-9981	Wood	4080±70
Pereschepino mound 1/ gr.7	Ukraine	Vi-?	Wood	4215±65
Pereschepino mound 1/ gr.7	Ukraine	Ki-9982	Wood	4105±70
Pereschepino mound 1/ gr.13	Ukraine	Ki-9980	Wood	4150±70
Zaporozhye mound /gr.14	Ukraine	Ki-7072	Wood	4360±70

Balki mound 1/ gr. 40	Ukraine	Le-1168	Wood	4080±90
Balki mound 1/ gr. 40	Ukraine	Ki-587	Wood	3990±140
Balki mound 1/ gr. 57	Ukraine	Ki-7073	Wood	3930±60
Verkhne-Tarasovka mound 9, gr.18	Ukraine	Ki-602	Wood	4070±120
Verkhne-Tarasovka mound 17, gr.3	Ukraine	Ki-581	Wood	3820±190
Khristoforovka mound 1/ gr.1	Ukraine	Ki-578	Wood	4160±170
Khristoforovka mound 1/ gr.11	Ukraine	Ki-549a	Wood	4200±70
Chkalovo mound 11/ gr.8	Ukraine	Ki-6827	Human bone	3910±45
Chkalovo mound 11/ gr.9	Ukraine	Ki-6571	Human bone	3985±45
Chkalovo mound 11/ gr.9	Ukraine	Ki-6571a	Human bone	4035±50
Chkalovo mound 11/ gr.9	Ukraine	Ki-6828	Human bone	3960±50
Chkalovo mound 11/ gr.11	Ukraine	Ki-6572	Human bone	4060±55
Chkalovo mound 11/ gr.11	Ukraine	Ki-6572a	Human bone	4005±55
Chkalovo mound 11/ gr.11	Ukraine	Ki-6829	Human bone	3900±55

Chkalovo mound 11/ gr.11	Ukraine	Ki-6829a	Human bone	3990±50
Shakhta mound 2/ gr.6	Ukraine	Ki-7132	Human bone	3930±70
Shakhta mound 2/ gr.6	Ukraine	Ki-6833	Human bone	3900±55
Shakhta mound 2/ gr.9	Ukraine	Ki-6834	Human bone	3970±50
Shakhta mound 2/ gr.9	Ukraine	Ki-6834a	Human bone	3930±50
Golovkovka mound 3/ gr.1	Ukraine	Ki-6718	Human bone	3920±60
Golovkovka mound 5/ gr.3	Ukraine	Ki-6730	Human bone	3960±60
Golovkovka mound 5/ gr.3	Ukraine	Ki-6730a	Human bone	3925±50
Golovkovka mound 5/ gr.5	Ukraine	Ki-6731	Human bone	4005±55
Golovkovka mound 5/ gr.5	Ukraine	Ki-7135	Human bone	4020±70
Golovkovka mound 6/ gr.8	Ukraine	Ki-6719	Human bone	3970±55
Golovkovka mound 6/ gr.8	Ukraine	Ki-7133	Human bone	3960±60
Golovkovka mound 6/ gr.9	Ukraine	Ki-6720	Human bone	3880±55
Golovkovka mound 6/ gr.11	Ukraine	Ki-6721	Human bone	3850±55
Golovkovka mound 7/ gr.4	Ukraine	Ki-6722	Human bone	3980±60

Golovkovka mound 7/ gr.4	Ukraine	Ki-7136	Human bone	3940±70
Golovkovka mound 11/ gr.5	Ukraine	Ki-6723	Human bone	4030±60
Golovkovka mound 11/ gr.5	Ukraine	Ki-7134	Human bone	4035±60
Golovkovka mound 12/ gr.3	Ukraine	Ki-6724	Human bone	3950±50
Golovkovka mound 14/ gr.2	Ukraine	Ki-6727	Human bone	3910±55
Golovkovka mound 14/ gr.3	Ukraine	Ki-6725	Human bone	3950±55
Golovkovka mound 14/ gr.4	Ukraine	Ki-6726	Human bone	3840±50
Golovkovka mound 14/ gr.7	Ukraine	Ki-6728	Human bone	3905±55
Golovkovka mound 14/ gr.9	Ukraine	Ki-6729	Human bone	3920±50
Protopopovka mound 1/ gr.2	Ukraine	Ki-6733	Human bone	3945±50
Protopopovka mound 1/ gr.3	Ukraine	Ki-6734	Human bone	3925±55
Protopopovka mound 1/ gr.3	Ukraine	Ki-7131	Human bone	3910±60
Protopopovka mound 1/ gr.4	Ukraine	Ki-6732	Human bone	3890±55
Protopopovka mound 1/ gr.4	Ukraine	Ki-7130	Human bone	3920±50
Talyanki mound 4/ gr.1	Ukraine	Ki-6714	Human bone	3990±50

Talyanki mound 4/ gr.2	Ukraine	Ki-6715	Human bone	3945±50
Talyanki mound 4/ gr.3	Ukraine	Ki-6716	Human bone	3905±60
Talyanki mound 4/ gr.4	Ukraine	Ki-6717	Human bone	3865±50
Myronivka mound 1/ gr.8	Ukraine	Ki-6741	Wood	4235±60
Myronivka mound 2/ gr.3	Ukraine	Ki-5826	Bone	3875±60
Myronivka mound 2/ gr.4	Ukraine	Ki-5825		3810±55
Myronivka mound 3/ gr.1	Ukraine	Ki-5828	Human bone	4010±60
Myronivka mound 7/ gr.2	Ukraine	Ki-5823	Human bone	3895±60
Otradnyi mound 1/gr. 17	Ukraine	Ki-437	Wood	3890±105
Otradnyi mound 1/gr. 21	Ukraine	Ki-7070	Wood	3890±65
Otradnyi mound 1/gr. 22	Ukraine	Ki-10013	Wood	3925±110
Otradnyi mound 26/gr. 9	Ukraine	Ki-7069	Wood	3920±60
Revova mound 3/gr.7	Ukraine	Ki-11058	Human bone	3910±60
Revova mound 3/ gr. 16	Ukraine	Ki-11059	Human bone	4135±60
Mound "Lyubasha" / gr.8	Ukraine	Ki-11177	Human bone	3990±70

Vinogradnoe mound 24/ gr. 20	Ukraine	Bln-4691	Wood	4371±36
Volonterovka mound 1/ gr.3	Ukraine	Ki-9917	Wood	4570±80
Volonterovka mound 1/ gr.4	Ukraine	Ki-9919	Wood	4535±80
Kremenevka mound 6/ gr.4	Ukraine	Ki-1708	Wood	4250±50
Kremenevka mound 6/ gr. 6	Ukraine	Ki-7076	Wood	4130±70
Kremenevka mound 6/ gr. 6	Ukraine	Ki-7124	Wood	4365±55
Kremenevka mound 6/ gr.7	Ukraine	Ki-7077	Wood	4170±60
Kremenevka mound 6/ gr.7	Ukraine	Ki-7125	Wood	4335±60
Kremenevka mound 6/ gr. 8	Ukraine	Ki-9898	Wood	4410±70
Kremenevka mound 6/ gr.9	Ukraine	Ki-7260	Wood	4465±60
Shakhter mound 29/ gr. 11	Ukraine	Ki-13873	Human bone	3800±80
Shakhter mound 29/ gr. 12	Ukraine	Ki-13876	Human bone	4220±90
Shakhter mound 29/ gr. 19	Ukraine	Ki-14719	Human bone	3965±80
Sugokleja /gr.5	Ukraine	KIA-29935	Human bone	4142±40
Sugokleja /gr.8	Ukraine	Ki-13859	Human bone	4250±70
Sugokleja /gr.8	Ukraine	KIA-29937	Human bone	4408±31

Sugokleja /gr.8	Ukraine	KIA-28682	Wood (rings 97-94)	4462±33
Sugokleja /gr.8	Ukraine	KIA-28683	Wood (rings 22-28)	4425±24
Sugokleja /gr.14	Ukraine	KIA-29934	Human bone	4316±33
Sugokleja /gr.16	Ukraine	KiA-13863	Human bone	3840±40
Sugokleja /gr.20	Ukraine	Ki-13858	Human bone	4370±90
Sugokleja /gr.20	Ukraine	KIA-29936	Human bone	4271±34
Sugokleja /gr.24	Ukraine	Ki-13864	Human bone	4340±80
Vishnevoye mound 17/ gr.4	Ukraine	Ki-1217	Wood	3950±90
Vishnevoye mound 17/ gr.17	Ukraine	Ki-7078	Wood	4180±60
Vishnevoye mound 17/ gr.36	Ukraine	Ki-9927	Wood	3920±70
Vishnevoye mound 17/ gr.37	Ukraine	Ki-1439	Wood	3800±120
Vishnevoye mound 17/ gr. 38	Ukraine	Ki-1711	Wood	4250±80
Vishnevoye mound 17/ gr. 38	Ukraine	Ki-7079	Wood	4105±65
Tarasova Mogila/ gr.11	Ukraine	Hd-19931	Human bone	4148±26
Raigorodka mound 1/ gr.9	Ukraine	Ki-9517	Human bone	3980±70
Raigorodka mound 1/ gr.10	Ukraine	Ki-9518	Human bone	3980±70
Liman mound 2/ gr.2	Ukraine	Ki-2394	Wood	4490±90

Semenovka mound 11/ gr.6	Ukraine	Ki-1753	Wood	4380±50
Semenovka mound 14/ gr.7	Ukraine	Ki-7088	Wood	4130±65
Semenovka mound 14/ gr.2	Ukraine	Ki-2126	Wood	4600±90
Novoselitsa mound 19/ gr. 7	Ukraine	Ki-1219	Wood	4490±70
Novoselitsa mound 19/ gr. 11	Ukraine	Ki-1220	Wood	3800±60
Novoselitsa mound 19/ gr. 16	Ukraine	Ki-7080	Wood	4205±55
Novoselitsa mound 19/ gr. 19	Ukraine	Ki-7085	Wood	4180±60
Novoselitsa mound 19/ gr. 19	Ukraine	Ki-7127	Wood	4055±65
Novoselitsa mound 20/ gr.8	Ukraine	Ki-7086	Wood	4235±55
Novoselitsa mound 20/ gr.8	Ukraine	Ki-7128	Wood	4005±50
Novoselitsa mound 20/ gr.9	Ukraine	Ki-8294	Wood	4190±80
Dobrovody mound 1/ gr. 2	Ukraine	Ki-2124	Wood	4200±70
Dobrovody mound 1/ gr. 6	Ukraine	Ki-7090	Wood	3960±60
Dobrovody mound 2/ gr. 3	Ukraine	Ki-7092	Wood	4040±55
Dobrovody mound 2/ gr. 4	Ukraine	Ki-2129	Wood	3960±55

Dobrovody mound 2/ gr. 6	Ukraine	Ki-2107	Wood	3980±45
Dobrovody mound 2/ gr. 10	Ukraine	KI-7091	Wood	3920±60
Starobogdanivka mound 1/ gr.6	Ukraine	Ki-2120	Wood	4760±55
Vapnyarka mound 4/ gr. 18	Ukraine	Ki-15015	Human bone	3880±60
Pidlisivka, Yampil mound 1/ gr. 1A	Ukraine	Ki-16892	Human bone	3895±70
Pidlisivka, Yampil mound 1/ gr. 1A	Ukraine	Poz-52424	Wood	4082±35
Pidlisivka, Yampil mound 1/ gr. 11	Ukraine	Poz-81793	Human bone	4085±30
Porohy, Yampil mound 3A/ gr. 11	Ukraine	Poz-47741	Human bone	4075±35
Pridnistryanske mound 4/ gr. 3	Ukraine	Poz-66228	Human bone	4090±35
Pridnistryanske mound 4/ gr. 4	Ukraine	Poz-66230	Wood	4455±35
Pridnistryanske mound 4/ gr. 4	Ukraine	Poz-66629	Human bone	4380±35
Pridnistryanske mound 4/ gr. 6	Ukraine	Poz-66231	Wood	4185±35
Pridnistryanske mound 4/ gr. 6	Ukraine	Poz-70673	Human bone	4090±40

Pridnistryanske mound 4/ gr. 8	Ukraine	Poz-66232	Human bone	4090±40
Mustaevo V mound 1/gr.1	Russia	LE 6732	Wood	4140±25
Mustaevo V mound 1/gr.1	Russia	IGAN 2780	Wood	4070±30
Mustaevo V mound 1/gr.1	Russia	IGAN 2869	humus of buried paleosol	4180±70
Mustaevo V mound 8/ gr.2	Russia	IGAN 3016	humus of buried paleosol	4480±100
Mustaevo V mound 8/ gr.2	Russia	Poz-47868	ceramics	4245±35
Mustaevo V mound 9/ gr.2	Russia	LE 7021	Human bone	4330±100
Mustaevo V mound 9/ gr.2	Russia	IGAN 3017	humus of buried paleosol	4290±80
Skvortsovka mound 7/ gr.1	Russia	LE 8580	Human bone	4230±150
Skvortsovka mound 8/ gr.1	Russia	LE 8578	Human bone	4180±140
Skvortsovka mound 9/ gr.1	Russia	LE 8579	Human bone	4440±140
Pershin mound 1/ gr.4	Russia	BM 3157	Human bone	4200±60
IK Shumaevo mound 2/2	Russia	LE 6088	wood	4100±40

IK Shumaevo mound 2/2	Russia	LE 6090	Human bone	4060±120
IK Shumaevo mound 2/2	Russia	IGAN 2448	wood	3980±50
IK Shumaevo mound 2/2	Russia	IGAN 2391	humus of buried paleosol	4030±120
KC Shumaevo II mound 6/ gr.6	Russia	LE 6087	Wood	4070±45
KC Shumaevo II mound 6/ gr.6	Russia	Le 6089	Human bone	4080±100
Shumaevo I mound 3/ gr.6	Russia	LE 6091	Human bone	4300±150
Kutuluk I mound 4/ gr. 1	Russia	OxA 4306	Human bone	4400±70
Kutuluk I mound 4/ gr. 1	Russia	AA 12570	Human bone	4370±75
Us'man mound 1/ gr. 13	Russia	UKLA-1271	Human bone	4150±80
Nizhnyaya Orlyanka I mound 4/ gr.2	Russia	AA 12573	Human bone	4520±75
Nizhnyaya Orlyanka I mound 1/ gr.4	Russia	OxA 4255	Human bone	4230±80
Nizhnyaya Orlyanka I mound 1/ gr.5	Russia	OxA 4254	Human bone	4520±75
Poludni II mound 2/ gr. 7	Russia	IGAN 3233	Human bone	4542±75

Grachevka I mound 1/gr. 2	Russia	GIN-11452	Human bone	4250±40
Grachevka II mound 5/gr.1	Russia	AA 53804	Human bone	4179±55
Grachevka II mound 5/ gr.1	Russia	IGAN 2876	Human bone	4050±70
Grachevka II mound 5/ gr.2 (primary)	Russia	AA 53805	Human bone	4324±56
Grachevka II mound 5/ gr.2 (primary)	Russia	IGAN 2875	Human bone	4330±60
Panitskoe 6B/ gr.6., ind. 2	Russia	Ki-13049	Human bone	4250±110
Panitskoe 6B/ gr.6., ind. 1	Russia	Ki-13050	Human bone	4500±120
Panitskoe 6B/ gr. 7	Russia	Ki-14744	Animal bone	4050±100
Podlesnoe I mound 3/gr. 3	Russia	GIN 13208	Wood	4290±50
Podlesnoe I mound 3/gr. 4	Russia	GIN 13206	Wood	4260±50
Krasnosamarskoe IV mound 1/ gr. 3	Russia	AA 37031	Human bone	4241±70
Boldyrevo I mound 1/ gr.1	Russia	Ki14518	Plant decay	4080±70
Boldyrevo I mound 1/ gr.1	Russia	Ki 14519	Plant decay	4340±80
Tamar-Utkul VII mound 1/ gr.1	Russia	GrA 54386	Human bone	4105±35

Tamar-Utkul VII mound 4/ gr.9	Russia	GrA 54383	Human bone	4145±35
Tamar-Utkul VII mound 8/ gr.4	Russia	GrA 54390	Human bone	4145±35
Tamar-Utkul VIII mound 4/ gr.1	Russia	GrA 54382	Human bone	4165±35
Tamar-Utkul VIII mound 8/ gr.1	Russia	Poz-47845	ceramics	4260±90
Pyatiletka V mound 5/gr. 2	Russia	GrA 54392	Human bone	4140±35
Nizhnyaya Pavlovka V 1/2	Russia	GrA 54391	Human bone	4175±35
Mu-Sharet-1 mound 5/ gr. 3	Russia	IGAN-2275	Human bone	4240±60
Mu-Sharet-1 mound 5/ gr. 3	Russia	GrA-17461	Wood	4045±35
Mu-Sharet 4 mound 12/gr.1	Russia	IGAN-2274	Human bone	4551±76
Mu-sharet-4 mound 11/ gr.3	Russia	GrA-17462	Charcoal	4180±35
Mu-sharet-4 mound 1/ gr.3	Russia	GrA-32892	Animal bone	4160±35
Mandjikiny-1 mound 3/ gr.2	Russia	IGAN-1850	Wood	3980±110
Mandjikiny-1 mound 14/ gr.10	Russia	IGAN-2402	Human bone	4350±76
Mandjikiny-1 mound 14/ gr.12	Russia	IGAN-2492	Human bone	4033±76

Mandjikiny-2 mound 11/ gr. 2	Russia	IGAN-2058	Human bone	4189±49
Mandjikiny-2 mound 11/ gr. 2	Russia	IGAN-2042	Wood	3920±70
Mandjikiny-2 mound 11/ gr. 3	Russia	GrA-39349	Bone pin (animal bone)	4320±60
Mandjikiny-2 mound 11/ gr. 3	Russia	GrA-12690	Wood	4060±50
Mandjikiny-2 mound 11/ gr. 3	Russia	IGAN-2056	Human bone	4050±50
Peschanyi V mound 1/ gr.3	Russia	IGAN-2880	Human bone	4312±94
Peschanyi V mound 15/ gr.6	Russia	IGAN 4212	Wood	3930±80
Peschanyi V mound 15/ gr.6	Russia	Gr-55092	Wood	4140±35
Khar-Zukha mound 2/ gr,3	Russia	OxA-4732	Human bone	4480±75
Chighir mound 2/ gr.3	Russia	IGAN-2705	Human bone	4213±57
Peschanyi IV mound 11/gr. 4	Russia	GrA67588	Human bone	4180±35
Peschanyi IV mound 11/gr. 4	Russia	GrA67587	Animal bone (sheep)	4175±35
Peschanyi IV mound 13/gr. 5	Russia	GrA64621	Human bone	4200±35
Peschanyi IV mound 13/gr.6	Russia	GrA64624	Wood	4145±35

Peschanyi IV mound 13/gr.6	Russia	GrA64622	Human bone (child)	4130±35
Peschanyi IV mound 16/gr.4	Russia	GrM16406	Human bone	4210±25
Lopatino I 35/1	Russia	Beta 39248	Human bone	4380±30

SUPPLEMENTARY TABLE 3. Calibrated dates for the sample.

SAMPLE CODE	**MATERIAL**	**DATE (BP)**	**FROM CALIBRATED DATE (OXCAL 4.4/ IntCal 2020 95,4%)/ calBC**	**TO CALIBRATED DATE (OXCAL 4.4/ IntCal 2020 95,4%)/ calBC**
DeA-10666	Human bone	4176±32	2886	2636
DeA-10667	Human bone	4123±33	2870	2578
DeA-10668	Human bone	4140±33	2875	2584
DeA-2797.1.1	Human bone	4287±38	3016	2871
DeA-8817	Human bone	4357±35	3089	2899
DeA-7739	Human bone	4240±54	3007	2630
DeA-7737	Human bone	4142±30	2875	2585
DeA-7735	Human bone	4126±31	2869	2580

DeA-8813	Human bone	4174±33	2886	2631
DeA-16952	Human bone	4212±29	2901	2676
DeA-7738	Human bone	4018±32	2623	2467
DeA 14449	Human bone	4353±28	3077	2902
Poz-46583	Wood	4220±35	2907	2674
Poz-65968	Human bone	3950±35	2571	2305
Poz 78170	Human bone	4130±35	2872	2580
Poz-56765	Carbonated wood	4135±30	2873	2583
RoAMS 5E	Carbonated wood	4147±31	2877	2623
Poz-53778	Human bone	4115±30	2867	2576
RoAMS 5C	Human tooth	4104±25	2861	2573
?1	Human bone	4225±37	2910	2674
?2	Human bone	4037±43	2846	2464
Poz-66988	Human bone	4190±35	2893	2635
Bln-609	Human bone	4265±80	3096	2583
Poz-39454	Human bone	4075±35	2875	2476
poz-39456	Human bone	4195±35	2895	2636
Poz-42724	Human bone	4215±35	2905	2672
Poz-38461	Human bone	4320±35	3021	2886
Poz-31405	Human bone	4210±35	2902	2671
deb-7182	Human bone	4135±60	2885	2501
deb-6871	Human bone	4060±50	2861	2468
deb-6639	Human bone	4350±40	3092	2893
Bln-3301	Human bone	4080±50	2866	2475
Bln-3302	Human bone	4360±50	3313	2886
Bln-2501	Human bone	4170±50	2891	2584
OxA-22951	Human bone	4186±27	2889	2668

SUERC-95534	Human bone	4184±24	2886	2670
SUERC-95535	Human bone	4138±22	2873	2623
SUERC-95536	Human bone	4176±24	2884	2640
SUERC-95544	Human bone	4372±23	3082	2912
SUERC-95545	Human bone	4145±22	2873	2628
SUERC-97444	Human bone	4127±30	2869	2581
SUERC-97448	Human bone	4154±27	2876	2630
SUERC-97442	Human bone	4117±25	2866	2577
SUERC-97443	Human bone	4158±29	2878	2631
SUERC-97450	Human bone	4158±25	2878	2631
SUERC-97451	Human bone	4142±29	2875	2586
SUERC-97452	Human bone	4172±27	2883	2635
MAMS-28025	Human bone	4360±27	3028	2905
MAMS-28026	Human bone	4397±27	3098	2917
MAMS-26934	Human bone	4333±20	3011	2898

MAMS-28031	Human bone	4308±28	3011	2884
SUERC-63817	Human bone	4428±33	3329	2922
SUERC-84759	Human bone	4314±26	3011	2887
SUERC-86512	Human bone	4520±34	3361	3099
SUERC-84760	Human bone	4123±26	2866	2580
SUERC-95537	Human bone	4414±25	3310	2920
SUERC-63829	Human bone	4342±33	3076	2894
SUERC-84750	Human bone	4380±26	3091	2912
Poz-88657	Wood	4170±40	2886	2627
Poz-88664	Human bone	4195±35	2895	2636
Poz-100501	Human bone	4125±35	2871	2578
Poz-100500	Human bone	4130±30	2871	2581
Bln-2219	Wood	4320±50	3094	2876
Poz-93213	Human bone	4100±40	2870	2489
Poz-88701	Human bone	4290±35	3012	2875
Lu-2476	Wood	4480±50	3361	2970
Lu-2459	Wood	4360±30	3085	2903
Lu-2474	Wood	4530±50	3482	3033
Ki-9980	Wood	4150±70	2896	2499
Ki-421	Wood	3970±80	2894	2206

Ki-491	Wood	3940±120	2868	2061
Le-?	Wood	3830±120	2621	1936
Ki-522	Wood	4530±130	3618	2907
Ki-494	Wood	4080±100	2896	2349
Ki-9981	Wood	4080±70	2873	2471
Vi-?	Wood	4215±65	2922	2581
Ki-9982	Wood	4105±70	2880	2488
Ki-9980	Wood	4150±70	2880	2488
Ki-7072	Wood	4360±70	3331	2880
Le-1168	Wood	4080±90	2893	2359
Ki-587	Wood	3990±140	2878	2201
Ki-7073	Wood	3930±60	2575	2207
Ki-602	Wood	4070±120	2907	2291
Ki-581	Wood	3820±190	2870	1771
Ki-578	Wood	4160±170	3332	2238
Ki-549a	Wood	4200±70	2917	2576
Ki-6827	Human bone	3910±45	2563	2209
Ki-6571	Human bone	3985±45	2625	2344
Ki-6571a	Human bone	4035±50	2855	2460
Ki-6828	Human bone	3960±50	2617	2293
Ki-6572	Human bone	4060±55	2866	2467
Ki-6572a	Human bone	4005±55	2846	2343
Ki-6829	Human bone	3900±55	2564	2204
Ki-6829a	Human bone	3990±50	2560	2206
Ki-7132	Human bone	3930±70	2621	2201
Ki-6833	Human bone	3900±55	2564	2204
Ki-6834	Human bone	3970±50	2621	2298
Ki-6834a	Human bone	3930±50	2572	2236
Ki-6718	Human bone	3920±60	2572	2206
Ki-6730	Human bone	3960±60	2627	2213

Ki-6730a	Human bone	3925±50	2571	2210
Ki-6731	Human bone	4005±55	2846	2343
Ki-7135	Human bone	4020±70	2866	2343
Ki-6719	Human bone	3970±55	2626	2293
Ki-7133	Human bone	3960±60	2627	2213
Ki-6720	Human bone	3880±55	2554	2150
Ki-6721	Human bone	3850±55	2467	2146
Ki-6722	Human bone	3980±60	2837	2291
Ki-7136	Human bone	3940±70	2624	2204
Ki-6723	Human bone	4030±60	2865	2350
Ki-7134	Human bone	4035±60	2867	2359
Ki-6724	Human bone	3950±50	2576	2291
Ki-6727	Human bone	3910±55	2567	2206
Ki-6725	Human bone	3950±55	2618	2235
Ki-6726	Human bone	3840±50	2462	2146
Ki-6728	Human bone	3905±55	2566	2204
Ki-6729	Human bone	3920±50	2569	2209
Ki-6733	Human bone	3945±50	2575	2290
Ki-6734	Human bone	3925±55	2571	2209
Ki-7131	Human bone	3910±60	2570	2204
Ki-6732	Human bone	3890±55	2561	2201
Ki-7130	Human bone	3920±50	2569	2209
Ki-6714	Human bone	3990±50	2828	2307
Ki-6715	Human bone	3945±50	2575	2290
Ki-6716	Human bone	3905±60	2568	2203
Ki-6717	Human bone	3865±50	2469	2154
Ki-6741	Wood	4235±60	3010	2624
Ki-5826	Bone	3875±60	2557	2146
Ki-5825		3810±55	2459	2054
Ki-5828	Human bone	4010±60	2852	2343

Ki-5823	Human bone	3895±60	2567	2201
Ki-437	Wood	3890±105	2833	2034
Ki-7070	Wood	3890±65	2657	2149
Ki-10013	Wood	3925±110	2857	2047
Ki-7069	Wood	3920±60	2572	2206
Ki-11058	Human bone	3910±60	2570	2204
Ki-11059	Human bone	4135±60	2885	2501
Ki-11177	Human bone	3990±70	2851	2290
Bln-4691	Wood	4371±36	3093	2905
Ki-9917	Wood	4570±80	3526	3021
Ki-9919	Wood	4535±80	3511	2934
Ki-1708	Wood	4250±50	3011	2636
Ki-7076	Wood	4130±70	2888	2495
Ki-7124	Wood	4365±55	3322	2887
Ki-7077	Wood	4170±60	2893	2581
Ki-7125	Wood	4335±60	3321	2783
Ki-9898	Wood	4410±70	3336	2906
Ki-7260	Wood	4465±60	3354	2931
Ki-13873	Human bone	3800±80	2468	1986
Ki-13876	Human bone	4220±90	3079	2499
Ki-14719	Human bone	3965±80	2848	2204
KIA-29935	Human bone	4142±40	2877	2583
Ki-13859	Human bone	4250±70	3076	2587
KIA-29937	Human bone	4408±31	3315	2915
KIA-28682	Wood (rings 97-94)	4462±33	3340	3018
KIA-28683	Wood (rings 22-28)	4425±24	3320	2926
KIA-29934	Human bone	4316±33	3016	2886
KiA-13863	Human bone	3840±40	2458	2152

Ki-13858	Human bone	4370±90	3354	2784
KIA-29936	Human bone	4271±34	3008	2706
Ki-13864	Human bone	4340±80	3336	2705
Ki-1217	Wood	3950±90	2849	2148
Ki-7078	Wood	4180±60	2898	2582
Ki-9927	Wood	3920±70	2579	2153
Ki-1439	Wood	3800±120	2572	1901
Ki-1711	Wood	4250±80	3087	2580
Ki-7079	Wood	4105±65	2880	2490
Hd-19931	Human bone	4148±26	2875	2627
Ki-9517	Human bone	3980±70	2848	2235
Ki-9518	Human bone	3980±70	2848	2235
Ki-2394	Wood	4490±90	3491	2914
Ki-1753	Wood	4380±50	3322	2896
Ki-7088	Wood	4130±65	2886	2497
Ki-2126	Wood	4600±90	3627	3030
Ki-1219	Wood	4490±70	3368	2930
Ki-1220	Wood	3800±60	2458	2041
Ki-7080	Wood	4205±55	2910	2625
Ki-7085	Wood	4180±60	2898	2582
Ki-7127	Wood	4055±65	2872	2462
Ki-7086	Wood	4235±55	3005	2627
Ki-7128	Wood	4005±50	2841	2346
Ki-8294	Wood	4190±80	3002	2496
Ki-2124	Wood	4200±70	2917	2576
Ki-7090	Wood	3960±60	2627	2213
Ki-7092	Wood	4040±55	2865	2458
Ki-2129	Wood	3960±55	2623	2289
Ki-2107	Wood	3980±45	2623	2343
KI-7091	Wood	3920±60	2572	2206

Ki-2120	Wood	4760±55	3641	3377
Ki-15015	Human bone	3880±60	2560	2149
Ki-16892	Human bone	3895±70	2571	2147
Poz-52424	Wood	4082±35	2862	2491
Poz-81793	Human bone	4085±30	2857	2495
Poz-47741	Human bone	4075±35	2857	2476
Poz-66228	Human bone	4090±35	2856	2494
Poz-66230	Wood	4455±35	3340	2937
Poz-66629	Human bone	4380±35	2998	2906
Poz-66231	Wood	4185±35	2891	2632
Poz-70673	Human bone	4090±40	2868	2493
Poz-66232	Human bone	4090±40	2868	2493
LE 6732	Wood	4140±25	2874	2586
IGAN 2780	Wood	4070±30	2850	2488
IGAN 2869	humus of buried paleosol	4180±70	2907	2575
IGAN 3016	humus of buried paleosol	4480±100	3495	2903
Poz-47868	ceramics	4245±35	2919	2697
LE 7021	Human bone	4330±100	3350	2636
IGAN 3017	humus of buried paleosol	4290±80	3316	2628
LE 8580	Human bone	4230±150	3339	2466
LE 8578	Human bone	4180±140	3321	2347
LE 8579	Human bone	4440±140	3626	2638
BM 3157	Human bone	4200±60	2910	2584

LE 6088	wood	4100±40	2870	2488
LE 6090	Human bone	4060±120	2904	2238
IGAN 2448	wood	3980±50	2626	2302
IGAN 2391	humus of buried paleosol	4030±120	2889	2209
LE 6087	Wood	4070±45	2861	2472
Le 6089	Human bone	4080±100	2896	2349
AA 47805	Human bone	4234±60	3010	2623
LE 6091	Human bone	4300±150	3365	2496
OxA 4306	Human bone	4400±70	3335	2900
AA 12570	Human bone	4370±75	3335	2883
UKLA-1271	Human bone	4150±80	2903	2493
AA 12573	Human bone	4520±75	3495	2930
OxA 4255	Human bone	4230±80	3022	2576
OxA 4254	Human bone	4520±75	3495	2930
IGAN 3233	Human bone	4542±75	3515	3012
GIN-11452	Human bone	4250±40	3002	2675
AA 53804	Human bone	4179±55	2896	2584
IGAN 2876	Human bone	4050±70	2876	2410
AA 53805	Human bone	4324±56	3283	2776
IGAN 2875	Human bone	4330±60	3319	2777
Ki-13049	Human bone	4250±110	3325	2495
Ki-13050	Human bone	4500±120	3516	2904
Ki-14744	Animal bone	4050±100	2885	2307
GIN 13208	Wood	4290±50	3085	2702
GIN 13206	Wood	4260±50	3014	2674
AA 37031	Human bone	4241±70	3020	2584
Ki14518	Plant decay	4080±70	2873	2471
Ki 14519	Plant decay	4340±80	3336	2705

GrA 54386	Human bone	4105±35	2868	2501
GrA 54383	Human bone	4145±35	2874	2581
GrA 54390	Human bone	4145±35	2877	2585
GrA 54382	Human bone	4165±35	2881	2630
Poz-47845	ceramics	4260±90	3307	2574
GrA 54392	Human bone	4140±35	2875	2584
GrA 54391	Human bone	4175±35	2886	2631
IGAN-2275	Human bone	4240±60	3011	2672
GrA-17461	Wood	4045±35	2839	2469
IGAN-2274	Human bone	4551±76	3516	3019
GrA-17462	Charcoal	4180±35	2888	2632
GrA-32892	Animal bone	4160±35	2881	2627
IGAN-1850	Wood	3980±110	2872	2201
IGAN-2402	Human bone	4350±76	3336	2782
IGAN-2492	Human bone	4033±76	2872	2347
IGAN-2058	Human bone	4189±49	2897	2627
IGAN-2042	Wood	3920±70	2579	2153
GrA-39349	Bone pin (animal bone)	4320±60	3312	2704
GrA-12690	Wood	4060±50	2861	2468
IGAN-2056	Human bone	4050±50	2858	2566
IGAN-2880	Human bone	4312±94	3335	2634
IGAN 4212	Wood	3930±80	2662	2145
Gr-55092	Wood	4140±35	2875	2584
OxA-4732	Human bone	4480±75	3366	2926
IGAN-2705	Human bone	4213±57	2916	2623
GrA67588	Human bone	4180±35	2888	2632
GrA67587	Animal bone (sheep)	4175±35	2886	2631

GrA64621	Human bone	4200±35	2898	2639
GrA64624	Wood	4145±35	2877	2585
GrA64622	Human bone (child)	4130±35	2872	2580
GrM16406	Human bone	4210±25	2898	2696
Beta 39248	Human bone	4380±30	3083	2911

SUPPLEMENTARY TABLE 4. The source of the dates.

SAMPLE CODE	**MATERIAL**	**DATE (BP)**	**SOURCE OF THE DATE**
DeA-10666	Human bone	4176±32	Frînculeasa 2019
DeA-10667	Human bone	4123±33	Frînculeasa 2019
DeA-10668	Human bone	4140±33	Frînculeasa 2019
DeA-2797.1.1	Human bone	4287±38	Frînculeasa *et al.*2014
DeA-8817	Human bone	4357±35	Frînculeasa *et al.*2017

DeA-7739	Human bone	4240±54	Frînculeasa *et al.*2017
DeA-7737	Human bone	4142±30	Frînculeasa *et al.*2017
DeA-7735	Human bone	4126±31	Frînculeasa *et al.*2017
DeA-8813	Human bone	4174±33	Frînculeasa *et al.*2019
DeA-16952	Human bone	4212±29	Frînculeasa *et al.*2019
DeA-7738	Human bone	4018±32	Frînculeasa *et al.*2019
DeA 14449	Human bone	4353±28	Frînculeasa *et al.*2018
Poz-46583	Wood	4220±35	Ailincai *et al.* 2014
Poz-65968	Human bone	3950±35	Ailincai *et al.* 2016
Poz 78170	Human bone	4130±35	Diaconescu & Tincu 2016, Diaconescu 2020
Poz-56765	Carbonated wood	4135±30	Diaconescu & Tincu 2016, Diaconescu 2020
RoAMS 5E	Carbonated wood	4147±31	Diaconescu & Tincu 2016, Diaconescu 2020

Poz-53778	Human bone	4115±30	Diaconescu & Tincu 2016, Diaconescu 2020
RoAMS 5C	Human tooth	4104±25	Diaconescu & Tincu 2016, Diaconescu 2020
?1	Human bone	4225±37	Frînculeasa 2020
?2	Human bone	4037±43	Frînculeasa 2020
Poz-66988	Human bone	4190±35	Krauss *et al.* 2016
Bln-609	Human bone	4265±80	Ecsedy 1979, Horváth *et al.* 2013
Poz-39454	Human bone	4075±35	Frinculeasa *et al*. 2015
poz-39456	Human bone	4195±35	Frinculeasa *et al*. 2015
Poz-42724	Human bone	4215±35	Frinculeasa *et al*. 2015
Poz-38461	Human bone	4320±35	Frinculeasa *et al*. 2015
Poz-31405	Human bone	4210±35	Frinculeasa *et al*. 2015
deb-7182	Human bone	4135±60	Dani & Nepper 2006,

			Frinculeasa *et al.* 2020
deb-6871	Human bone	4060±50	Dani & Nepper 2006, Frinculeasa *et al.* 2021
deb-6639	Human bone	4350±40	Dani & Nepper 2006, Frinculeasa *et al.* 2022
Bln-3301	Human bone	4080±50	Panayotov & Derhachev 1984, Boyadziev 1995, Kaiser & Winger 2015, Frînculeasa *et al.* 2015
Bln-3302	Human bone	4360±50	Panayotov 1989, Boyadziev 1995, Kaiser & Winger 2015, Frînculeasa *et al*. 2015
Bln-2501	Human bone	4170±50	Panayotov 1989, Boyadziev 1995, Kaiser & Winger 2015,

			Frînculeasa *et al*. 2015
OxA-22951	Human bone	4186±27	Agre 2015, Kaiser & Winger 2015
SUERC-95534	Human bone	4184±24	Alexandrov *et al.* 2021
SUERC-95535	Human bone	4138±22	Alexandrov *et al.* 2021
SUERC-95536	Human bone	4176±24	Alexandrov *et al.* 2021
SUERC-95544	Human bone	4372±23	Alexandrov *et al.* 2021
SUERC-95545	Human bone	4145±22	Alexandrov *et al.* 2021
SUERC-97444	Human bone	4127±30	Alexandrov *et al.* 2021
SUERC-97448	Human bone	4154±27	Alexandrov *et al.* 2021
SUERC-97442	Human bone	4117±25	Alexandrov *et al.* 2021
SUERC-97443	Human bone	4158±29	Alexandrov *et al.* 2021
SUERC-97450	Human bone	4158±25	Alexandrov *et al.* 2021
SUERC-97451	Human bone	4142±29	Alexandrov *et al.* 2021
SUERC-97452	Human bone	4172±27	Alexandrov *et al.* 2021

MAMS-28025	Human bone	4360±27	Alexandrov *et al.* 2016
MAMS-28026	Human bone	4397±27	Alexandrov *et al.* 2016
MAMS-26934	Human bone	4333±20	Panayotov & Alexandrov 1995
MAMS-28031	Human bone	4308±28	Alexandrov 2018, Alexandrov *in prep*
SUERC-63817	Human bone	4428±33	Iliev 2018, Alexandrov *in prep*
SUERC-84759	Human bone	4314±26	Alexandrov *in prep*
SUERC-86512	Human bone	4520±34	Alexandrov 2011
SUERC-84760	Human bone	4123±26	Alexandrov 2011
SUERC-95537	Human bone	4414±25	Alexandrov *in prep*
SUERC-63829	Human bone	4342±33	Alexandrov & Hristova 2009
SUERC-84750	Human bone	4380±26	Alexandrov et al. 2019
Poz-88657	Wood	4170±40	Koledin *et al*. 2020
Poz-88664	Human bone	4195±35	Koledin *et al*. 2020

Poz-100501	Human bone	4125±35	Koledin *et al*. 2020
Poz-100500	Human bone	4130±30	Koledin *et al*. 2020
Bln-2219	Wood	4320±50	Koledin *et al*. 2020
Poz-93213	Human bone	4100±40	Koledin *et al*. 2020
Poz-88701	Human bone	4290±35	Koledin *et al*. 2020
Lu-2476	Wood	4480±50	Levizki *et al.* 1996, Rassmakin & Nikolova 2008
Lu-2459	Wood	4360±30	Levizki *et al.* 1996, Rassamakin & Nikolova 2008
Lu-2474	Wood	4530±50	Yarovoi 2000, Rassamakin & Nikolova 2008
Ki-9980	Wood	4150±70	Telegin 1977, Telegin *et al*. 2003, Rassamakin & Nikolova 2008
Ki-421	Wood	3970±80	Telegin 1977, Rassamakin & Nikolova 2008

Ki-491	Wood	3940±120	Telegin 1977, Rassamakin & Nikolova 2008
Le-?	Wood	3830±120	Telegin 1977, Rassamakin & Nikolova 2008
Ki-522	Wood	4530±130	Telegin 1977, Rassamakin & Nikolova 2008
Ki-494	Wood	4080±100	Telegin 1977, Rassamakin & Nikolova 2008
Ki-9981	Wood	4080±70	Telegin *et al*. 2003, Rassamakin & Nikolova 2008
Vi-?	Wood	4215±65	Telegin 1977, Rassamakin & Nikolova 2008
Ki-9982	Wood	4105±70	Telegin 1977, Rassamakin & Nikolova 2008
Ki-9980	Wood	4150±70	Telegin 1977, Rassamakin & Nikolova 2008
Ki-7072	Wood	4360±70	Telegin 1977, Nazarov & Kovalyukh 1999, Rassamakin & Nikolova 2008

Le-1168	Wood	4080±90	Telegin 1977, Lyashko & Otroschenko 1986, Rassamakin & Nikolova 2008
Ki-587	Wood	3990±140	Telegin 1977, Lyashko & Otroschenko 1986, Rassamakin & Nikolova 2008
Ki-7073	Wood	3930±60	Telegin 1977, Nazarov & Kovalyukh 1999, Rassamakin & Nikolova 2008
Ki-602	Wood	4070±120	Telegin 1977, Rassamakin & Nikolova 2008
Ki-581	Wood	3820±190	Telegin 1977, Rassamakin & Nikolova 2008
Ki-578	Wood	4160±170	Telegin 1977, Telegin et al. 2003, Rassamakin & Nikolova 2008
Ki-549a	Wood	4200±70	Telegin 1977, Telegin et al.

			2003, Rassamakin & Nikolova 2008
Ki-6827	Human bone	3910±45	Nikolova 1999a, Rassamakin & Nikolova 2008
Ki-6571	Human bone	3985±45	Nikolova 1999a, Rassamakin & Nikolova 2008
Ki-6571a	Human bone	4035±50	Nikolova 1999a, Rassamakin & Nikolova 2008
Ki-6828	Human bone	3960±50	Nikolova 1999a, Rassamakin & Nikolova 2008
Ki-6572	Human bone	4060±55	Nikolova 1999a, Rassamakin & Nikolova 2008
Ki-6572a	Human bone	4005±55	Nikolova 1999a, Rassamakin & Nikolova 2008
Ki-6829	Human bone	3900±55	Nikolova 1999a, Rassamakin & Nikolova 2008

Ki-6829a	Human bone	3990±50	Nikolova 1999a, Rassamakin & Nikolova 2008
Ki-7132	Human bone	3930±70	Nikolova 1999a, Rassamakin & Nikolova 2008
Ki-6833	Human bone	3900±55	Nikolova 1999a, Rassamakin & Nikolova 2008
Ki-6834	Human bone	3970±50	Nikolova 1999a, Rassamakin & Nikolova 2008
Ki-6834a	Human bone	3930±50	Nikolova 1999a, Rassamakin & Nikolova 2008
Ki-6718	Human bone	3920±60	Nikolova 1999b
Ki-6730	Human bone	3960±60	Nikolova 1999b
Ki-6730a	Human bone	3925±50	Nikolova 1999b
Ki-6731	Human bone	4005±55	Nikolova 1999b, Rassamakin & Nikolova 2008

Ki-7135	Human bone	4020±70	Kovalyukh & Nazarov 1999, Rassamakin & Nikolova 2008
Ki-6719	Human bone	3970±55	Nikolova 1999b, Rassamakin & Nikolova 2008
Ki-7133	Human bone	3960±60	Kovalyukh & Nazarov 1999, Rassamakin & Nikolova 2008
Ki-6720	Human bone	3880±55	Nikolova 1999b, Rassamakin & Nikolova 2008
Ki-6721	Human bone	3850±55	Nikolova 1999b, Rassamakin & Nikolova 2008
Ki-6722	Human bone	3980±60	Nikolova 1999b, Rassamakin & Nikolova 2008
Ki-7136	Human bone	3940±70	Kovalyukh & Nazarov 1999, Rassamakin & Nikolova 2008
Ki-6723	Human bone	4030±60	Nikolova 1999b,

			Rassamakin & Nikolova 2008
Ki-7134	Human bone	4035±60	Kovalyukh & Nazarov 1999, Rassamakin & Nikolova 2008
Ki-6724	Human bone	3950±50	Nikolova 1999b, Rassamakin & Nikolova 2008
Ki-6727	Human bone	3910±55	Nikolova 1999b, Rassamakin & Nikolova 2008
Ki-6725	Human bone	3950±55	Nikolova 1999b, Rassamakin & Nikolova 2008
Ki-6726	Human bone	3840±50	Nikolova 1999b, Rassamakin & Nikolova 2008
Ki-6728	Human bone	3905±55	Nikolova 1999b, Rassamakin & Nikolova 2008
Ki-6729	Human bone	3920±50	Nikolova 1999b, Rassamakin & Nikolova 2008

Ki-6733	Human bone	3945±50	Nikolova 1999b, Rassamakin & Nikolova 2008
Ki-6734	Human bone	3925±55	Nikolova 1999b, Rassamakin & Nikolova 2008
Ki-7131	Human bone	3910±60	Nikolova 1999b, Rassamakin & Nikolova 2008
Ki-6732	Human bone	3890±55	Nikolova 1999b, Rassamakin & Nikolova 2008
Ki-7130	Human bone	3920±50	Nikolova 1999b, Rassamakin & Nikolova 2008
Ki-6714	Human bone	3990±50	Klochko & Kruts 1999, Rassamakin & Nikolova 2008
Ki-6715	Human bone	3945±50	Klochko & Kruts 1999, Rassamakin & Nikolova 2008
Ki-6716	Human bone	3905±60	Klochko & Kruts 1999,

			Rassamakin & Nikolova 2008
Ki-6717	Human bone	3865±50	Klochko & Kruts 1999, Rassamakin & Nikolova 2008
Ki-6741	Wood	4235±60	Klochko 1999, Rassamakin & Nikolova 2008
Ki-5826	Bone	3875±60	Klochko 1999, Rassamakin & Nikolova 2008
Ki-5825		3810±55	Klochko 1999, Rassamakin & Nikolova 2008
Ki-5828	Human bone	4010±60	Klochko 1999, Rassamakin & Nikolova 2008
Ki-5823	Human bone	3895±60	Klochcko 1999
Ki-437	Wood	3890±105	Telegin 1977, Rassamakin & Nikolova 2008
Ki-7070	Wood	3890±65	Telegin 1977, Nazarov & Kovalyukh 1999, Rassamakin & Nikolova 2008
Ki-10013	Wood	3925±110	Telegin 1977, Rassamakin & Nikolova 2008

Ki-7069	Wood	3920±60	Telegin 1977, Rassamakin & Nikolova 2008
Ki-11058	Human bone	3910±60	Ivanova, Petrenko & Vetchinnikova 2005
Ki-11059	Human bone	4135±60	Ivanova, Petrenko & Vetchinnikova 2005
Ki-11177	Human bone	3990±70	Ivanova, Petrenko & Vetchinnikova 2005
Bln-4691	Wood	4371±36	Görsdorf *et al.* 2004, Rassamakin 2013
Ki-9917	Wood	4570±80	Konstantinesku 1984, Rassamakin & Nikolova 2008
Ki-9919	Wood	4535±80	Konstantinesku 1984, Rassamakin & Nikolova 2008
Ki-1708	Wood	4250±50	Kontanstinesku 1984, Nazarov & Kovalyukh 1999,

			Rassamakin & Nikolova 2008
Ki-7076	Wood	4130±70	Kontanstinesku 1984, Nazarov & Kovalyukh 1999, Rassamakin & Nikolova 2008
Ki-7124	Wood	4365±55	Kontanstinesku 1984, Nazarov & Kovalyukh 1999, Rassamakin & Nikolova 2008
Ki-7077	Wood	4170±60	Kontanstinesku 1984, Nazarov & Kovalyukh 1999, Rassamakin & Nikolova 2008
Ki-7125	Wood	4335±60	Kontanstinesku 1984, Nazarov & Kovalyukh 1999, Rassamakin & Nikolova 2008
Ki-9898	Wood	4410±70	Kontanstinesku 1984, Nazarov & Kovalyukh 1999,

			Rassamakin & Nikolova 2008
Ki-7260	Wood	4465±60	Kontanstinesku 1984, Nazarov & Kovalyukh 1999, Rassamakin & Nikolova 2008
Ki-13873	Human bone	3800±80	Chernykh & Daragan 2014, Rassamakin 2014
Ki-13876	Human bone	4220±90	Chernykh & Daragan 2014, Rassamakin 2014
Ki-14719	Human bone	3965±80	Chernykh & Daragan 2014, Rassamakin 2014
KIA-29935	Human bone	4142±40	Nikolova & Kaiser 2009, Nikolova 2009
Ki-13859	Human bone	4250±70	Nikolova & Kaiser 2009, Nikolova 2009
KIA-29937	Human bone	4408±31	Nikolova & Kaiser 2009, Nikolova 2009

KIA-28682	Wood (rings 97-94)	4462±33	Nikolova & Kaiser 2009, Nikolova 2009
KIA-28683	Wood (rings 22-28)	4425±24	Nikolova & Kaiser 2009, Nikolova 2009
KIA-29934	Human bone	4316±33	Nikolova & Kaiser 2009, Nikolova 2009
KiA-13863	Human bone	3840±40	Nikolova & Kaiser 2009, Nikolova 2009
Ki-13858	Human bone	4370±90	Nikolova & Kaiser 2009, Nikolova 2009
KIA-29936	Human bone	4271±34	Nikolova & Kaiser 2009, Nikolova 2009
Ki-13864	Human bone	4340±80	Nikolova & Kaiser 2009, Nikolova 2009
Ki-1217	Wood	3950±90	Dvoryaninov *et al.* 1985, Rassamakin & Nikolova 2008
Ki-7078	Wood	4180±60	Dvoryaninov *et al.* 1985, Rassamakin & Nikolova 2008
Ki-9927	Wood	3920±70	Dvoryaninov *et al.* 1985,

			Rassamakin & Nikolova 2008
Ki-1439	Wood	3800±120	Dvoryaninov *et al.* 1985, Rassamakin & Nikolova 2008
Ki-1711	Wood	4250±80	Dvoryaninov *et al.* 1985, Rassamakin & Nikolova 2008
Ki-7079	Wood	4105±65	Dvoryaninov *et al.* 1985, Rassamakin & Nikolova 2008
Hd-19931	Human bone	4148±26	Govedarica *et al.* 2006
Ki-9517	Human bone	3980±70	Sanzharov & Chernykh 2011
Ki-9518	Human bone	3980±70	Sanzharov & Chernykh 2011
Ki-2394	Wood	4490±90	Subbotin & Toschev 2002, Rassamankin & Nikolova 2008
Ki-1753	Wood	4380±50	Rassamankin & Nikolova 2008, Subbotin, Razumov & Sinika 2017

Ki-7088	Wood	4130±65	Rassamankin & Nikolova 2008, Subbotin, Razumov & Sinika 2017
Ki-2126	Wood	4600±90	Rassamankin & Nikolova 2008, Subbotin, Razumov & Sinika 2017
Ki-1219	Wood	4490±70	Subbotin *et al.* 1995, Rassamakin & Nikolova 2008
Ki-1220	Wood	3800±60	Subbotin *et al.* 1995, Rassamakin & Nikolova 2008
Ki-7080	Wood	4205±55	Subbotin *et al.* 1995, Rassamakin & Nikolova 2008
Ki-7085	Wood	4180±60	Subbotin *et al*. 1995 1995, Nazarov & Kovalyukh 1999, Rassamakin & Nikolova 2008

Ki-7127	Wood	4055±65	Subbotin *et al*. 1995 1995, Telegin et al. 2003, Rassamakin & Nikolova 2008
Ki-7086	Wood	4235±55	Subbotin *et al*. 1995 1995, Nazarov & Kovalyukh 1999, Rassamakin & Nikolova 2008
Ki-7128	Wood	4005±50	Subbotin *et al*. 1995 1995, Telegin et al. 2003, Rassamakin & Nikolova 2008
Ki-8294	Wood	4190±80	Subbotin *et al.* 1995 1995, Telegin et al. 2003, Rassamakin & Nikolova 2008
Ki-2124	Wood	4200±70	Nazarov & Kovlyukh 1999, Rassamakin & Nikolova 2008,

			Bunyatyan & Nikolova 2010
Ki-7090	Wood	3960±60	Nazarov & Kovlyukh 1999, Rassamakin & Nikolova 2008, Bunyatyan & Nikolova 2010
Ki-7092	Wood	4040±55	Nazarov & Kovlyukh 1999, Rassamakin & Nikolova 2008, Bunyatyan & Nikolova 2010
Ki-2129	Wood	3960±55	Rassamakin & Nikolova 2008, Bunyatyan & Nikolova 2010
Ki-2107	Wood	3980±45	Rassamakin & Nikolova 2008, Bunyatyan & Nikolova 2010
KI-7091	Wood	3920±60	Rassamakin & Nikolova 2008, Bunyatyan & Nikolova 2010
Ki-2120	Wood	4760±55	Rassamakin 2006,

			Rassamakin & Nikolova 2008
Ki-15015	Human bone	3880±60	Ivanova & Vetchinnikova 2009
Ki-16892	Human bone	3895±70	Klochko *et al*. 2015a
Poz-52424	Wood	4082±35	Klochko *et al.* 2015a
Poz-81793	Human bone	4085±30	Klochko *et al.* 2015a
Poz-47741	Human bone	4075±35	Klochko *et al.* 2015b
Poz-66228	Human bone	4090±35	Klochko *et al.* 2015c
Poz-66230	Wood	4455±35	Klochko *et al.* 2015c
Poz-66629	Human bone	4380±35	Klochko *et al.* 2015c
Poz-66231	Wood	4185±35	Klochko *et al.* 2015c
Poz-70673	Human bone	4090±40	Klochko *et al.* 2015c
Poz-66232	Human bone	4090±40	Klochko *et al.* 2015c
LE 6732	Wood	4140±25	Morgunova & Khokhlova 2013, Morgunova 2014

IGAN 2780	Wood	4070±30	Morgunova & Khokhlova 2013, Morgunova 2014
IGAN 2869	humus of buried paleosol	4180±70	Morgunova & Khokhlova 2013, Morgunova 2014
IGAN 3016	humus of buried paleosol	4480±100	Morgunova & Khokhlova 2013, Morgunova 2014
Poz-47868	ceramics	4245±35	Morgunova & Khokhlova 2013, Morgunova 2014
LE 7021	Human bone	4330±100	Morgunova & Khokhlova 2013, Morgunova 2014
IGAN 3017	humus of buried paleosol	4290±80	Morgunova & Khokhlova 2013, Morgunova 2014

LE 8580	Human bone	4230±150	Morgunova 2010, Morgunova & Khokhlova 2013
LE 8578	Human bone	4180±140	Morgunova 2010, Morgunova & Khokhlova 2013
LE 8579	Human bone	4440±140	Morgunova 2010, Morgunova & Khokhlova 2013
BM 3157	Human bone	4200±60	Morgunova & Khokhlova 2013, Morgunova 2014
LE 6088	wood	4100±40	Morgunova *et al*. 2003, Morgunova & Khokhlova 2013
LE 6090	Human bone	4060±120	Morgunova *et al*. 2003, Morgunova & Khokhlova 2013

IGAN 2448	wood	3980±50	Morgunova *et al*. 2003, Morgunova & Khokhlova 2013
IGAN 2391	humus of buried paleosol	4030±120	Morgunova *et al*. 2003, Morgunova & Khokhlova 2013
LE 6087	Wood	4070±45	Morgunova & Khokhlova 2013, Morgunova 2014
Le 6089	Human bone	4080±100	Morgunova & Khokhlova 2013, Morgunova 2014
AA 47805	Human bone	4234±60	Morgunova & Khokhlova 2013, Morgunova 2014
LE 6091	Human bone	4300±150	Morgunova & Khokhlova 2013, Morgunova 2014

OxA 4306	Human bone	4400±70	Morgunova & Khokhlova 2013, Morgunova 2014
AA 12570	Human bone	4370±75	Morgunova & Khokhlova 2013, Morgunova 2014
UKLA-1271	Human bone	4150±80	Faifert 2017
AA 12573	Human bone	4520±75	Morgunova 2013, Morgunova & Khokhlova 2013, Morgunova 2014
OxA 4255	Human bone	4230±80	Kuznetsov 2010, Morgunova & Khoklova 2013
OxA 4254	Human bone	4520±75	Morgunova 2013, Morgunova & Khokhlova 2013, Morgunova 2014

IGAN 3233	Human bone	4542±75	Morgunova 2013, Morgunova & Khokhlova 2013, Morgunova 2014
GIN-11452	Human bone	4250±40	Kuznetsov 2010, Morgunova & Khoklova 2013
AA 53804	Human bone	4179±55	Kuznetsov 2010, Morgunova 2013
IGAN 2876	Human bone	4050±70	Kuznetsov 2010, Morgunova 2013
AA 53805	Human bone	4324±56	Morgunova 2014
IGAN 2875	Human bone	4330±60	Morgunova 2014
Ki-13049	Human bone	4250±110	Mimokhod 2009
Ki-13050	Human bone	4500±120	Mimokhod 2009
Ki-14744	Animal bone	4050±100	Mimokhod 2009
GIN 13208	Wood	4290±50	Kuznetsov 2010,

			Morgunova 2013
GIN 13206	Wood	4260±50	Kuznetsov 2010, Morgunova 2013
AA 37031	Human bone	4241±70	Kuznetsov 2010, Morgunova 2013
Ki14518	Plant decay	4080±70	Morgunova & Khokhlova 2013, Morgunova 2014
Ki 14519	Plant decay	4340±80	Morgunova & Khokhlova 2013, Morgunova 2014
GrA 54386	Human bone	4105±35	Morgunova & Khokhlova 2013, Morgunova 2014
GrA 54383	Human bone	4145±35	Morgunova & Khokhlova 2013, Morgunova 2014

GrA 54390	Human bone	4145±35	Morgunova & Khokhlova 2013, Morgunova 2014
GrA 54382	Human bone	4165±35	Morgunova & Khokhlova 2013, Morgunova 2014
Poz-47845	ceramics	4260±90	Morgunova & Khokhlova 2013, Morgunova 2014
GrA 54392	Human bone	4140±35	Morgunova & Khokhlova 2013, Morgunova 2014
GrA 54391	Human bone	4175±35	Morgunova & Khokhlova 2013, Morgunova 2014
IGAN-2275	Human bone	4240±60	Shishlina 2008
GrA-17461	Wood	4045±35	Shishlina 2008
IGAN-2274	Human bone	4551±76	Shishlina 2008

GrA-17462	Charcoal	4180±35	Shishlina 2008
GrA-32892	Animal bone	4160±35	Shishlina 2008
IGAN-1850	Wood	3980±110	Shishlina 2008
IGAN-2402	Human bone	4350±76	Shishlina 2008
IGAN-2492	Human bone	4033±76	Shishlina 2008
IGAN-2058	Human bone	4189±49	Shislina 2008
IGAN-2042	Wood	3920±70	Shislina 2008
GrA-39349	Bone pin (animal bone)	4320±60	Shishlina *et al.* 2010
GrA-12690	Wood	4060±50	Shishlina *et al*. 2010
IGAN-2056	Human bone	4050±50	Shishlina *et al*. 2010
IGAN-2880	Human bone	4312±94	Shishlina 2008
IGAN 4212	Wood	3930±80	Shishlina 2014
Gr-55092	Wood	4140±35	Shishlina 2014
OxA-4732	Human bone	4480±75	Shishlina 2008
IGAN-2705	Human bone	4213±57	Shishlina 2008

GrA67588	Human bone	4180±35	Shishlina *et al.* 2021
GrA67587	Animal bone (sheep)	4175±35	Shishlina *et al.* 2021
GrA64621	Human bone	4200±35	Shishlina *et al.* 2021
GrA64624	Wood	4145±35	Shishlina *et al.* 2021
GrA64622	Human bone (child)	4130±35	Shishlina *et al.* 2021
GrM16406	Human bone	4210±25	Shishlina *et al.* 2021
Beta 39248	Human bone	4380±30	Mathieson *et al.* 2015

SUPPLEMENTARY TABLE 5. Comprehensive dataset. Dates marked in red are outliers.

DeA-10666	2747	2739
DeA-10667	2696	2690
DeA-10668	2717	2708
DeA-2797.1.1	2900	2900
DeA-8817	2958	2956
DeA-16952	2779	2778
DeA-7738	2616	2567
DeA 14449	2954	2956
Poz-46583	2780	2779
Poz 78170	2705	2682
RoAMS 5E	2723	2707
?1	2781	2781
?2	2634	2643
Poz-66988	2594	2603
Bln-609	2822	2807
Poz-39454	2758	2812
poz-39456	2788	2788

Poz-42724	2799	2792
Poz-38461	2930	2917
Poz-31405	2796	2791
deb-6871	2757	2800
Bln-3302	2874	2963
OxA-22951	2880	2871
MAMS-28026	2992	2980
SUERC-63817	3043	3034
SUERC-84759	2923	2912
SUERC-86512	3185	3172
SUERC-95537	3015	3016
SUERC-84750	2975	2968
Poz-88664	2786	2784
Poz-100501	2931	2923
Bln-2219	2931	2932
Lu-2476	3150	3146
Lu-2459	2696	2964
Ki-421	2506	2492
Ki-494	2611	2596
Vi-?	2751	2751
Ki-9980	2692	2689
Ki-7072	2993	2977
Le-1168	2614	2599
Ki-7073	2461	2453
Ki-581	2542	2510
Ki-549a	2734	2730
Ki-6827	2438	2437
Ki-6571a	2558	2541
Ki-6572	2594	2579
Ki-6718	2454	2447
Ki-6731	2528	2521
Ki-6719	2493	2488
Ki-6720	2433	2433
Ki-6721	2427	2430

Ki-6722	2504	2497
Ki-7134	2511	2509
Ki-6724	2472	2467
Ki-6733	2467	2462
Ki-6734	2454	2448
Ki-6714	2512	2510
Ki-6715	2467	2463
Ki-6716	2446	2441
Ki-6741	2776	2774
Ki-5828	2535	2525
Ki-5823	2442	2438
Ki-7070	2443	2438
Ki-7069	2454	2447
Ki-11058	2449	2443
Ki-11059	2688	2681
Ki-11177	2518	2509
Bln-4691	2980	2973
Ki-9919	3172	3163
Ki-7124	2992	2977
Ki-9898	3049	3024
Ki-13873	2432	2432
Ki-13876	2737	2730
KIA-29935	2713	2705
KIA-28682	3148	3134
KIA-29934	2935	2918
Ki-13858	2994	2982
Ki-13864	2956	2954
Ki-1217	2497	2481
Ki-9927	2462	2452
Ki-1711	2780	2772
Hd-19931	2730	2723
Ki-9517	2509	2499
Ki-9518	2508	2499
Ki-2394	3122	3113
Ki-2126	3246	3218
Ki-1219	3137	3132
Ki-7080	2751	2753
Ki-7085	2727	2724
Ki-7086	2781	2778
Ki-8294	2717	2714
Ki-7092	2567	2550
Ki-2129	2483	2578
Poz-52424	2624	2611

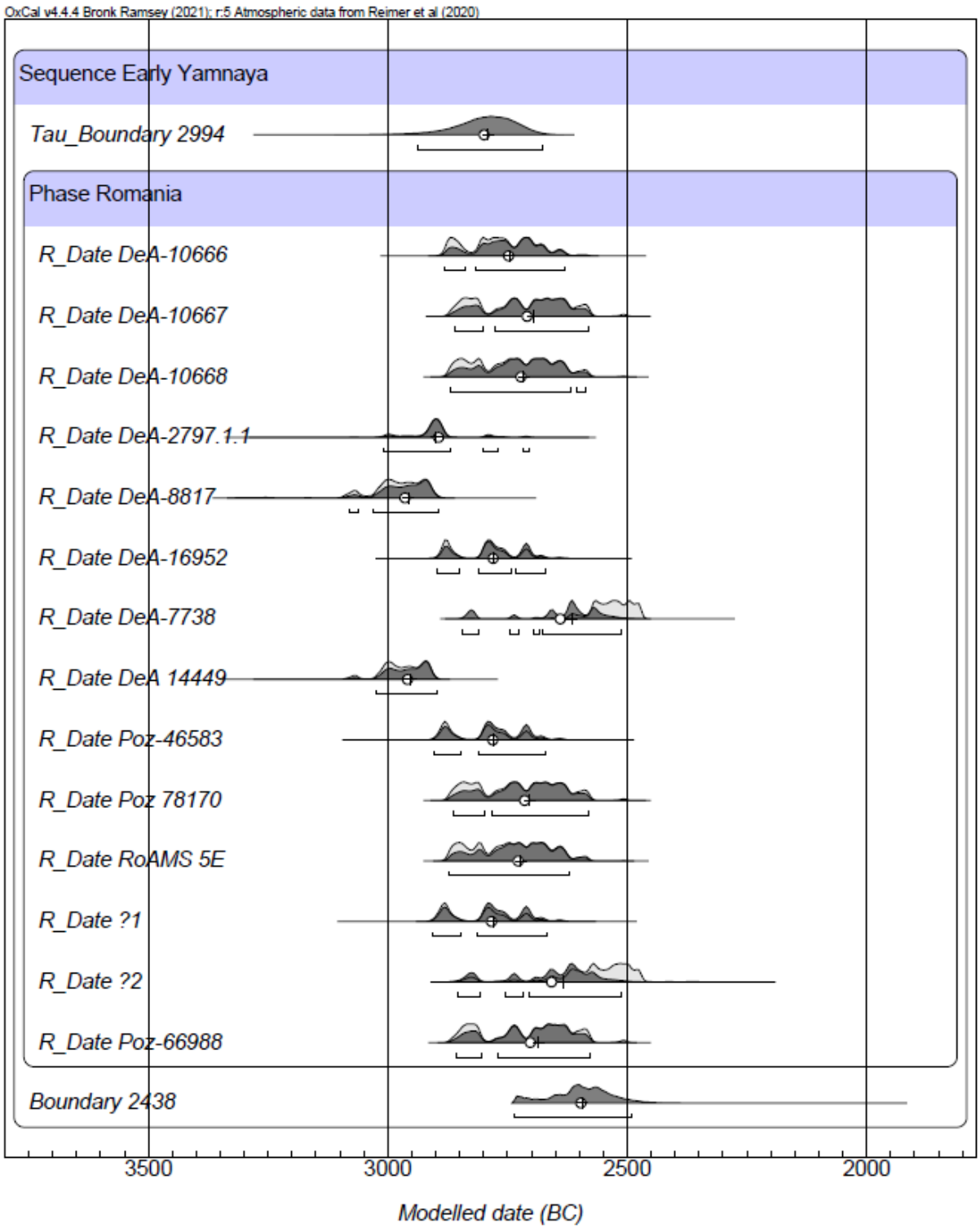
Poz-81793	2630	2615
Poz-47741	2610	2601
Poz-66228	2640	2624
Poz-66230	3130	3105
Poz-66231	2755	2757
Poz-66232	2640	2624
BM 3157	2812	2804
LE 6087	2809	2824
OxA 4306	2991	2971
UKLA-1271	2808	2810
AA 12573	3082	3069
OxA 4254	2871	2859
AA 53804	2807	2804
IGAN 2875	2936	2929
GIN 13208	2891	2899
GIN 13206	2847	2873
AA 37031	2846	2872
IGAN-2275	2827	2813
IGAN-2274	3117	3116
GrA-17462	2804	2799
GrA-32892	2803	2804
IGAN-1850	2808	2818
IGAN-2402	2945	2938
IGAN-2492	2807	2820
IGAN-2058	2808	2801
GrA-39349	2925	2920
IGAN-2880	2890	2894
Gr-55092	2804	2812
OxA-4732	3054	3036
IGAN-2705	2814	2803
GrA67588	2804	2798
GrA64621	2808	2797
GrA64624	2804	2810
GrM16406	2814	2796
Beta 39248	2971	2963

SUPPLEMENTARY TABLE 6. Audited dataset with quality control. Those marked in red are outliers. Some dates excluded due to clear reservoir or old-wood effect.

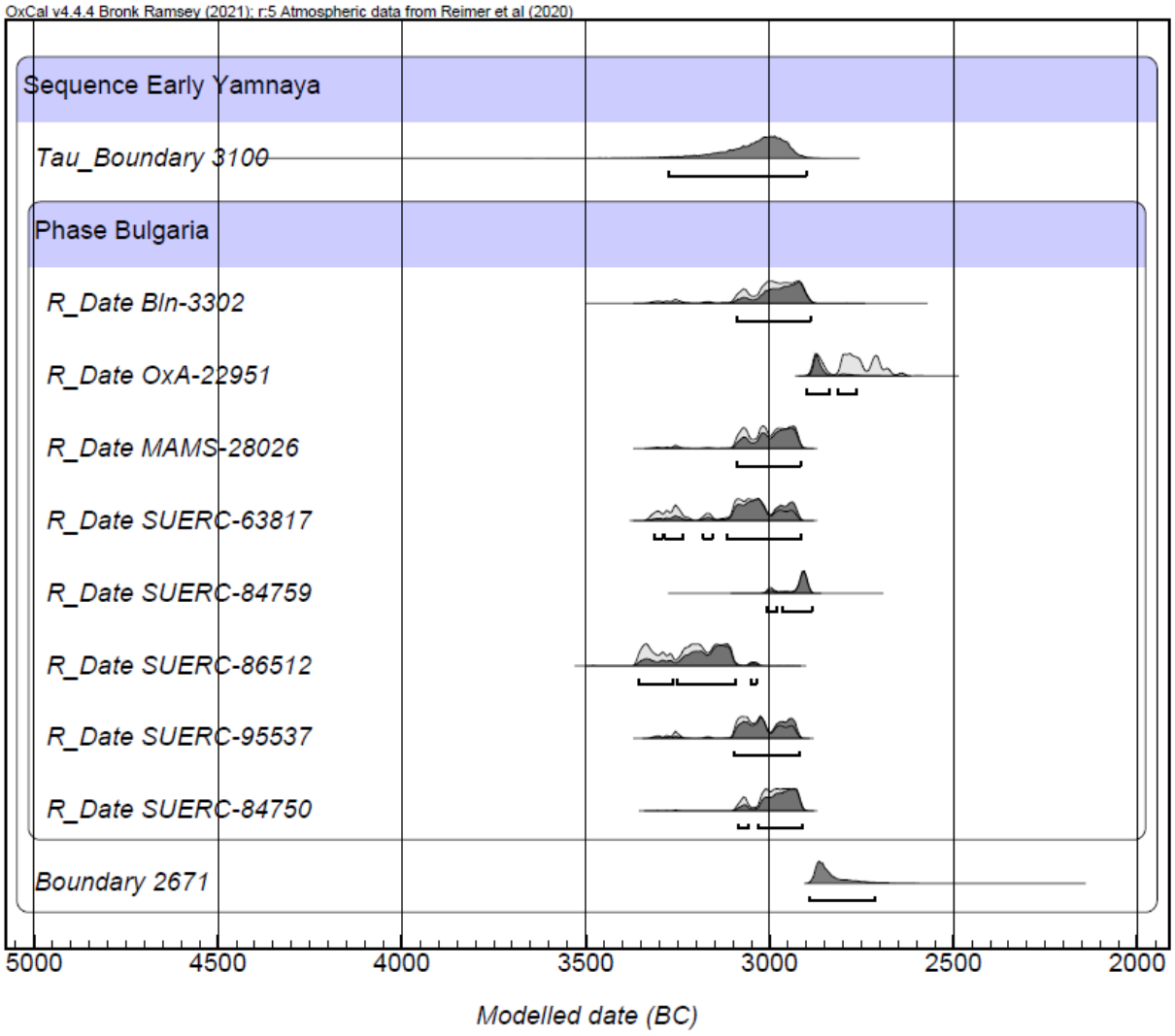
A	Târgşoru Vechi mound/gr. 2a	Romania	DeA-10666
A	Târgşoru Vechi mound/gr. 9	Romania	DeA-10667
A	Târgşoru Vechi mound/gr. 10a	Romania	DeA-10668
A	Ariçeşti IV/gr.2	Romania	DeA-2797.1.1
A	Smeeni/gr.5	Romania	DeA-8817
A	Blejoi IV/gr.1	Romania	DeA-16952
A	Ariçeşti-Rahtivani mound 1/gr.1	Romania	DeA-7738
A	Coada Izvorului/ gr.3	Romania	DeA 14449
A	Rahman mound 1/ gr.1	Romania	Poz-46583
A	Silvaşu de Jos mound 3/gr. 1	Romania	Poz 78170
A	Silvaşu de Jos mound 4/gr. 1	Romania	RoAMS 5E
A	Nedelea mound 2/gr.1	Romania	?1
A	Târgşoru Nou/ gr.2	Romania	?2
A	Bucova Pusta/ Hügel IV	Romania	Poz-66988
A	Ketegyhaza-Törökhalom mound 3/gr.4	Hungary	Bln-609
A	Kunhegyes-Nagyallashalom/ gr.14	Hungary	Poz-39454
A	Kunhegyes-Nagyallashalom/ gr.18	Hungary	poz-39456
A	Püspökladany-Kincesdomb/ gr.1	Hungary	Poz-42724
A	Balmazújváros-Hortobágy-Árkus-Kettőshalom/	Hungary	Poz-38461
A	Hajdúnánás-Tedej-Lyukashalom	Hungary	Poz-31405
A	Sarredudvari Örhalom gr.9	Hungary	deb-6871
A	Poruchik Geshanovo mound 1/gr.3	Bulgaria	Bln-3302
A	Boyanovo, Lozianska Mogila/gr.14	Bulgaria	OxA-22951
A	Beli Bryag, gr. 3/2	Bulgaria	MAMS-28026
A	Riltsi mound 260, gr. 1	Bulgaria	SUERC-84759
A	Kozlovets mound 1, gr. 1	Bulgaria	SUERC-84750
A	Sajkas, "Ciganska humka"/gr.1	Serbia	Poz-88664
A	Zabalj, "Medisova humka" / gr.1	Serbia	Poz-100501
A	Padej, "Humka u Barnahatu"/ gr.2	Serbia	Bln-2219
B	Sarateni mound 1/ gr.4	Moldova	Lu-2476
B	Sarateni mound 1/ gr.5	Moldova	Lu-2459
D	Balki mound 1/ gr. 57	Ukraine	Ki-7073
D	Chkalovo mound 11/ gr.8	Ukraine	Ki-6827
D	Chkalovo mound 11/ gr.9	Ukraine	Ki-6571a

D	Chkalovo mound 11/ gr.11	Ukraine	Ki-6572
D	Golovkovka mound 3/ gr.1	Ukraine	Ki-6718
D	Golovkovka mound 5/ gr.5	Ukraine	Ki-6731
D	Golovkovka mound 6/ gr.8	Ukraine	Ki-6719
D	Golovkovka mound 6/ gr.9	Ukraine	Ki-6720
D	Golovkovka mound 6/ gr.11	Ukraine	Ki-6721
D	Golovkovka mound 7/ gr.4	Ukraine	Ki-6722
D	Golovkovka mound 11/ gr.5	Ukraine	Ki-7134
D	Golovkovka mound 12/ gr.3	Ukraine	Ki-6724
D	Protopopovka mound 1/ gr.2	Ukraine	Ki-6733
D	Protopopovka mound 1/ gr.3	Ukraine	Ki-6734
D	Talyanki mound 4/ gr.1	Ukraine	Ki-6714
D	Talyanki mound 4/ gr.2	Ukraine	Ki-6715
D	Talyanki mound 4/ gr.3	Ukraine	Ki-6716
D	Myronivka mound 1/ gr.8	Ukraine	Ki-6741
D	Myronivka mound 3/ gr.1	Ukraine	Ki-5828
D	Myronivka mound 7/ gr.2	Ukraine	Ki-5823
D	Otradnyi mound 26/gr. 9	Ukraine	Ki-7069
D	Revova mound 3/gr.7	Ukraine	Ki-11058
D	Revova mound 3/ gr. 16	Ukraine	Ki-11059
A	Vinogradnoe mound 24/ gr. 20	Ukraine	Bln-4691
D	Kremenevka mound 6/ gr. 6	Ukraine	Ki-7124
D	Sugokleja /gr.5	Ukraine	KIA-29935
D	Sugokleja /gr.8	Ukraine	KIA-28682
D	Sugokleja /gr.14	Ukraine	KIA-29934
A	Tarasova Mogila/ gr.11	Ukraine	Hd-19931
D	Novoselitsa mound 19/ gr. 16	Ukraine	Ki-7080
D	Novoselitsa mound 19/ gr. 19	Ukraine	Ki-7085
D	Novoselitsa mound 20/ gr.8	Ukraine	Ki-7086
D	Dobrovody mound 2/ gr. 3	Ukraine	Ki-7092
D	Dobrovody mound 2/ gr. 4	Ukraine	Ki-2129
A	Pidlisivka, Yampil mound 1/ gr. 1A	Ukraine	Poz-52424
A	Pidlisivka, Yampil mound 1/ gr. 11	Ukraine	Poz-81793
A	Porohy, Yampil mound 3A/ gr. 11	Ukraine	Poz-47741
A	Pridnistryanske mound 4/ gr. 3	Ukraine	Poz-66228
A	Pridnistryanske mound 4/ gr. 6	Ukraine	Poz-66231
A	Pridnistryanske mound 4/ gr. 8	Ukraine	Poz-66232
A	Pershin mound 1/ gr.4	Russia	BM 3157
A	KC Shumaevo II mound 6/ gr.6	Russia	LE 6087
A	Grachevka II mound 5/gr.1	Russia	AA 53804
A	Grachevka II mound 5/ gr.2 (primary)	Russia	IGAN 2875
A	Podlesnoe I mound 3/gr. 3	Russia	GIN 13208

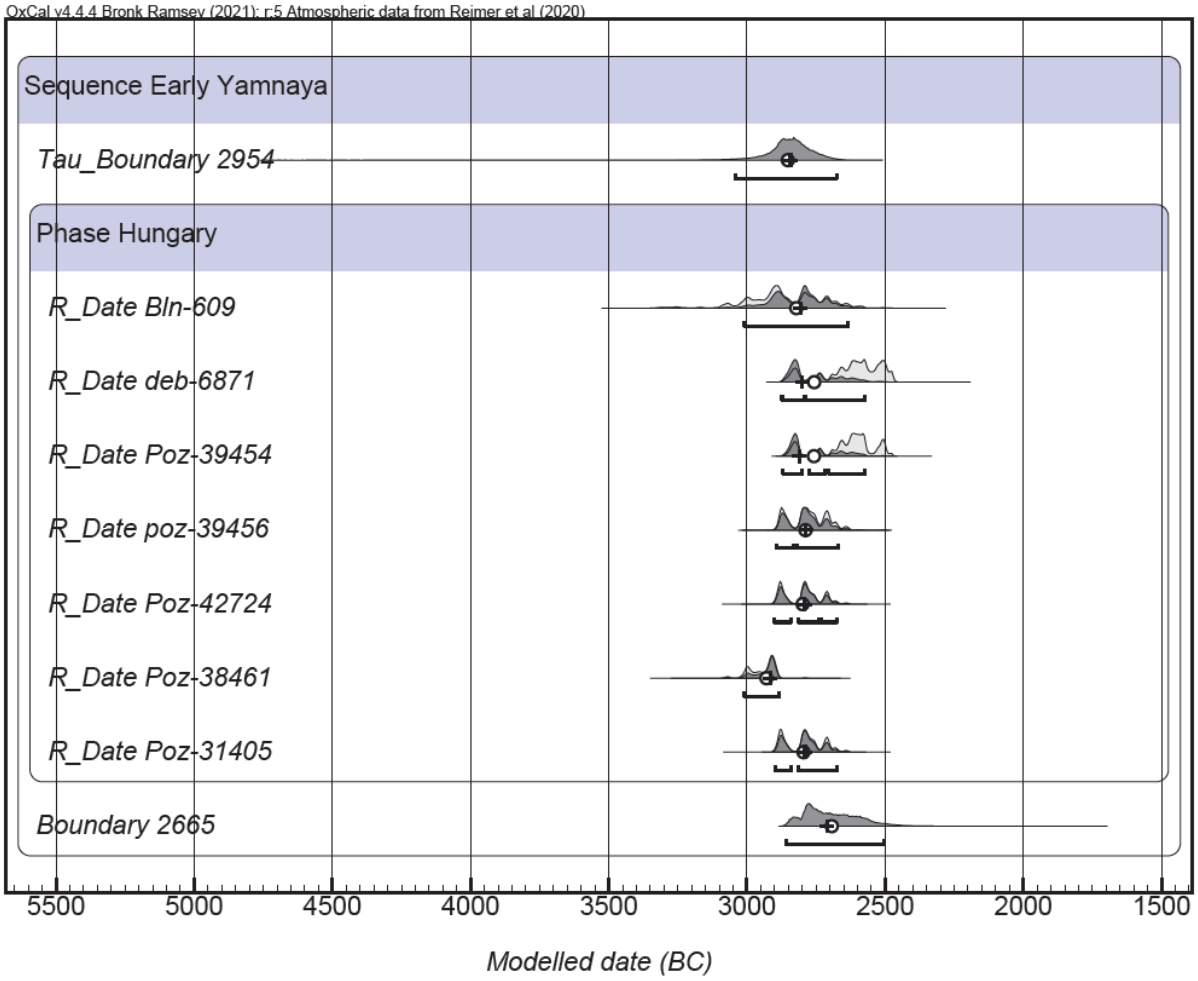
A	Podlesnoe I mound 3/gr. 4	Russia	GIN 13206
A	Mu-Sharet-1 mound 5/ gr. 3	Russia	IGAN-2275
A	Mu-sharet-4 mound 11/ gr.3	Russia	GrA-17462
A	Mandjikiny-2 mound 11/ gr. 2	Russia	IGAN-2058
A	Peschanyi V mound 15/ gr.6	Russia	Gr-55092
A	Chighir mound 2/ gr.3	Russia	IGAN-2705
A	Peschanyi IV mound 11/gr. 4	Russia	GrA67588
A	Peschanyi IV mound 13/gr. 5	Russia	GrA64621
A	Peschanyi IV mound 13/gr.6	Russia	GrA64624
A	Peschanyi IV mound 16/gr.4	Russia	GrM16406
A	Lopatino I 35/1	Russia	Beta 39248



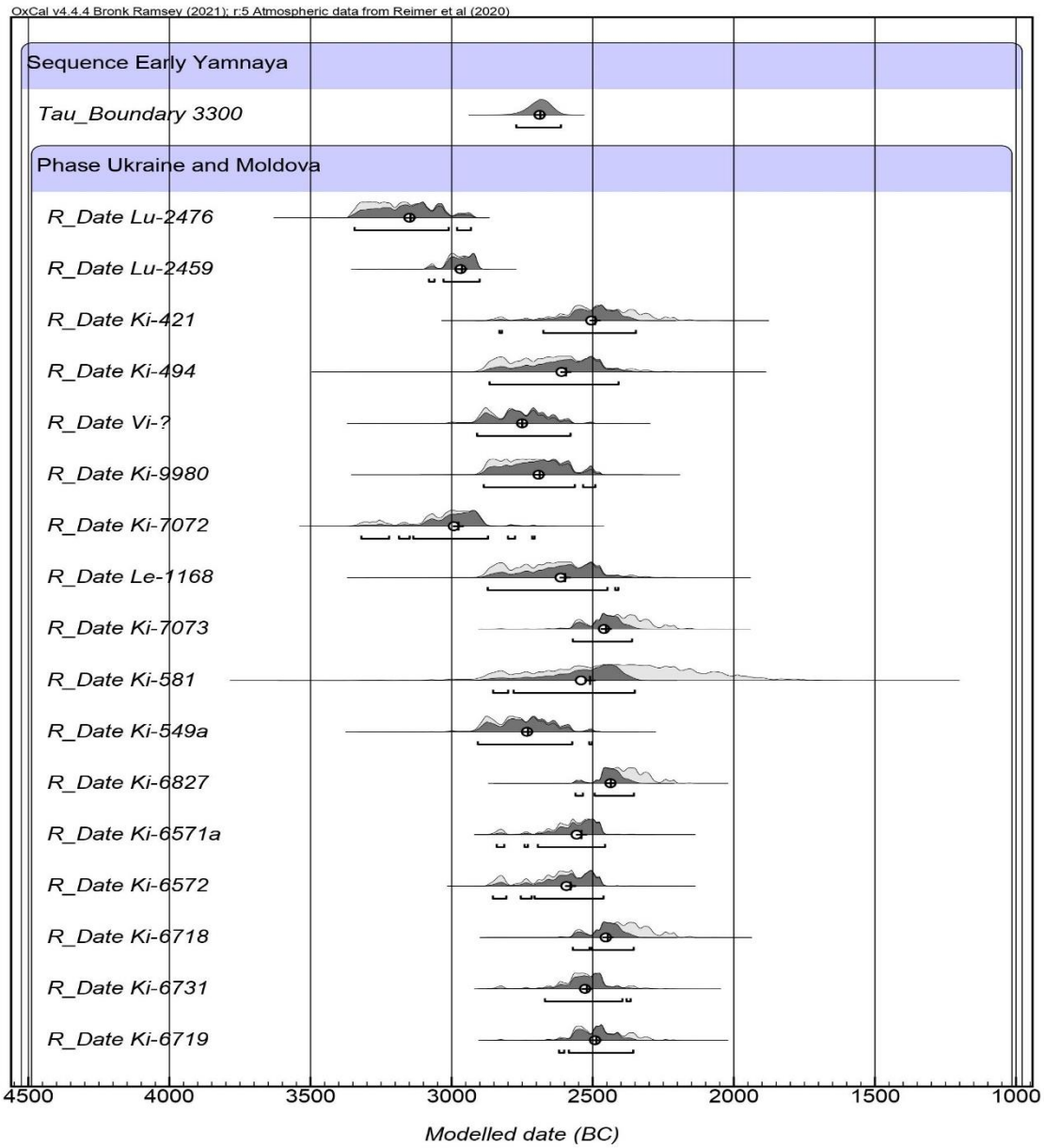
Supplementary Figure 1. Bayesian Model of Romanian Dates for the Comprehensive Dataset. Same Dates Were Used for the Audited dataset.



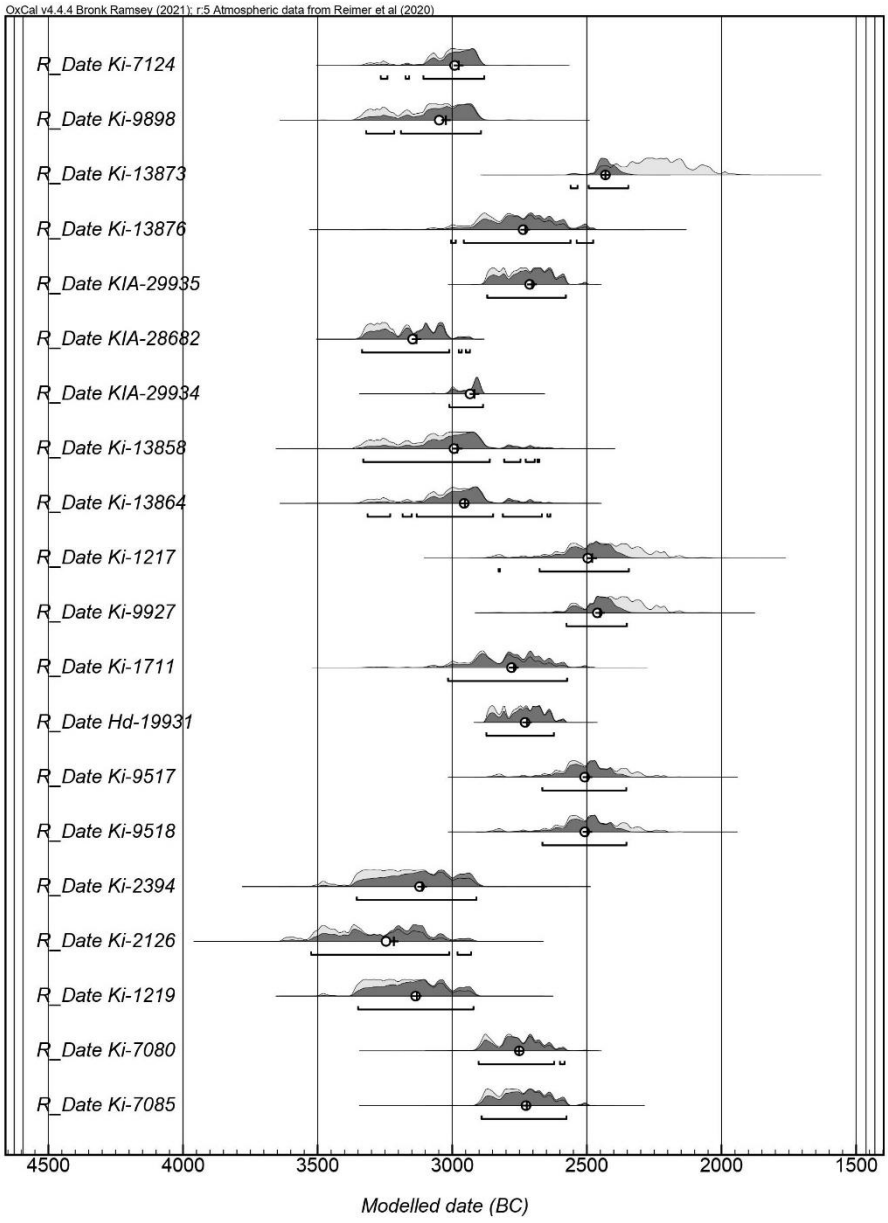
Supplementary Figure 2. Bayesian Model of Bulgarian Dates for Comprehensive Dataset.



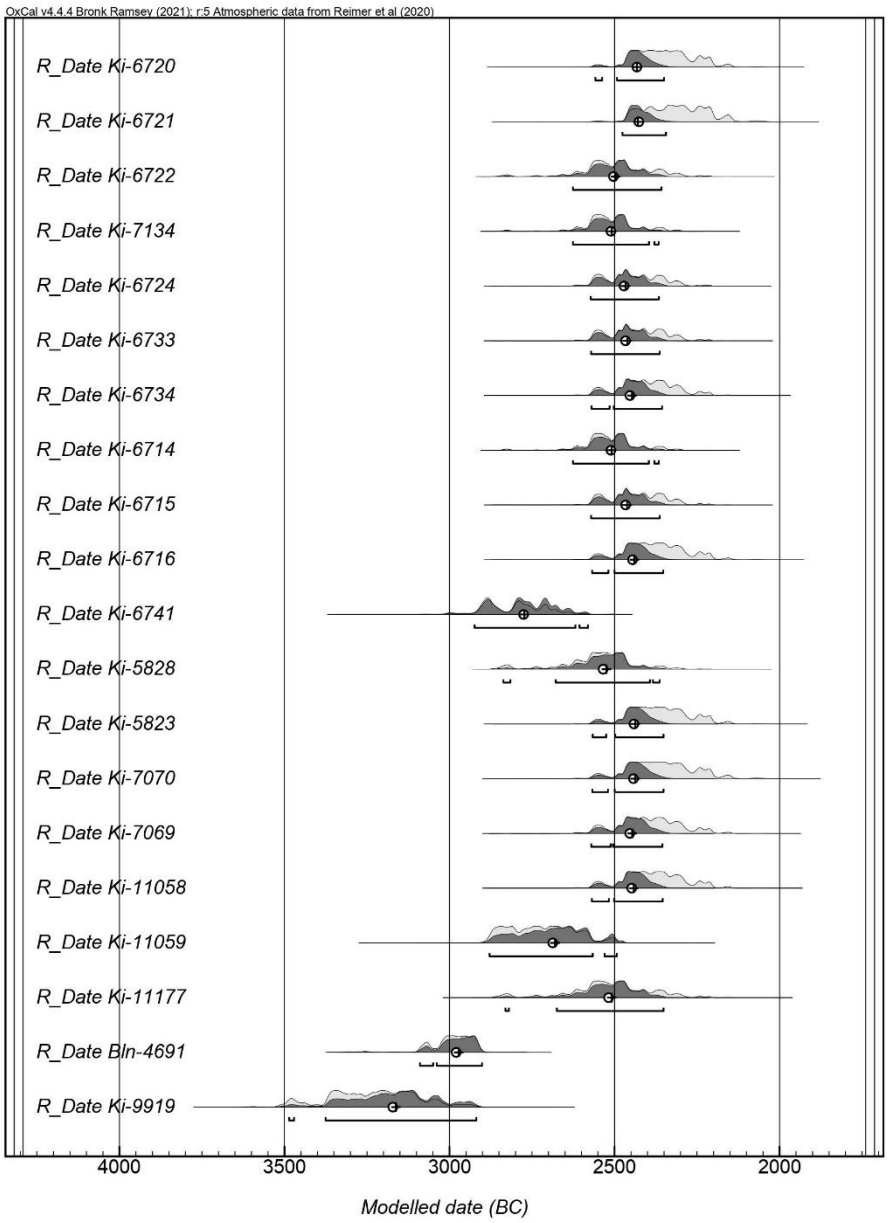
Supplementary Figure 3. Bayesian Model of Hungarian Dates for Comprehensive Dataset. Same Dates Were Used for the Audited Dataset.



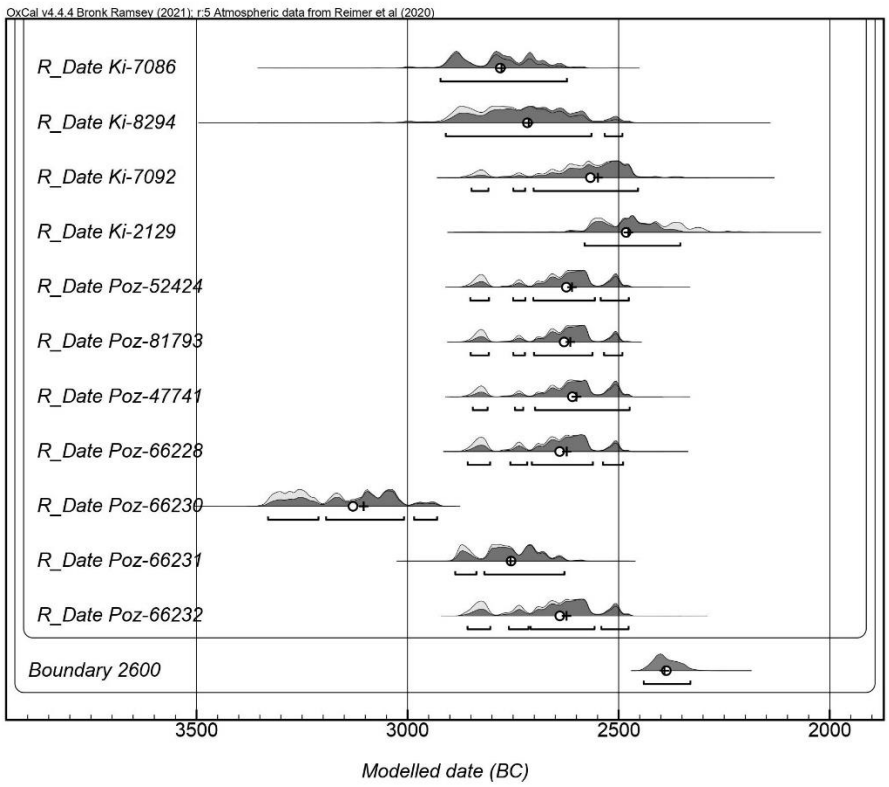
Supplementary Figure 4. Bayesian Model of Ukrainian Dates for Comprehensive Dataset.



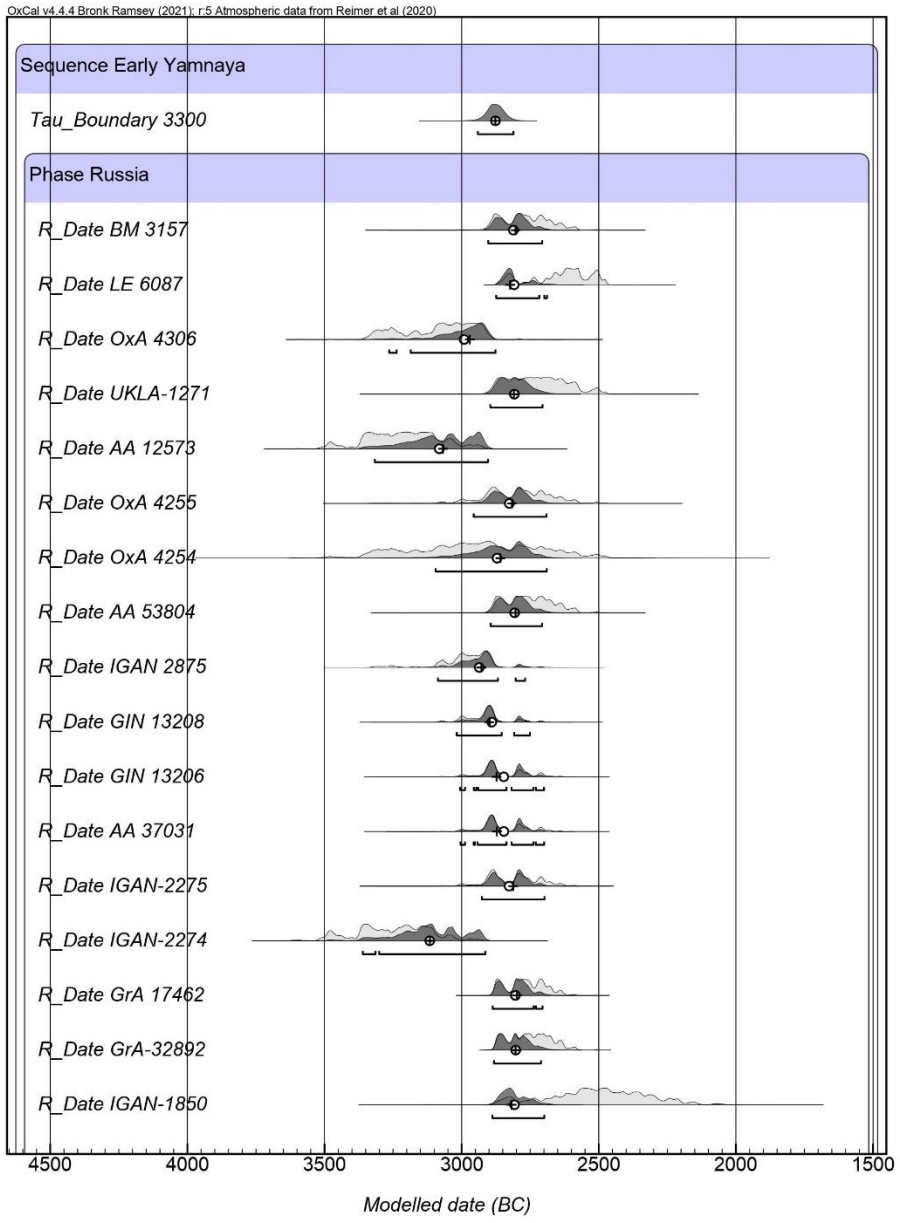
Supplementary Figure 4. Continuation.



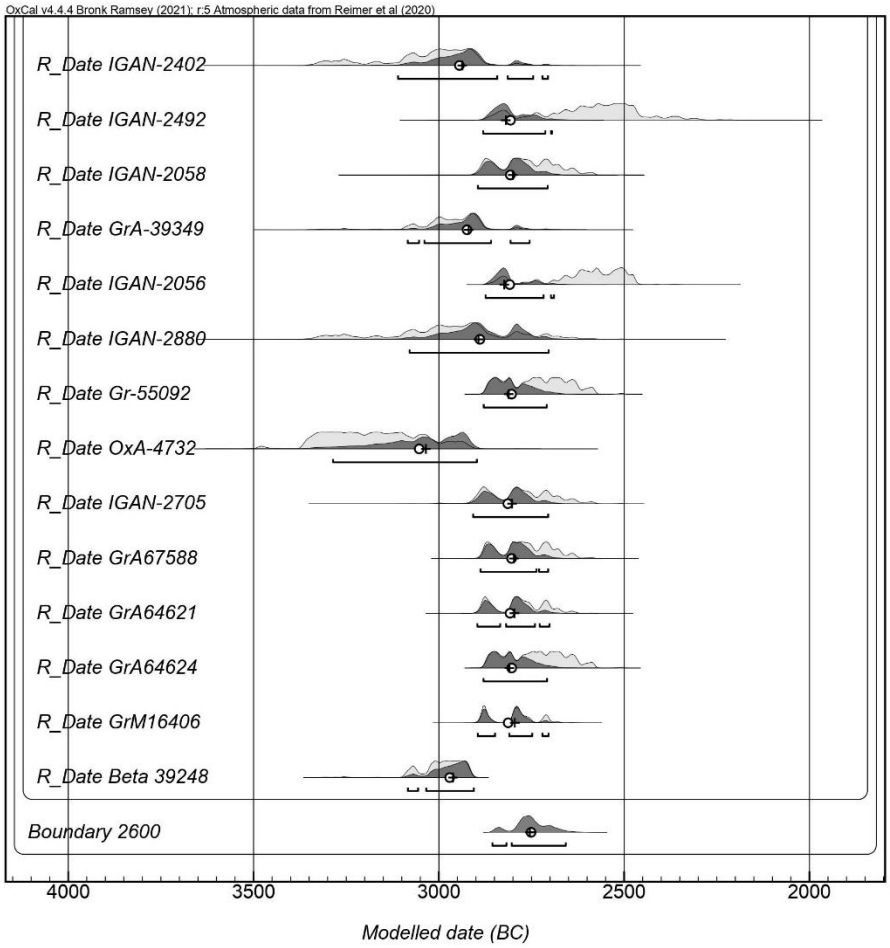
Supplementary Figure 4. Continuation



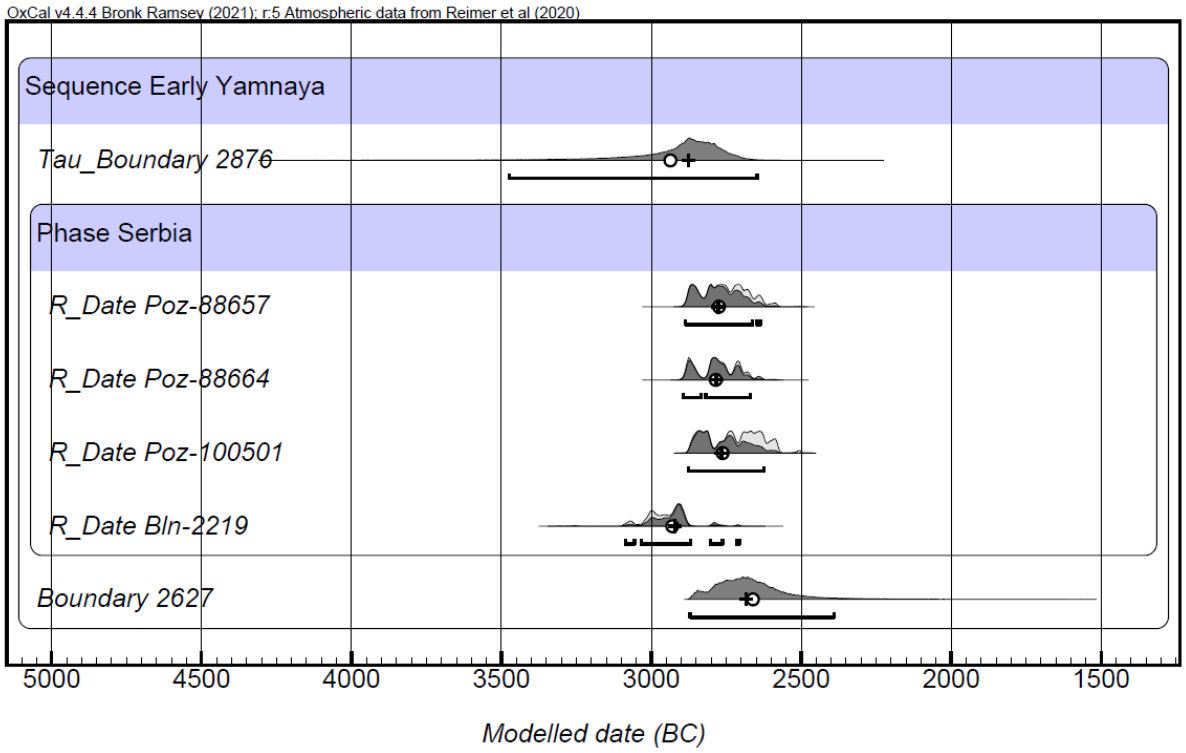
Supplementary Figure 4. Bayesian Model of Ukrainian Dates for Comprehensive Dataset.



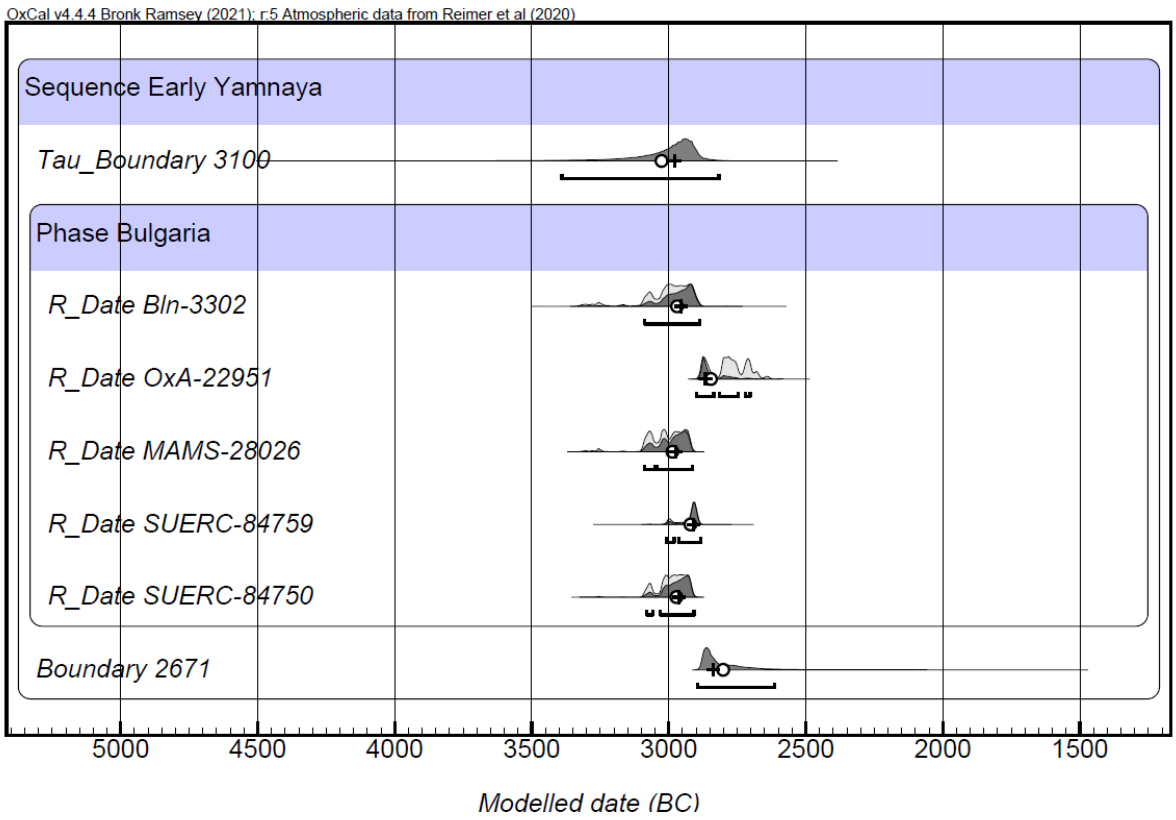
Supplementary Figure 5. Bayesian Model of Russian Dates for Comprehensive Dataset.



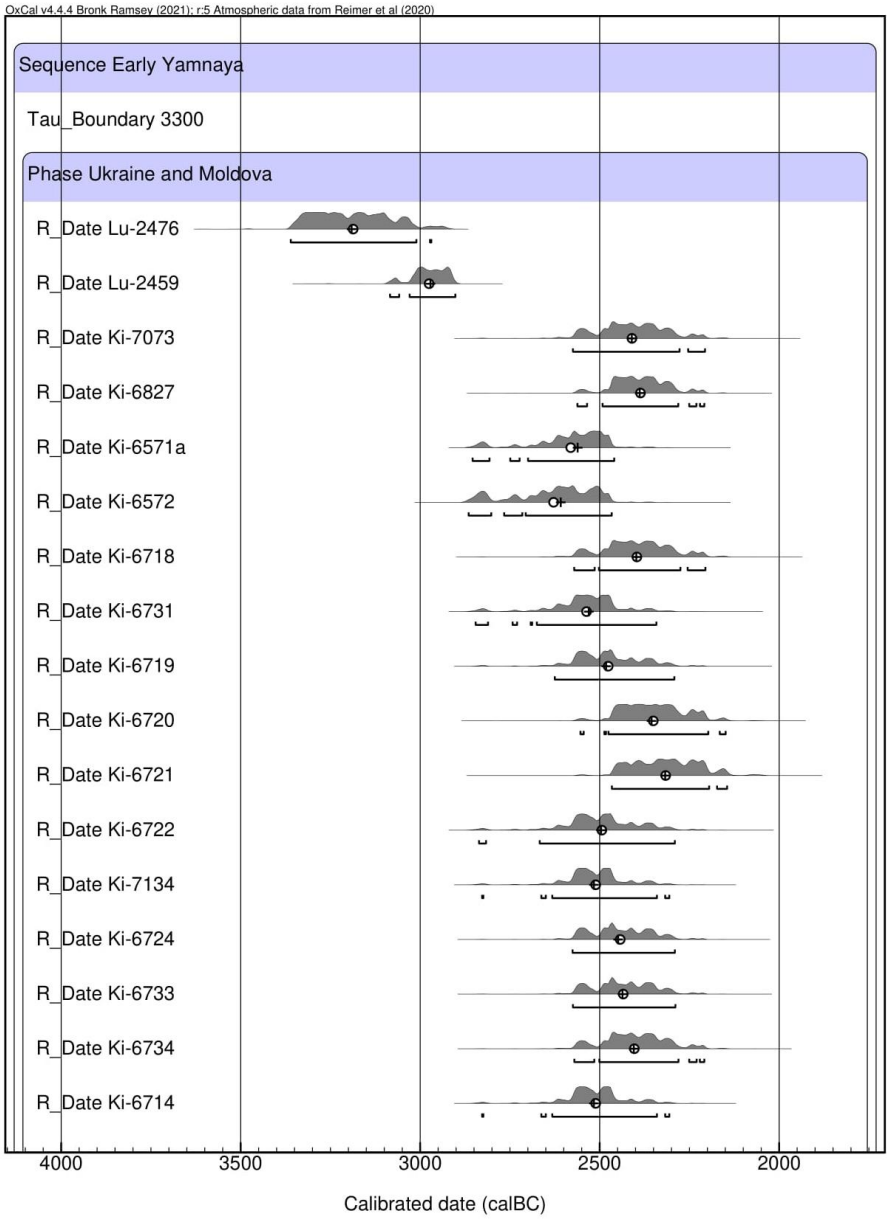
Supplementary Figure 5. Continuation



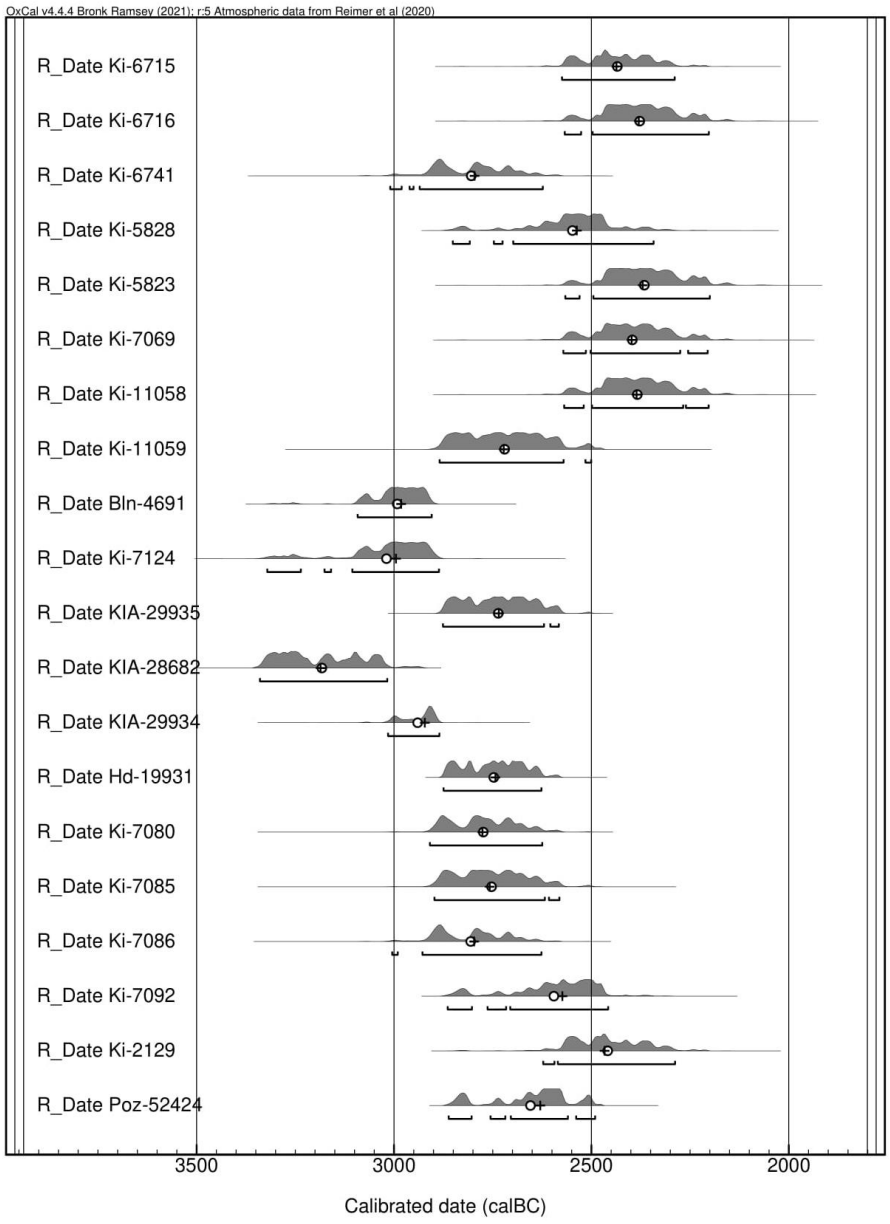
Supplementary Figure 6. Bayesian Model of Serbian Dates for Comprehensive Dataset. Same Dates were Used for the Audited Dataset.



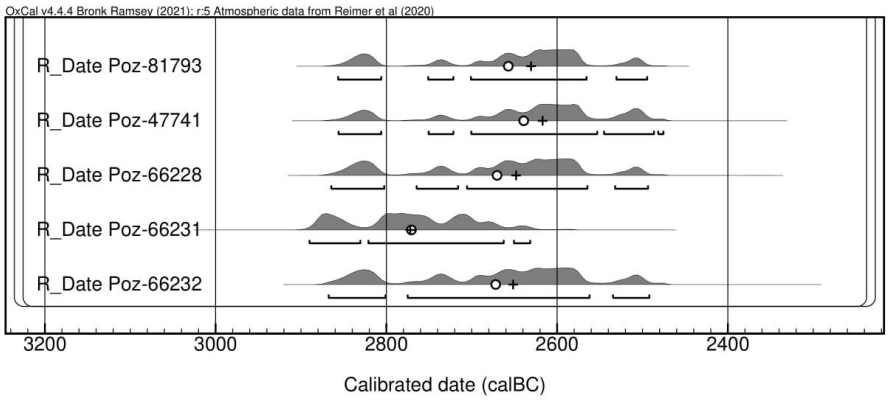
Supplementary Figure 7. Bayesian Model of Audited Bulgarian Dates.



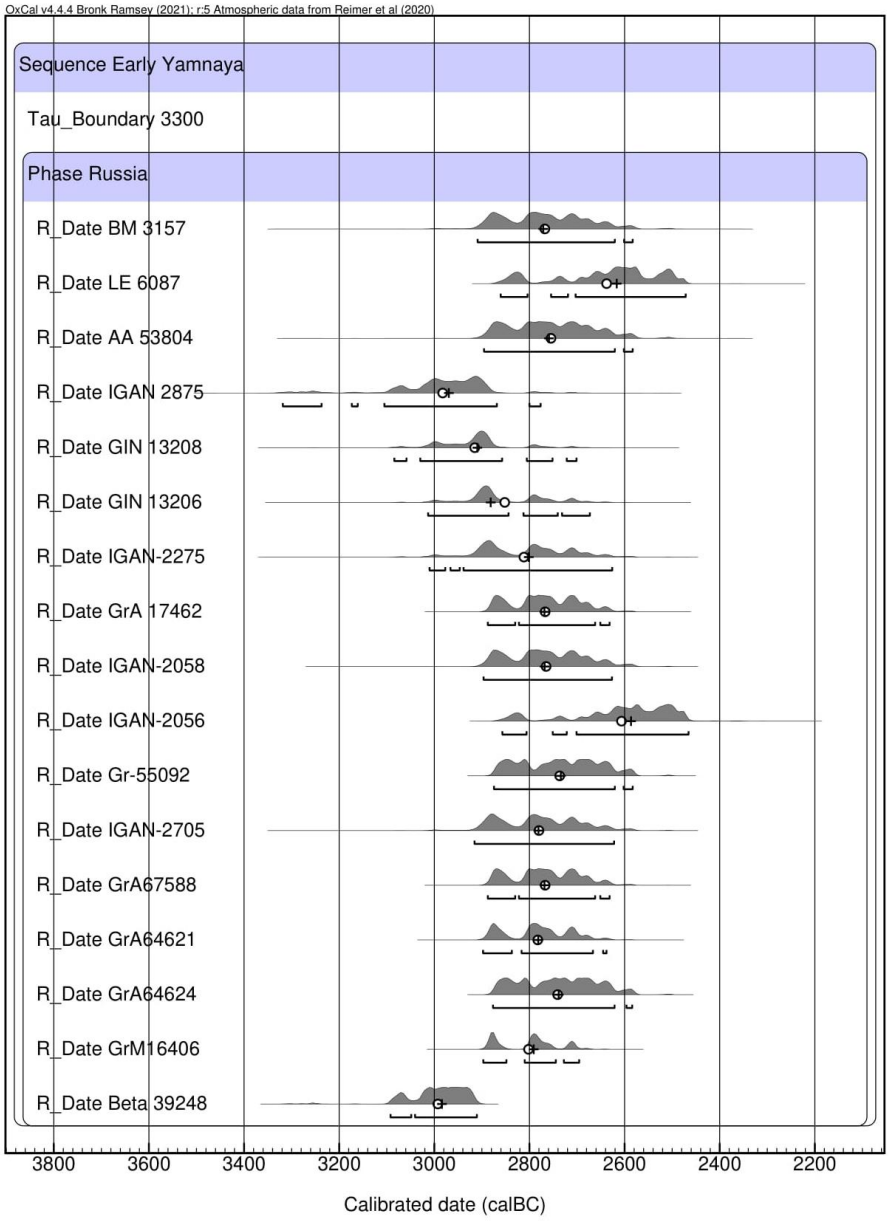
Supplementary Figure 8. Bayesian Model of Audited Ukrainian Dates.



Supplementary Figure 8. Continuation.



Supplementary Figure 8. Continuation.



Supplementary Figure 9. Bayesian Model of Audited Russian Dates.