CLIMATE FACTOR IN CULTURAL TRANSFORMATIONS OF EURASIA IN THE MID-4TH – MID-3RD MILLENNIA BC, AND POSSIBILITIES OF CREATING AN ABSOLUTE CHRONOLOGY

EL FACTOR CLIMÁTICO EN LAS TRANSFORMACIONES CULTURALES DE EURASIA A MEDIADOS DEL CUARTO AL TERCER MILENIO A.C., Y LAS POSIBILIDADES DE CREAR UNA CRONOLOGÍA ABSOLUTA

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Abstract

When studying ancient historical processes, we are faced with the problem of chronology, since the confidence intervals of radiocarbon dates are too wide, as are the lifetimes of particular types of artifacts. A solution to the problem may be to study the appearance of new cultures as a result of migration. Climate changes were the most important factor that stimulated migration in antiquity. It was they which led to the appearance of monuments of the megalithic tradition in the Northwestern Black Sea region (Usatovo), in the North Caucasus (Novosvobodnaya), in the Urals, and in Central Asia (Chemurchek) in the 4th – 3rd millennia B.C. This also caused the spread of the tradition of Yamnaya culture to Central Europe, the appearance of the Corded Ware cultures and many other changes. However, the general process of climate change could not be a trigger for migrations. These were short-term drastic climatic changes, which are recorded by dendrochronology. The latter can also be used as chronological markers, making it possible to create the Eurasian chronology independent of radiocarbon analyses, which have too wide confidence intervals. This approach made it possible to determine the date of the Yamnaya migration to the Carpathian Basin and the formation of the Corded Ware cultures ca. 2910/2850 B.C., and the date of the Fatyanovo migration from Europe to the east ca. 2564 B.C. Unfortunately, the dates of the appearance of megaliths in the east are not determined with a similar accuracy, due to the impossibility to verify this with alternative sources. Their appearance can be dated to ca. the mid-4th millennium B.C. in Eastern Europe, in the last quarter of the 4th millennium B.C. in the Urals, and in the 25th century B.C. in Central Asia.

Palabras clave

cronología radiocarbónica
cronología histórica
dendrocronología

Resumen

Al estudiar los procesos históricos de la antigüedad, enfrentamos el problema de la cronología, ya que los intervalos de confianza de las fechas de radiocarbono son demasiado amplios, al igual que los tiempos de vida de determinados tipos de artefactos. Una solución puede ser estudiar la aparición de nuevas culturas como resultado de migraciones. Al

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respecto, los cambios climáticos fueron uno de los estímulos más importantes de las mismas en la Antigüedad. El clima permite explicar la aparición de monumentos de tradición megalítica en la región noroccidental del Mar Negro (Usatovo), en el Cáucaso septentrional (Novosvobodnaya), en los Urales y en Asia central (Chemurchek) entre el cuarto y tercer milenio a.C., y también la propagación de la cultura Yamnaya en Europa central, la aparición de las culturas de la Cerámica Cordada ("Corded Ware"), entre otros cambios. Sin embargo, el proceso general de cambio climático no pudo ser el desencadenante de las migraciones, sino que estas fueron fomentadas por cambios climáticos drásticos a corto plazo registrados por la dendrocronología. Las ventajas de la aproximación dendrocronológica es que puede utilizarse como proxy temporal, de manera independiente a los análisis de radiocarbono, los cuales tienen intervalos de confianza demasiado amplios. El enfoque dendrocronológico permitió determinar la fecha de la migración Yamnaya a la cuenca de los Cárpatos y la formación de las culturas de la Cerámica Cordada hacia ca. 2910-2850 a.C., y la fecha de la migración Fatyanovo desde Europa central hacia el Este hacia ca. 2564 a.C. Desgraciadamente, las fechas de aparición de los megalitos en el Este no se determinan con una precisión similar, debido a la imposibilidad de verificarlo con fuentes alternativas. Su aparición puede fecharse hacia mediados del cuarto milenio a.C. en Europa Oriental, en los últimos siglos del cuarto milenio a.C. en los Urales y hacia mediados del tercer milenio a.C. en Asia Central.

Introduction

Problems of chronology are the most important in the reconstruction of ancient historical processes. The basic method for this is radiocarbon analysis. But its confidence intervals are extremely wide, and the result is sometimes unpredictable due to various possible errors. It is difficult to rely on it in studying migration that influenced the formation of a particular archaeological culture, since the chronological interval of the donor culture often completely or partly coincides with the interval of the recipient culture. These intervals are especially wide if we use the method correctly, with a probability of 95,4 %, not 68,2 %. In this case, a comparison of two complexes is often impossible.

Synchronization of the Chinese and Eastern Mediterranean chronologies showed their coincidence, as well as the coincidence with dendrochronology. As a result, it was concluded that these chronologies are more correct than radiocarbon analysis (Grigoriev 2023). But in many areas, we cannot use historical chronology and dendrochronology. We can only use typological comparisons to connect these complexes with chronologies of those areas where such a possibility exists. But there are also problems with chronologies of individual types, which could be asynchronous even in two neighboring areas. A single solution is to use situations when some type or culture appeared in a new region for the first time as a result of migration. Migration was always a forced process, often stimulated by abrupt climate changes. Those changes that are reconstructed on the basis of pollen analyzes were smooth and insignificant, within 1-3 °C. Human collectives could adapt to them. Even annual climate fluctuations can be more significant. The stimulus for migration could only be sharp changes for a short period. Therefore, evidences of such abrupt climatic changes can be used in chronology. A significant part of such changes is local, it is caused by changes in solar activity and various atmospheric processes. They could cause migrations, but they do not allow us to synchronize these processes in different areas. The most useful are global changes, allowing us to synchronize materials from remote areas. In some cases, the triggers for these changes were volcanic eruptions, which can provide individual chronological benchmarks. Moreover, in the 17th-16th centuries BC, important benchmarks, that made it possible to synchronize materials from distant territories, were major volcanic eruptions in 1654, 1628, and 1560 B.C. (Grigoriev 2023, 2023a, 2024). This article is an attempt to apply it to earlier materials of the mid-4th - mid-3rd millennia B.C.[1]

Climate changes and migrations

It is quite obvious that migration over a large distance was always a forced process. The main reason for migration is climate change. Climate fluctuations of the period under discussion were caused, first of all, by fluctuations in solar activity. The most difficult for human communities were periods of decreased solar activity. In this case, temperatures in Northern Europe decreased and humidity increased, which led to the decrease in harvest. But cooling of the water surface in the North Atlantic leads to changes in air movement, which blocks the Asian monsoon and provokes aridization in the southern regions (Wanner *et al.* 2008). However, this is a smooth and slow process. The decrease in temperature was below the possible annual fluctuations, and human communities are quite adaptive. However this created a negative background, and the sharp climate fluctuations could cause migration. Such changes could be triggered by local atmospheric phenomena, and they could cause some kind of migration from that particular region, especially in periods of decreased solar activity. There are many methods that allow us to understand the general dynamics of climate change (palynology, isotopic studies of speleological data, etc.), but these methods have a very low resolution, and their dating is usually based on the same radiocarbon method. Therefore, these studies do not reliably determine the date of possible migration. They indicate only an interval in which the migration was likely. Exact dates can only be obtained using dendrochronology; moreover, this method makes it possible to determine the years when sharp cold events or frosts occurred. But to synchronize this with historical events, it is necessary to connect the archaeological material with the dendrochronological scale. Otherwise, we will not have confidence that it was this climatic event that triggered the migration. However, these events, being local, do not allow us to connect processes in different regions into a single chronological system. This possibility arises only in cases of sudden global changes lasted for a short period. This happens when they are triggered by volcanic eruptions, and their traces are clearly visible in ice cores from Greenland and Antarctica. There is a consensus on the volcanic influence on climate (Boulanger 2013; Helama *et al.* 2013; Sigl *et al.* 2022; Zielinski 2002). However, not every eruption provokes this effect. During an eruption, a screen of sulfur volcanic aerosols is formed in the atmosphere, which reduces the solar heating of the surface. But in most cases, these aerosols reach the troposphere and soon fall off. Only in the case of large explosive eruptions do aerosols reach the stratosphere and can influence the planet's climate for a long period (Sigl *et al.* 2022; Zielinski 2002). This could even create the effect of volcanic winter and provoke migrations in different regions, which can be synchronized. But dating the annual deposition of snow in ice caps used to be unreliable (Alley *et al.* 1997; Southon 2002); dates with good resolution are needed, which only dendrochronology can provide since it also identifies years with a sharp decrease in temperatures.

Such attempts at synchronization were made several times (*e.g.* Helama *et al.* 2013), but there was always uncertainty about the possibility of synchronization with a specific volcanic event. The problem is that some volcanic signal in the ice, close in date, could reflect only a small local event. In addition, the nature of the volcanic impact depends on the season in which the eruption occurred and many other factors (Sigl *et al.* 2022; Zielinski 2002). However, gradually, thanks to the study of chemical compositions of sediments, it became possible to synchronize the signals of some large eruptions in the ice of Greenland and Antarctica and even connect them with dendrochronology. This was done quite reliably for the events of the 17th-16th centuries B.C. (Pearson *et al.* 2022). Recent work has produced a unified database of eruptions and its accuracy is estimated to be ±5-15 years for periods spanning the Chalcolithic and Bronze Ages (Sigl *et al.* 2022). However, it is possible that in some cases the accuracy is somewhat lower, and the older the layer, the lower the accuracy. Work in this direction is continuing, and the situation will certainly improve, but for the period discussed here, 4th-3rd millennia BC, the problem will probably persist. Theoretically, to identify global events, we can compare data on frosts in different regions, but this is not possible for all periods: for example, if for Lapland there is data from 5500 B.C., then in the southwestern United States only from 3000 B.C. (Helama *et al.* 2013; Salzer and Hughes 2006), which makes it almost impossible to accurately date the events of the 4th millennium BC. In addition, absolute matches are not always achievable, for example, a signal of a low latitude eruption appears in Antarctica with a lag of 1-2 years (Cole-Dai *et al.* 2000).

An additional complication is that the largest eruptions with significant sulfur emissions were in the early Holocene, which is associated with deglaciation processes. The discussed 4th and 3rd millennia B.C. were relatively calm, although for these periods some peaks of volcanic emissions have been also found at the beginning, middle, and end of the 4th millennium B.C., at the beginning and before the middle of the 3rd millennium B.C. (Cole-Dai *et al.* 2021, fig. 4; Sigl *et al.* 2022, fig. 9). Therefore, these events could potentially be used as chronological markers if they are reliably linked to dendrochronology.

There are also archaeological problems. Compared to the 2nd and 1st millennia BC, the number of artifact types was not so large, and their evolution was slower. Therefore, the identity of artifacts in different areas does not allow them to be accurately synchronized. In addition, the spread of artifacts to another territory does not always mean migration, although paleogenetics has shown the role of migration in this process. It would be wrong to delve into the typological justification of migrations within the framework of this small work devoted to another problem. Therefore, only those migrations which have been reliably justified are discussed here. First of all, this is the spread of the megalithic tradition and the catacomb burial rite. The fact is that these specific forms of structures were inextricably linked with ideology and religion, so their spread had to have physical bearers. Finally, those cases are discussed in which these phenomena were transferred through a significant area in which there is nothing similar. Accordingly, we can only talk about migration, but not about the spread of ideas. But it must be emphasized that the examples discussed below are only a small fraction of actual migrations that took place during these two millennia.

Cultural changes and climate in the 4th millennium BC

Cultural changes

In the 4th millennium B.C., megalithic objects appeared in three Eurasian regions: Novosvobodnaya culture in the Northern Caucasus, Usatovo sites in the North-West Pontic region, and various objects of the megalithic tradition in the Urals (Figure 1). And, in all these cases the appearance of the tradition was connected with long-distance migration stimulated by some significant shocks. However, there is no reason to synchronize these events.

The earliest megaliths arose in Iberia and Western France in the 5th millennium Cal. B.C., although there were stone cists in the Western

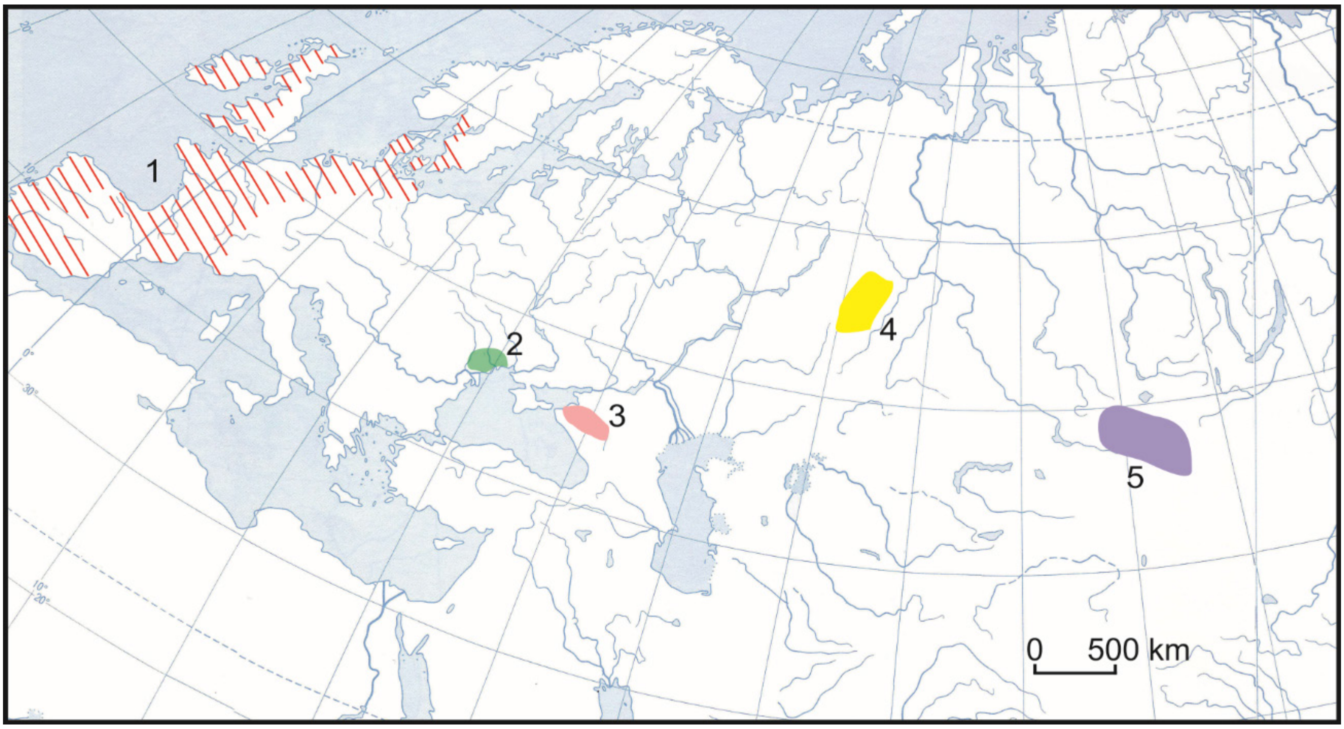

Figure 1. Areas of the megalithic tradition: 1. European megaliths; 2. Usatovo culture; 3. Novosvobodnaya culture; 4. Ural megaliths; 5. Chemurchek sites.

Alps and long barrows in Northern Europe which merged later with the megalithic tradition. In the British Isles, the megaliths appeared *ca*. 4000 Cal. B.C., and *ca*. 3600-3500 Cal. B.C. the megalithic tradition began to spread to the Baltic (Müller 1998; Scarre *et al.* 2003). Therefore, it is possible that the emergence of this tradition in Eastern Europe and the Transurals was associated with this process. In the Urals, the tradition is presented by megaliths of Vera Island (with features of both passage and gallery graves), dolmens, menhirs, and enclosures. Unfortunately, it is impossible to obtain adequate radiocarbon dates on the island with its granite bedrocks, and dates for other objects of this tradition fall into the interval of the 32nd - 28th centuries Cal. B.C. Based on the European parallels, this complex may be dated after the mid-4th millennium Cal. B.C, but some ceramic parallels point to a later date of the last quarter of the 4th - early 3rd millennia Cal. B.C. For this reason, we wrote about the date within the 4th millennium Cal. B.C. or after the mid-4th millennium Cal. B.C., although we may discuss only the date since the 32nd century Cal. B.C. as quite reliable. The possibility of the earlier date since the middle of the 4th millennium Cal. B.C. was caused by the date from the Shatanov 3 settlement (3500-3090 Cal. B.C.) with ceramics similar to those on the cult place of Vera Island 9 (Grigoriev and Vasina 2019). But this date is actually a probability interval. Therefore, the megaliths appeared in the Urals in the second half of the 4th millennium Cal. B.C., more likely in the last quarter of this millennium.

In the early 4th millennium Cal. B.C., migration from Eastern Anatolia resulted in the Maikop culture formation in the Northern Caucasus. Later, Novosvobodnaya culture formed in the same region, and this coincided with the second Inozemtsevo-Kostromskaya stage of the Maikop culture. Within the second horizon of the Klady cemetery (Novosvobodnaya culture) a mighty impulse of the Uruk civilization took place, corresponding to its middle stage, dated to the second third of the 4th millennium Cal. B.C. The latest generalization of radiocarbon dates from the early Novosvobodnaya horizon (with admixtures of the proper Maikop materials) allows this horizon to be dated to the early 36th - first half of the 35th centuries Cal. B.C., and it can be synchronized with the end of Tripillia BI-II. But the Uruk impulses probably repeated, which has made it possible to synchronize the beginning of the 3rd horizon of the Klady cemetery with Arslantepe VI-A in Anatolia. This horizon is synchronous with Tripillia CII. One more impulse, that formed the early Novosvobodnaya, came from the West, and it brought the tradition of megalithic tombs. Its connection with the Baalberg group of Central Europe is most probable. This impulse was the source of beakers and amphorae close to the ware of the Funnel Beaker culture (Rezepkin 2012, 2022). This is confirmed by the fact that the Novosvobodnaya people had genes of the Funnel Beaker people (Nedoluzhko *et al.* 2014). Thus, even though we have evidence of obvious migrations from two different regions, they do not indicate a powerful natural disaster, because they were events of different times: the European impulse had been the first, and only then, *ca*. the 35th century Cal. B.C., it was followed by the Near Eastern impulse.

In the North-West Pontic steppes, the megalithic tradition appeared in the Usatovo culture, whose early phase is dated to ca. 3500/3400–3450/3350 Cal. B.C. It is presented by mounds with cromlechs, in some instances with monumental enclosures and gates built of massive slabs. Stone anthropomorphic statues and sculptures of bovine heads found in the burial structures are noteworthy: the former have analogies in the European megaliths and the latter in megalith 1 of Vera Island. Principal forms of the Usatovo ware are similar to the Vykhvatintsy ware of the early phase of late Tripillia, *i.e.* the period Cγ-II,1, which reflects influences from the upper Dniester to the south. In addition to this, many objects indicate the Caucasian Maikop influences, although some of them have Anatolian analogies too: a crook-shaped pin; stemmed riveted daggers with a triangular blade, and a rib in some instances; asymmetric adzes, chisels, shaft-hole axe. Objects with high arsenic content and silver jewelry are typical (Dergachov 2022). Thus, these sites formed later than Novosvobodnaya (which is indicated by their radiocarbon dates and synchronization with different Tripillia phases), but it is not excluded, that they were close in time to the 3rd horizon of the Klady cemetery and the new Uruk impulses to the North Caucasus. The time of their formation was close to the solar minimum of 3495 B.C., but this does not give an exact date, since the data on climate crises in Germany and Lapland may indicate periods shortly after this date (Figure 2), and we do not know whether similar crises occurred in Central Europe or the Middle East.

In the last quarter of the 4th millennium Cal. B.C., sites of the Final Eneolithic spread in the Eastern European steppes, in particular, the Zhivotilovka-Volchansk group, whose representatives migrated to Central Europe, and a system of reverse influences formed, that brought Central European elements into the steppe (Grigoriev 2022).

All said above shows that the spread of the megalithic tradition in the Urals and Eastern Europe was not a synchronous process, and it cannot be explained by any single climatic catastrophe. In radiocarbon chronology, these processes have different dates: *ca*. the first half of the 36th century Cal. B.C. - migration from Europe to the Northern Caucasus and the formation of Novosvobodnaya, 2) *ca*. the 35th century Cal. B.C. - Uruk impulses to the Northern Caucasus and European impulses to the North-West Pontic, as well as the Maikop-Novosvobodnaya impulses to this region and the formation of Usatovo, 3) the last quarter of the 4th millennium Cal. B.C. - migration of bearers of the megalithic tradition to the Urals, and the appearance of the Final Eneolithic in Eastern Europe.

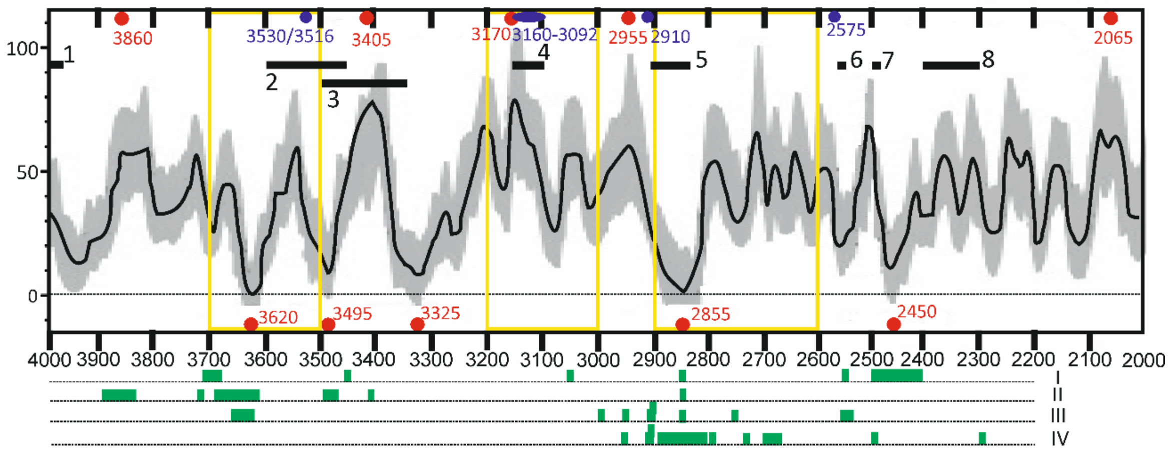

Figure 2. Solar activity graph with Solar Maxima and Minima (red circles) (after Usoskin 2017); periods of climate crises with low resolution (palynology, speleological data, etc.) (yellow frames, see text for details); major volcanic eruptions (blue circles and ovals): 3530/3516 B.C. (after Baldia 2013); 3160-3092, 2910, 2575 B.C. (after Sigl *et al.* 2022). The coldest years and periods in tree-rings (green squares): I. Lapland - 3712-3683, 3453, 3053, 2850, 2564, 2500-2401 B.C. (after Helama *et al.* 2002, 2013); II. Northern Germany - 3895-3838, 3720, 3691-3614, 3496-3473, 2850 BC; III. Scotland, Ireland - 3660-3620, 3000-2990, 2960-2950, 2905, 2910-2900, 2850, 2750, 2569, 2642 B.C. (after Moir *et al.* 2010; Moir 2012); IV. the southwest USA - 2951*, 2911*, 2906*, 2905*, 2885, 2879, 2872, 2862, 2853, 2841*, 2821, 2800, 2794, 2732*, 2731*, 2699, 2685, 2677, 2670, 2495*, 2294* B.C. (after Salzer, Hughes 2006: * - frost signals and possible connection with eruptions). Dates and probable intervals (black rectangles) of the cultures discussed in the article: 1. radiocarbon date of the beginning of the Maikop culture in the North Caucasus; 2. radiocarbon interval of the early Novosvobodnaya culture in the North Caucasus (36th century Cal. B.C.); 3. formation of the Usatovo culture in the Northwestern Black Sea region, the beginning of the 3rd phase of the Novosvobodnaya culture and repeated Uruk influences in the North Caucasus (35th century Cal. B.C.); 4. final Chalcolithic in the steppe of Eastern Europe, Zhivotilovka-Volchansk group, megaliths in the Urals (32nd century B.C., more likely interval 3160-3092 B.C.); 5. Yamnaya migration to Central Europe and the formation of the Corded Ware culture (2910-2850-2844 B.C.); 6. formation of the Fatyanovo culture (2564 B.C.); 7. formation of the pre-Donetsk Catacomb and Okunev cultures (the early 25th century B.C.); 8. probable interval of formation of the Donetsk Catacomb culture and catacombs in Palestine (24th century B.C.).

Undoubtedly, these processes had significant reasons, the most probable of which were climatic changes. It is assumed that the climate worsening in Europe in the 37th-36th centuries Cal. B.C., which forced an increase in the role of hunting in the economy, was partly caused by volcanism. From the ice cores in Greenland (GISP2 project) two peak concentrations of the volcanic ions SO_4 are noted - about 3530 B.C.; and between 3300 and 3100 B.C., with a peak in about 3200 B.C. Another project (GRIP) has identified decreases in temperature in about 3516 and 3383 B.C. This could certainly destabilize the situation (Baldia 2013). Therefore, in principle, the events of 3530/3516 B.C. and 3200 B.C. could trigger the episodes 1-3, but the Greenland ice chronology in those years was inaccurate.

Climate

The early 4th millennium B.C. coincides with the final part of the phase of decreasing solar activity and with noticeable volcanic activity (Figure 2 and Figure 3). It is possible that it caused the migration of the Eastern Anatolian people to the North Caucasus and the formation of Maykop culture. Unfortunately, we use different dating systems here: radiocarbon analysis and glaciochronology, and they are poorly comparable. Therefore, it is not possible to obtain more accurate dates. Studies of tree rings reveal a series of grand minima in solar activity. Their dating is based on radiocarbon method, but since the samples have been analyzed from a sequential context, it is approximately correct. In the discussed time, periods of decreasing solar activity are revealed *ca*. 3800–3600 Cal. B.C. and 3200–2900 Cal. B.C., with the increasing phase between them and a series of shorter ups and downs. The grand minima are revealed *ca*. 3620, 3495 and 3325 Cal. B.C.[2] (Usoskin 2017: 60, fig. 18, 20). The major volcanic events (Sigl *et al.* 2022) correlate with this. These fluctuations likely influenced the climate instability in the 37th-36th centuries B.C., which is clearly reflected in the palynological data.

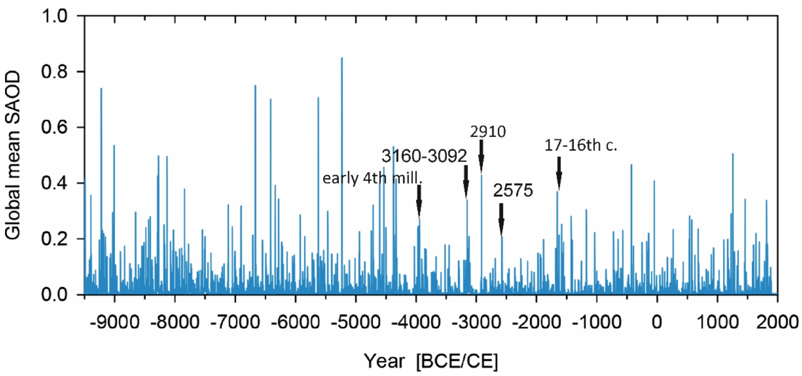

Figure 3. Global annual mean stratospheric aerosol optical depth (SAOD) (modified after Sigl *et al.* 2022, fig. 9).

A noticeable drift toward aridization began *ca*. 3700–3600 Cal. B.C. throughout the Near East. The aridization in Sakhara with a series of significant droughts is dated to this time. In the Levant, this process is indicated by the study of oxygen and carbon isotopes in the Soreq Cave, and the level of the Dead Sea decreased. There is no exact date of this process since some evidence suggests it began *ca*. 3700 Cal. B.C., and the others a little later. It differently influenced human communities. It is noteworthy that these climatic changes were accompanied by the Uruk expansion along the Euphrates that started *ca*. 3700 Cal. B.C. (Clarke *et al.* 2016). In North-central Iran, severe floods and droughts are also dated to the period of 3700-3500 cal. BC (Amirkhiz and Islam 2020), but in Lake Mirabad in Western Iran a long 600-year drought began *ca*. 5500 Cal. BP (Stevens *et al.* 2006), *i.e.* a little later, but the data are not of high resolution.

Besides, it was global. Even in the Yangtze delta after *ca*. 5600 Cal. BP the dry land finally formed, but *ca*. 5500 Cal. BP especially powerful floods and cooling took place (Wu *et al.* 2021), which coincides with the solar minimum in 3495 B.C. and the increased volcanism (Figure 2 and Figure 3), as well as with the volcanic events of 3530/3516 B.C., reconstructed from the Greenland ice, but this date is not reliable, since it is based on old chronologies. Between 5500 and 4570 Cal. BP remains of planktonic foraminiferal species, *Globorotalia truncatulinoides*, sharply increased in the Tyrrhenian Sea sediments, and pollen analyses in Central and Southern Italy indicate a drift towards drier and warmer conditions (Lirer *et al.* 2013). It seems that the process was rather smooth and started earlier in arid areas, but this may be an effect of the low resolution of the data, which cannot reflect abrupt short-term fluctuations.

Contrary to this, *ca*. 5500 Cal. BP in Moravia and many other parts of Europe, the climate became wetter and cooler, which caused cultural transformations (Dreslerová 2012). In North-western Germany *ca*. 3600 B.C., the peak in the marshes development took place, which was probably caused by the transgression of the North Sea (Eckstein *et al.* 2011). In Northern Scotland *ca*. 5500-5000 Cal. BP, vegetation changed, in particular, elms disappeared in the highlands (Tipping *et al.* 2008). It stimulated changes in the economy. In the canton of Valais in the Central Alps, research of sediments of Lake Lac de Champex has indicated the intensification of pasture *ca*. 5500 Cal. BP (*ca*. 3550 cal. BC) (Rey *et al.* 2022). *Ca*. 5600 Cal. BP the same took place in the Italian Alps, where since that time the cultures of the Copper Age formed, although this is the low-resolution data too (Pini *et al.* 2017).

Thus, we see a well-consistent pattern of heterogeneous changes: the increase in humidity and a decrease in temperatures in Europe, mainly in the north, and the increase in aridity in the Middle East and North Africa. Certainly, this reduced the adaptive capabilities of human collectives, but only strong sharp changes could trigger migrations. Unfortunately, the evidences above are of a low resolution and they are unable to indicate sharp short fluctuations.

The situation was the same as during the so called 2200 B.C. event, when a cooling in the North Atlantic caused a weakening of the Asian monsoons and more arid conditions in Asia (Weiss *et al.* 1993). It is explained by orbital changes (Wanner *et al.* 2008), but serious natural disasters took place only in the Near East, and they were caused by a major volcanic eruption (Grigoriev 2023a). Besides, the most common reason for climate change is cycles of solar activity of different durations. And the probability of small earthquakes and eruptions decreases in periods of decreasing solar activity, but the probability of large ones increases, and *visa versa*. The major eruptions are associated with changes in the cycles (Belov *et al.* 2009). The situation in the 4th and 3rd millennia B.C. was the same (Figure 2).

Dendrochronological studies in marshes of North-western Germany have revealed for the 4th millennium BC several periods of sharp increase in humidity, when trees died after the rise of water level: 3895-3838, 3691-3614, 3496-3473, and 3407-3403 B.C. The period 3600-3500 B.C. was relatively dry (Achterberg *et al.* 2018). But they could also be caused by some local events, because on another bog the trees died in other periods: 3720 B.C. and 3660-3620 B.C. (Eckstein *et al.* 2008), although the second interval falls into one of the above and corresponds to the solar minimum of 3620 B.C. (Figure 2). It is close to the changes in solar activity, but we must remember that they are dated by different methods. Volcanic events 3530/3516 B.C. and 3200 B.C., recorded in the Greenland ice, match nothing, which may be explained by either the inaccuracy of ice dating or special conditions in Northern Europe. However, the event 3530/3516 B.C. coincides with the beginning of a phase of decreasing solar activity, so the problems of the period could be partly caused by this.

As a result, it is quite obvious that the appearance of the megalithic tradition in the Northern Caucasus *ca*. the 36th century Cal. B.C., and in the North-western Pontic *ca*. the 35th century Cal. B.C., as well as the Uruk influences in the Caucasus in the last period were associated with these climatic changes, but we are not able to suggest an exact date since none of the events may be checked by alternative dates of a high resolution. As a result, for most of the 4th millennium B.C. constructing an exact chronology is impossible. The spread of the megalithic tradition to the Urals was probably caused by later events.

Stronger negative climate changes throughout the Near East were recorded for the period 3300-3100 Cal. B.C. (it was a time of decreasing solar activity), when aridization had begun that was continuing in the early 3rd millennium Cal. B.C. It is well visible in the drop in the level of the Dead Sea. In this period, the Uruk expansion to the north ceased, the Uruk colonies on the Middle Euphrates disappeared, but the 'urban revolution' in Mesopotamia started, where the Uruk-Warka culture formed, followed by the transition to the Early Dynastic Period. At the same time, there were no changes in Western Syria inhabited by pastoral communities (Clarke *et al.* 2016). This aridization is marked also by dust inclusions of Mesopotamian origin in sediments of the Persian Gulf (Cullen *et al.* 2000). In Central and Northern Iran, floods and droughts of the late 4th millennium Cal. B.C. led to the disappearance of the Uruk influences and to the collapse of some cultures, such as Sialk

IV (Amirkhiz and Islam 2020; Islam *et al.* 2016). The formation of statehood in Egypt and the first Pharaoh Narmer belong also to this time.

Climatic changes took place in Europe too. Studies of peat sediments in Western Ireland reveal evidence for an extreme climatic event, probably a storm or series of storms, *ca.* 5200-5100 Cal. BP caused the deposition of an extensive layer of silt across blanket peat (Caseldine *et al.* 2005). However, in general, the period from 3200 to 3000 B.C. in Ireland, Northern Scotland and Northern Britain is characterized by dry conditions with the reduction of water level, which caused the re-establishment of pine trees on the peats. In this case, the chronology is based on the floating dendrochronological scale dated by the radiocarbon method (Moir 2012; Moir *et al.* 2010; Tipping *et al.* 2008). Some cooling is recorded in Northern Sweden between *ca.* 5250 and 5000 Cal. BP (Vorren *et al.* 2011) and in the Austrian Alps *ca.* 5200 Cal. BP (Ilyashuk *et al.* 2011). But in the Italian Alps sharp climatic changes have not been recorded, although the use of Alpine pastures intensified (Pini *et al.* 2017).

In this case, we already have the opportunity to specify the date of historical events, and the beginning of this crisis can hardly be dated earlier than the solar maximum in 3170 B.C., which was followed by a rapid decrease in solar activity, accompanied by one of the longest volcanic events from 3160 to 3092 B.C. (Usoskin 2017, table 20; Sigl *et al.* 2022) (Figure 2 and Figure 3). These climatic problems stimulated migration. Probably, the appearance of the Ural megaliths, Zhivotilovka-Volchansk group in Ukraine, and the early kurgan tradition in the Northern Balkans belong to this time. However we cannot create an accurate chronology for these events, since all the palinological data are of extremely low resolution, and the volcanic event was so long that it cannot be used as an accurate chronological benchmark. Chronologically, these events were very close to the formation of statehood in Egypt and Mesopotamia, but we have no reason for their complete synchronization, and the Near Eastern chronology of this period is too vague.

Thus, for the entire 4th millennium Cal. B.C., we may discuss a connection of cultural transformations in Northern Eurasia with these climatic changes, but we cannot date them accurately. Such a possibility for the Eurasian EBA cultures appeared only at the beginning of the 3rd millennium Cal. B.C., due to the high resolution data from Europe.

3rd millennium BC

About 3000 BC solar activity began to increase to the grand maximum of *ca.* 2955 B.C., followed by a sharp decrease in solar activity with the grand minimum *ca.* 2855 Cal. B.C. At the beginning of this decline, a major volcanic eruption occurred in *ca.* 2910 B.C. (Usoskin 2017; Sigl *et al.* 2022). The actual dates of these events may differ slightly; they could be accompanied by other smaller eruptions. But in this case, we already have dendrochronological data: signals of cold years in the British Isles and the southwestern United States in 2960-2950 B.C., and different regions in 2910-2905 B.C. The solar minimum corresponds to the coldest years in 2853 B.C. in the southwestern United States and 2850 B.C. throughout Northern Europe (Figure 2). Then there was a rise, and in 2575 B.C. a volcanic eruption, close in time to the sharp decline in solar activity, which was changed by the rise and new decline to the solar minimum in 2450 B.C. After the eruption in 2575 B.C. a long 317-year period (until 2258 B.C.) without major volcanic events started (Usoskin 2017; Sigl *et al.* 2022).

These processes are reflected in global climate change. In the Near East, the development of arid conditions continued. And it again corresponded to the heterogeneous changes in Europe. The change in the hydroclimatic system in Britain occurred *ca*. 3000 Cal. B.C., resulting in more frequent and severe flooding. In Scotland, the humidity increased during the next century, it was not a smooth process, but in the form of individual phases *ca*. 3000-2990, 2960-2950 and 2910-2900 B.C. These dates are based on the floating dendrochronology linked to the radiocarbon dates. Dying-off phases and depression of growth of pines in the peatlands reflect a change to wetter conditions between 3023 and 3002 B.C. and a terminal decline between 2809 and 2782 B.C. (Moir 2012; Moir *et al.* 2010). Contrary to this, on the highlands of the region, the decrease in the number of trees began after *ca*. 5100 Cal. BP, but already *ca*. 4900 Cal. BP the vegetation began to recover, and after *ca*. 4830 Cal. BP the quantity of the pine pollen increased (Tipping *et al*. 2008). In Western Ireland *ca*. 4700 Cal. BP, a marked increase in humidity and a decrease in the productivity of fields are recorded, resulting in the building of stone walls around the fields to protect them against bogs (Turney *et al.* 2006).

A rapid peat accumulation is recorded in Southern Sweden between 5000 and 4000 Cal. BP. At the same time, the number of pine and linden trees decreased, which means a transition to a more humid and colder climate; but in South-central Sweden this transition is dated to 4600 Cal. BP (Edvardsson *et al*. 2014). About 4800 Cal. BP in the mountains of Northern Sweden, the tree line dropped abruptly by 200 m, and remained so low for a long time (Kullman 2013).

In the Central Alps *ca*. 5000 Cal. BP, the European silver firs (*Abies alba*) were replaced by spruces (*Picea abies*), but this could be caused by human activities in the mountains (Rey *et al.* 2022). About 4800 Cal. BP, the tree line shifted down, which could have been the same reason (Lotter *et al.* 2006; Schwörer *et al.* 2014). But it is also possible that the intensifying pastoralism in the highlands was provoked by problems with agriculture in the lowlands. In the Northern Carpathians *ca*. 4900 Cal. BP the tree line dropped too, and the reduction of spruces is recorded, which was caused by colder summer seasons (Feurdean *et al.* 2016). In Central Poland, lake sediments indicate an increase in humidity between *ca*. 4.5 and 3.9 ka BP (*ca*. 2500-1900 Cal. B.C.), but these are the LSC dates of a low resolution (Pawłowski *et al.* 2012). Similar processes took place in Northern Eurasia. Studies of lake sediments on the Lower Yenisei reveal the beginning of the permafrost between 5000 and 4500 Cal. BP (Wolfe *et al.* 2000). About 4800 Cal. BP its formation began in the Pechora delta, as well as the retreat of the tree line to the south, but the resolution of this data, which has been obtained from a section in the Ortino II peatland, is low: there are only nine dates for 7000 years of the section, and only two of them are close to the discussed time - 5640-5630 Cal. BP and 3240-3230 Cal. BP. The dating of other layers is based on modelling (Väliranta *et al.* 2003)[3].

Thus, the general processes of the increasing aridity in the Near East and increasing humidity and cooling in high attitudes resulted in the reduction of the adaptive capacities of people, but they were insufficient to trigger large-scale migration. In addition, these processes could not be smooth, but more abrupt and oscillatory, which palynology is not able to show. Evidence of more dramatic changes are provided by dendrochronology.

Investigations of tree rings in Northern Finland have revealed two coldest centuries in this millennium: 4850-4750 and 4450-4350 Cal. BP, but in this instance, we deal with a floating scale associated with radiocarbon analysis (Vorren *et al.* 2011). Narrower intervals of the changes have been identified in Ireland based on oak dendrochronology: decades of slower growth of annual rings, starting since 2850 B.C. and 2750 B.C. (Moir *et al.* 2010). In this period (based on pine chronology) the forests in England reduced, which was accompanied by the rising water level (Boswijk and Whitehouse 2002). But in those years in England, an accurate chronology existed only for oak, the pine chronology was less reliable (Chambers *et al.* 1997), but these dates coincide with solar minima.

In Eastern England *ca*. 2905 B.C. and 2857-2855 B.C., the pine annual rings did not grow, which has been explained by strong climatic stresses. In North-western Germany, long wet phases started in 2850 B.C. (Eckstein *et al.* 2011). In the year 2850 B.C. July temperatures were also the lowest in Finnish Lapland. And, it was an individual event, because the decade of this year was quite usual. But then the coldest century 2500-2401 B.C. started (Helama *et al.* 2002). In this period a gradual transition to a wetter climate is marked by the disappearance of trees in peatlands of Eastern England, in particular, on the White Moss *ca*. 2559 B.C. In Northern Ireland, on the Sluggan Bog and Garry Bog, trees stopped growing in 2642 and 2569 B.C. (Moir *et al.* 2010; Boswijk and Whitehouse 2002).

In general, the tree rings of Northern Europe indicate that 2850 and 2564 B.C. were extremely cold, and it was assumed that the first event coincided with volcanic activities reconstructed by studying the Greenland ice. It resulted in the absence of tree growth for two years (Helama *et al.* 2002, 2013). But this conclusion was made on the previous ice dating, whose accuracy was low. Sharp global cooling in 2850 B.C. coincides with the solar minimum, although additional volcanic influence cannot be ruled out. But 60-55 years earlier there was a global eruption and frost signals in the tree-rings. Thus, two different global events took place. Therefore, we are not able to confidently choose one of the two dates (2910 or 2850 B.C.) when interpreting cultural events that are not confirmed by dendrochronology. But it is obvious that at this time, 2910/2850 B.C., cultural transformations could take place anywhere. The cold episode of 2564 B.C. most certainly marks the volcanic eruption of 2575 B.C., whose date can be corrected by dendrochronology, since it is within the deviations declared for the dating of volcanic events, but the date 2564 B.C. is accurate.

Climate changes and chronology of historical processes in the 3rd millennium BC

In the late 4th - 3rd millennia Cal. B.C., significant cultural transformations occurred in Europe and Northern Eurasia. Probably, just in this period, the Ural megaliths appeared. In the Northern Pontic, the Zhivotilovka-Volchansk group formed, whose bearers penetrated to the north of the Balkans and into the Danube region, where the early pre-Yamnaya kurgans appeared. In the early 3rd millennium Cal. B.C., the Yamnaya culture formed in the steppes of Eastern Europe and its groups penetrated the Carpathian basin. As a result, the bearers of the first kurgan wave, who had been already mixed with local people, moved to the north and north-west, where the formation of the Corded Ware Culture (CWC) began (Figure 4). Then from this region, an impulse to the east followed, with the formation of the Fatyanovo and Balanovo cultures in the Volga region. Based on typology, their formation can be synchronized with the second phase of the Corded Ware Culture (Grigoriev 2022).

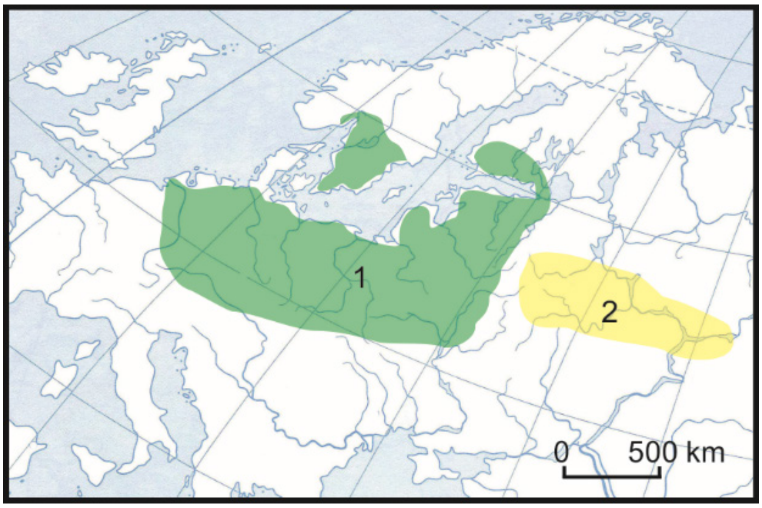

Figure 4. Map of the Corded Ware cultures (1) and

Fatyanovo culture (2).

Due to a lack of high resolution data from different areas, we are not able to create an accurate chronology of the events of the late 4th millennium Cal. B.C. Their most probable date is the long period of volcanic activity in 3160-3092 B.C. But there are possibilities for more accurate dates for the 3rd millennium B.C. The CWC formation exactly corresponds to the climatic event of 2850 B.C. caused by volcanic activity, because dendrodates of the early CWC from Lower Saxony (Eschenund and Erlenproben) correspond to the interval 2844-2737 B.C. (Włodarczak 2012). Therefore, we can assume that it was at this time the Yamnaya groups penetrated the Carpathian basin and displaced the descendants of the first kurgan wave from there. However, it is very doubtful that the cultural transformation was so rapid, and only six years passed between the Yamnaya migration and the formation of the Corded Ware stereotypes. Therefore, it is more likely that this migration coincided with the volcanic and cooling events in 2910-2905 B.C., but later the cooling event of 2850 B.C. influenced this process too. In this case, the difference between the formation of the Yamnaya culture and the migration of its people to Central Europe was small. We are not able to connect the earlier Yamnaya complexes (or some of their elements) with the Near Eastern sites, and it is very difficult to connect the latter with the chronology of Mesopotamia, where just at this time the Early Dynastic I period began. Besides, the Near Eastern chronology of this period is too vague. Therefore, in contrast to the CWC, the Yamnaya culture beginning cannot be checked by alternative sources, it is possible that in the west it was close to the date of the event 2910 B.C. But in the East, the Yamnaya stereotypes could arise earlier.

The AMS dates of the early western Fatyanovo sites fall into the interval 2750-2500 Cal. B.C. (Krenke 2019). But since radiocarbon method often shows earlier intervals, it is necessary to search for a possibility to connect the culture with dendrochronology. In Swiss, the early CWC phase is dated to 2718-2675 B.C., and the middle phase to 2625-2568 B.C. (Włodarczak 2012). It is noteworthy that the end of this phase is very close to 2564 B.C., the second coldest year in Europe after 2850 B.C. Therefore, it is not excluded that the transformations that led to the formation of the third CWC phase were caused by the stress connected with this event. Because the main parallels in Fatyanovo culture can be synchronized with the second CWC horizon, the emergence of the culture was suggested after the middle of the 27th century B.C., *i.e.* after the beginning of this horizon. However, it is necessary to take into account some parallels with the IIIa phase of the CWC (Grigoriev 2022). This long-distance migration needed some essential trigger, and the 2564 B.C. climatic event can be regarded as it, which allows us to suggest the date of the Fatyanovo migration *ca*. the middle of the 26th century B.C., at the transition to the 3rd CWC horizon. This later date can be confirmed also by some parallels between the Fatyanovo culture and late Yamnaya and early Catacomb complexes (Kiyashko 2003).

Another complex indicating migrations in the 3rd millennium B.C. is a series of cultures with catacomb burials and some other common features (skeletons crouched on their sides facing the entrance shaft, partitions, some types of metal, and incense burners). These include the Catacomb cultures of Eastern Europe, Eastern Iran and elements of this culture in the early Uybat phase of the Okunev culture on the Yenisei. Previously, the spread of these cultures from northeastern Iran was assumed (Grigoriev 2002), but much earlier this ritual was known in southeastern Iran (*e.g.* Heydari *et al.* 2019).

In general, from *ca*. 2500 Cal. B.C. there was a decrease in solar activity to the grand minimum *ca*. 2450 Cal. B.C. (Usoskin 2017, Fig. 18, 20). Under these conditions, the processes of cooling in the northern latitudes and aridization in the south could have taken place. The formation of the earliest Catacomb culture (pre-Donets) in Eastern Europe occurred east of the Azov Sea, on the Lower Don and Lower Kuban (Figure 5), slightly later than the Fatyanovo formation (Gey 2011). At this time the EBA/MBA transition started in the steppe of Eastern Europe. It is important that the climate in the MBA was noticeably drier than that in the previous Yamnaya period (Borisov *et al.* 2011). Radiocarbon dates for the Catacomb culture give extremely wide intervals, which is explained by the fact that the steep sections of the calibration curve for the 3rd millennium BC are very short: 2920-2860 Cal. B.C. and 2480-2460 Cal. B.C. (Kaiser 2011). Significantly, these two intervals coincide with a sharp decrease in solar activity (Figure 2). Since the early Catacomb sites appear a little later than the Fatyanovo ones, their date should be around the middle of the 3rd millennium B.C. Based on the historical chronology of the Middle East and synchronization with the late stage of the Kura-Arax culture, the later classical Donetsk sites used to be dated to the period 2400-2300 B.C. (Smirnov 1996). In the Levant, the catacomb burials occurred in the EB IV period. Earlier it was dated since *ca.* 2500 Cal. B.C., but the use of Bayesian statistics for samples from the successive layers of Jericho suggested for the entire period the interval 2300-2000 Cal. B.C., which corresponds to its historical chronology: 2400/2300-2000 B.C. (Nigro *et al.* 2019; Regev *et al.* 2012).

In the east, in the Minusinsk basin, the early Uybat phase of the Okunev culture is dated to ca. 26th-23rd centuries Cal. B.C. (Figure 5). But if to take into account the earlier Afanasievo culture, the boundary between them is the late 26th - early 25th centuries Cal. B.C. Here, rectangular enclosures around the burial ground appeared, and catacombs with an oval chamber separated by a stone partition from the shaft. The buried lay in the contracted position on their back, like in the Afanasievo culture, but there are also contracted on the right, rarely left side burials. It was an absolutely new custom whose roots are seen in the early Catacomb culture of the North-west Caspian area (Lazaretov 2019).

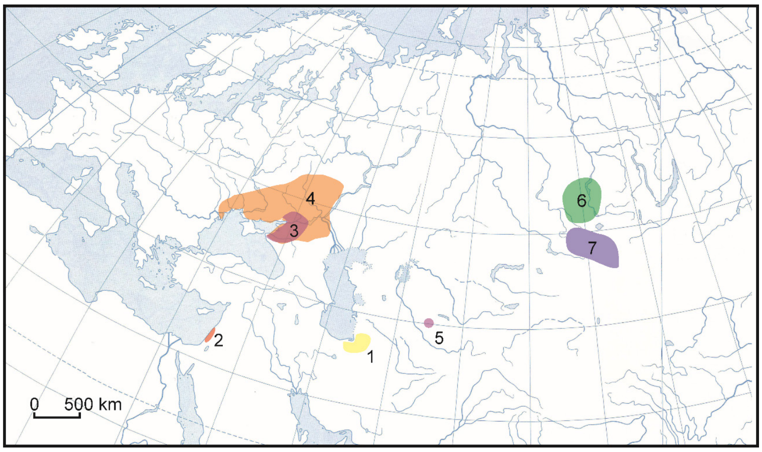

Figure 5. Cultural changes *ca.* the 25th century Cal. B.C. (24th century B.C.): 1. Catacomb sites of the South-eastern Caspian area (Parkhai, Sumbar, Tureng-tepe); 2. EB IV of the Levant; 3. early (pre-Donets) Catacomb culture; 4. area of the maximum distribution of the Catacomb culture in Eastern Europe; 5. Zaman Baba; 6. Okunev culture; 7. Chemurchek sites.

Thus, throughout Northern Eurasia, the early catacombs appeared around the middle of the 3rd millennium B.C., which coincides with the interval of the abrupt decrease in solar activity *ca.* 2500-2450 B.C. The following development of Catacomb cultures (Donetsk and Levantine catacombs) are dated to the 24th century B.C., and we do not have any way to make this date more accurate.

In the same period in the Mongolian Altai and South-east Kazakhstan, sites of the Chemurchek type appeared, with megalithic tombs in rectangular stone enclosures and with statue menhirs (Figure 5). Features of these tombs and statues, as well as some types of vessels, have exact analogies in the megalithic cultures of Western Europe, principally in Western and Southern France, where they are dated within 3200-2600 Cal. B.C. Some objects make it possible to synchronize these sites with the late Afanasievo and Okunev complexes. Radiocarbon dates of the Chemurchek sites are 2700/2600-1800 Cal. B.C. It allowed a migration from Western Europe to Central Asia to be reconstructed (Kovalev 2022). It was also assumed that it was the migration of Yamnaya tribes, that resulted in the appearance of the Tocharians in Central Asia, and its date is *ca*. the mid-3rd millennium Cal. B.C. or slightly later (Jia and Betts 2010). However, the parallels in Western Europe are quite convincing. We must remember that the Bell Beaker tradition spread from Iberia at this time. Therefore, it is possible that just this movement triggered the migration of some enclaves of the last bearers of the megalithic tradition.

Thus, we see large-scale and relatively synchronous changes throughout Eurasia, which can be dated *ca*. the first half of the 25th century Cal. B.C., and the following ones *ca*. the 24th century B.C. in the historical dates. They were stimulated by impulses from two areas: Iberia and Iran. They could cause the Chemurchek migration to Central Asia, and the distribution of the catacomb burial rite. However, we have no ground for a complete synchronization of these processes. The migration from Iran was caused more likely by the increasing aridity in the Middle East, which took place also in the Eurasian steppes. This corresponds also to the colder period in Northern Europe. But we have no data on a global climatic disaster, that could trigger all these events, and which can be used as a chronological benchmark. In principle, this could coincide with the solar minimum of *ca*. 2450 Cal. B.C. Since it was reconstructed based on tree rings, increased volcanic activity cannot be ruled out. But this needs to be confirmed by the data from ice-cores.

Conclusions

The main migrations of the period between the mid-4th and mid-3rd millennia Cal. B.C. were stimulated by the cyclic climate changes caused by changes in solar activity. Periodically, the abrupt changes created conditions that triggered people to migrate. Paleoclimatic data of a high resolution allow us to reveal these episodes and use them as chronological benchmarks for archaeological cultures. This approach has been applied to materials of the late 3rd - the middle of the 2nd millennia B.C. But its application to the period under discussion cannot be called quite successful, because of the lack of high-resolution data, and it is very difficult to check any hypothesis with alternative sources. Almost everywhere these data are presented by sediments dated by rare radiocarbon analyses, whose chronology is also unreliable. Only in Central and Northern Europe can we use dendrodates. We cannot check these results with historical chronology, which for most of this period is either very approximate or absent. In this case, we would be interested in abrupt changes caused by large volcanic eruptions, which can be detected in the ice of Greenland and Antarctica. Unfortunately, at the moment, there is no exact ice chronology for this period. Perhaps it will appear later, as it has been done recently for the 17th-16th centuries B.C. (Pearson *et al.* 2022). In this case, we will be also able to obtain an accurate chronology of migrations in this period. Another possible solution to the problem is a detailed comparison of tree rings in different regions, which can also make it possible to identify global abrupt climatic events. Until then, we have only very rough ideas about the chronology of this period.

It is obvious that the appearance of megalithic tradition in Novosvobodnaya in the Northern Caucasus and Usatovo was associated with climatic problems of the 36th-35th centuries cal. BC, but it is impossible to suggest a more accurate date. The next worsening of climate *ca*. the 32nd century Cal. B.C. stimulated the appearance of some groups of the final Eneolithic in the steppe of Northern Eurasia (Zhivotilovka-Volchanskoe, perhaps some others). It was more expressed in the arid areas of the Middle East and was less significant in Europe. However since a reliable historical chronology of this period is absent, we are not able to do the date more accurately. A more probable is the interval of volcanic activity 3160-3092 B.C. What is interesting is that the increase in volcanic activity in this and other cases corresponds to the beginning of periods of decreased solar activity.

It is more probable to create an accurate chronology for the 3rd millennium B.C. In the middle of the 30th century B.C. a sharp decrease in solar activity started, which was accompanied by a powerful eruption in 2910 B.C.; this decrease lasted to the solar minimum in 2855 B.C., and in 2850 B.C. an abrupt cooling occurred in Europe. This date corresponds to the earliest date of the Corded Ware Culture, *ca*. 2844 B.C. Accordingly, this 2910 and 2850 B.C. event could cause the rapid westward distribution of the Yamnaya stereotypes from the drier Volga-Ural region and the formation of the Corded Ware Culture. However, the emergence of the Yamnaya stereotypes began earlier. Both these dates, 2910 and 2850 B.C., can be used for other areas, since they were connected with serious climate events, which could also provoke cultural transformations, but it is difficult to choose between them, and we may talk about the time 2910/2850 B.C. The second powerful cooling in Europe in 2564 B.C. caused the Fatyanovo migration to the east. But in this instance, it would be desirable to obtain confirmation from alternative sources.

The dating of the events of the 25th/24th century B.C. is less reliable. In this period several cultural traditions spread in Eurasia: Catacomb cultures in many areas, Bell Beaker in Europe, EH IIb traditions in Greece, Chemurchek type in Central Asia. Probably, it was partly stimulated by the continuing aridization in the Middle East, but we cannot synchronize these processes and find a single trigger, that could be used for the absolute chronology.

However, these preliminary results demonstrate that we have to continue the attempts to base our chronological schemes on dendrochronology and historical chronology, which suggest younger and more accurate intervals. As dendrochronology and the study of ice, ancient cold events, and volcanic processes develop, and as new methods emerge that will allow us to compare the layers of archaeological sites with these events, we will have more and more opportunities for this work.

Notes

[1] Because of the difference between radiocarbon dates on the one hand and historical dates and dendrodates on the other, the latter are designated “B.C.”and the former “Cal. B.C.”. But paleoclymatologists use the cal. BP dates, i.e. before 1950 A.D. Thus, their values differ by almost 2000 years from the Cal. B.C. dates, which should be kept in mind when reading the text, since the dates are given according to the original publications.

[2] Unfortunately, the dating technique is not described in the publication, and I am grateful to I.G. Usokin for his consultation.

[3] For the Eurasian Arctic, there is other data, about a later cooling associated with the 2200 B.C. event. The retreat of the forest into the continent took place between 4000 and 3000 cal. BP (MacDonald *et al.* 2000). At the same time, ca. 4300-4100 Cal. BP, the number of spruce (*Picea abies*) reduced (Pitkänen *et al.* 2002). In the Pechora tundra during 8000–3500 Cal. BP, summer temperatures were 3°C higher than today, and only then the cooling and permafrost formation begin in the region (Salonen *et al.* 2011).

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