quaternary

Article

Prehistoric Astronomical Observatories and Paleoclimatic Records in Bulgaria Estimate Astroclimate during 4000–4500 BCE: A Critical Assessment

Alexey Stoev [1], Yavor Shopov [2,3,4], Penka Maglova [1,*], Ognyan Ognyanov [1] and Lyubomira Raykova [1]

[1] Stara Zagora Department, Space Research and Technology Institute, Bulgarian Academy of Sciences, 6000 Stara Zagora, Bulgaria
[2] University Centre for Space Research and Technologies, Faculty of Physics, Sofia University "St. Kliment Ohridski", 1504 Sofia, Bulgaria
[3] Medical Physics and Biophysics Department, Medical University of Sofia, 1431 Sofia, Bulgaria
[4] Institute for Systems Science, Durban University of Technology, P.O. Box 1334, Durban 4000, South Africa
[*] Correspondence: seac2021stz@abv.bg; Tel.: +395-876-25-34-13

Abstract: Prehistoric astronomical observatories include a specific type of rock-cut monuments from the Mountainous Thrace in Bulgaria, with a specific shape and orientation in space, which are part of the characteristic representatives of the archeoastronomical sites on the Balkan Peninsula from the period of 4000–4500 BCE. Earlier societies focused on the triad "astronomical instrument"—celestial objects—trained observers. When choosing sites for the construction of oriented stone complexes for astronomical observations, prehistoric people were interested in the number of clear days and nights within the tropical year, which is connected with the paleoclimate of the region and to the astroclimate, which determines the possibility of observing heavenly bodies. Here we examine 13 prehistoric astronomical observatories using the methods of archaeoastronomy in order to determine the period of their operation. Since the existence of a large number of such objects is indirect evidence of a good astroclimate, we make an assessment of the paleoclimate in the relevant era in the Bulgarian lands in order to find out if it was suitable for astronomical observations. The estimations are made according to the geological data and solar insolation luminescence proxy records of the evolution of cave speleothems from Duhlata cave in the village of Bosnek, Pernik municipality, which is still the only available experimental record of past solar insolation in Europe covering the last 20,000 years. The number of clear days and nights are estimated, and a critical assessment of the possibility of successful observations of the Sun during equinoxes and solstices is made using the methods of "horizon" astronomy and meridional culminations. It is also shown that the climate at the end of the Ice Age was cooler than today. About 11,700 years ago (11,700 radiocarbon years before 1950 CE or 11,700 BP), the climate began to warm, and forest vegetation developed on the territory liberated from the glaciers. During the Upper Atlantic (6–8 thousand years BCE), the average annual temperature on the Balkan Peninsula and in particular in Bulgaria was about 2–2.5 °C higher than it is today. This climate allows some very good astroclimatic conditions for observations of the Sun near the horizon and increases the accuracy of the observational data in determining the time of occurrence in its extreme positions on the horizon. We show that changes in climate (and astroclimate accordingly) influence the type of prehistoric astronomical observatories.

Keywords: prehistoric observatories; archaeoastronomy; astroclimate; paleoclimatic records; cave speleothems

Citation: Stoev, A.; Shopov, Y.; Maglova, P.; Ognyanov, O.; Raykova, L. Prehistoric Astronomical Observatories and Paleoclimatic Records in Bulgaria Estimate Astroclimate during 4000–4500 BCE: A Critical Assessment. *Quaternary* **2023**, *6*, 6. https://doi.org/10.3390/quat6010006

Academic Editors: Ioannis Liritzis and James B. Innes

Received: 10 August 2022
Revised: 5 December 2022
Accepted: 20 December 2022
Published: 5 January 2023

1. Introduction

The beauty of the sky has always attracted our eyes. Undoubtedly, man has observed the starry sky and celestial bodies since ancient times. Astronomy is part of culture and society; it has a clear social character. Archaeoastronomy studies the ways in which people in the past have understood the phenomena in the sky, how they used them and what role the sky played in their cultures [1].

With the advent of man, the Earth's climate has changed under the influence of a complex of factors, including human activity. The replacement of natural vegetation with agricultural crops, deforestation and/or the burning of forests and the emergence and growth of settlements change the natural albedo (reflection of the solar radiation) of the territory. This causes reflectivity changes, which are the reason for changes in the Earth's surface heat balance. An attempt has been made to answer the question, "When did these processes begin?" One of the reasons is agriculture, which is associated with a sedentary lifestyle, and which first appeared in the Neolithic (10–11 thousand years BCE) [2]. On the territory of Bulgaria, Neolithic settlements appeared about 8.1–8.6 thousand years ago (radiocarbon years before 1950 CE). At the beginning of the Neolithic and later in the Eneolithic (Chalcolithic, Copper Age), from 4000–4500 BCE, human influence on the environment was limited, so climate change during this period was little affected by anthropogenic activity.

Every major region in the world has its own individual destiny for development in prehistory. Almost all of them go through certain stages in the formation of societies, religions and technologies. All previous studies show that the basic notions of time and timing are developed during these periods, and that the foundations of these culture share common features and characteristics of the hearths of civilization. The architecture of the special facilities for the observation of celestial objects studied here shows the skills of the people of that time in planning, creating construction technology and making long-term observations.

Rock monuments of this type, despite their initial antiquity and diversity, can arise only in the presence of a sufficiently developed triad of "astronomical instrument—celestial objects—trained observers", as well as in the presence of certain socio-cultural, economic and spatial-climatic conditions. As a specific cultural phenomenon, rock-cut monuments for astronomical observations span many different periods of time in different regions of the world. From the creation of the first rock sanctuaries by various communities with places for the contemplation of heaven and prayers, to the emergence of much later, extremely complex rock structures for targeted observations, long periods of historical time pass. It can be tentatively believed that the first astronomical rock structures appeared on Earth at the beginning of the 6th millennium BCE [3,4].

The prehistoric astronomical observatories consisting of rock-cut monuments from the Mountainous Thrace in Bulgaria are characteristic representatives of the archaeoastronomical sites on the Balkan Peninsula from the period 4000–4500 BCE. When choosing sites for the construction of these oriented stone complexes for astronomical observations, prehistoric people were interested in the number of clear days and nights within the tropical year, which is connected with the paleoclimate in the region and with its astroclimate, which determines the possibility of observing heavenly bodies.

The aim of our research is to examine 13 prehistoric astronomical observatories using the methods of archaeoastronomy and determine the period of their functioning, which is indirect evidence of a good astroclimate. In order to find out if the astroclimate was suitable for astronomical observations, we make an assessment of the paleoclimate in the relevant era in the Bulgarian lands. The estimations are made according to geological data and solar insolation luminescence proxy records of the evolution of cave speleothems from Duhlata cave in the village of Bosnek, Pernik municipality, which is still the only available experimental record of past solar insolation in Europe covering the last 20,000 years.

2. Geographical, Climatic and Socio-Cultural Preconditions for the Appearance of Astronomical Observation Facilities in Prehistory

Today, we know that, for the emergence of long-term settlements and economic structures in prehistoric times, a mild climate and the availability of fresh water and natural shelters are required, as well as fertile soils and materials for the production of tools. These conditions mostly correspond to the strip of the globe between 43° and 23° North latitude. The fertile valleys of the great rivers Tigris and Euphrates, the Yellow River and the Yangtze, the Indus, the Nile, the Mediterranean coast and the mountainous foothills of present-day Syria and Iran find themselves in this vast and favorable territory. In this strip, one can find the largest number of the ancient settlements, religious sites and production centers that serve as the basis for the emergence of all major ancient civilizations on the Eurasian continent, beginning in the 9th millennium BCE. It was at that time that the most significant migrations of ancient peoples took place. Traces of the movement of pastoralists and farmers, merchants and builders of cult ensembles spread throughout Europe. The area in which those tribes and peoples existed depended directly on the size of the favorable territory.

Climate in the region of ancient settlements is one of the basic conditions for determining their size and population. The migration of tribes of farmers and pastoralists is often associated with the search for new habitable lands. The socio-cultural sphere of this period is characterized by the completion of the formation of pagan cults with a hierarchy of deities. Most often, the pantheon of gods is governed by a supreme god (the Sun). Specific ornaments of a solar or astral nature play an important role, carrying significant and diverse information, which often includes a magical component. It has become the structural backbone of almost all prehistoric arts. An agricultural calendar is emerging in many of these areas. Cult components sooner or later begin to be associated with the agricultural calendar, gradually becoming the behavioral basis of prehistoric society. During the same period, cults are built and actively spread, especially the cult of the Sun and natural forces, as well as the cult of ancestors. Cult structures and complexes are realized variously: from small areas in the structure of houses or settlements to large cult ensembles, which become the ritual center of the surrounding villages.

The history of the prehistoric tribes that inhabited the Bulgarian lands and the Balkan Peninsula during the Neolithic and Eneolithic Ages is an integral part of the history of Southeast Europe. Unlike in the past, when technical possibilities did not allow such a detailed study of prehistory, today it is possible, and new horizons and data are being discovered. Of particular importance are the achievements of the radiocarbon method, dendrochronology and the study of cave speleothems, which give prehistory real chronological boundaries [5–7].

Figure 1 depicts several of the so-called "cultural-territorial zones", which are determined primarily by the geographical factor. During the Neolithic and Eneolithic epochs, three such zones emerged: Zone I—North, Zone II—Forest and Zone III—South. Each of them has its own way of life, and the settlement in it is engaged in various activities of life. Between the individual zones, there are others that carry the legacies of these three zones interwoven within them. During the Neolithic era, several closely related ethnocultural areas can be traced, having formed at the end of the 9th millennium BCE. They are the result of the Neolithic consolidation of the Neolithic agricultural and livestock economy [8,9].

In the south, the cultures with Early Neolithic ceramics stand out (the groups in Thessaly and the Eastern Mediterranean; the groups from Karanovo—Kremikovtsi—Starchevo, etc.). The characteristic features of these areas are painted ceramics, ground dwellings, well-organized settlement structures and trade relations. Exceptions include the groups to the north, where ground dwellings and dugouts meet in one place. This is obviously due to the close coexistence of the two cultures [8].

The second area covers the region between the Balkans and the Carpathians. It includes the cultures Ovcharovo, Krish and others. Their characteristic features are pottery with impurities of chaff, an almost complete absence of painted pottery and a settlement built only on the plateaus, and their main residential forms are the dugout and the ground dwelling. At the end of the Neolithic era (end of the 8th millennium BCE), Thrace probably experienced its first demographic explosion. The population began a gradual movement to the north, where the Neolithic population was much less compact. That is why here, at the level of the cultures of Polyanitsa, Sava, etc., in the Balkan Northeast, ground buildings appear, close to each other, and settlement mounds appear, which until then were typical only for the southern regions [8,9].

Figure 1. Scope of cultural-territorial zones on the Balkan Peninsula: Zone I—North, Zone II—Forest and Zone III—South.

Studies on the structure and planning of a Neolithic settlement can be given only if a large part of the settlement space has been discovered. In recent years, this has proved to be very real and possible, and many hitherto unknown facts about the structure of settlements, the manner of the construction of housing and its orientation and many other facts have been established. The plans of entire Neolithic sites, such as Karanovo, Golyamo Delchevo I, Podgorica and many others, have been revealed. Scattered throughout Bulgaria, they give a realistic idea of the peculiarities of the housing construction, settlement traditions, culture and technologies of their inhabitants [8,9].

3. Ancient Astronomical Observatories in Bulgaria (Horizon and Meridional Astronomy)

In ancient times, when choosing sites for the construction of oriented stone complexes (rock-cut monuments) for astronomical observations, prehistoric people were interested in the number of clear days and nights within the tropical year. The set of atmospheric conditions that affect the quality and quantity of astronomical observations of a particular object determine the clear days and nights. The most important of them are the transparency of the air, the degree of its homogeneity and the ability to obtain a long series of observations. The "horizon" and "meridian" astronomical practices during the Eneolithic are less strongly influenced by the astroclimate, mainly due to the lack of optical instruments. The observations were made with the naked eye, using sighting and projection devices made mainly of stone. However, the need for a good astroclimate also applies to them, mainly due to the need to accurately record the equinoxes and solstices throughout the year. This was a particularly important procedure for creating and maintaining the prehistoric calendar.

A lot of prehistoric observatories are found in the mountainous regions of Bulgaria (Figure 2). They can be defined as spatial structures of different reliefs, rock shapes and cuts connected in a certain functional dependence with the horizon, the sky and the heavenly objects and phenomena. Archaeoastronomical research has been made taking into account the structural elements and orientation of the rock-cut monuments as well as archaeological artifacts found on their territory.

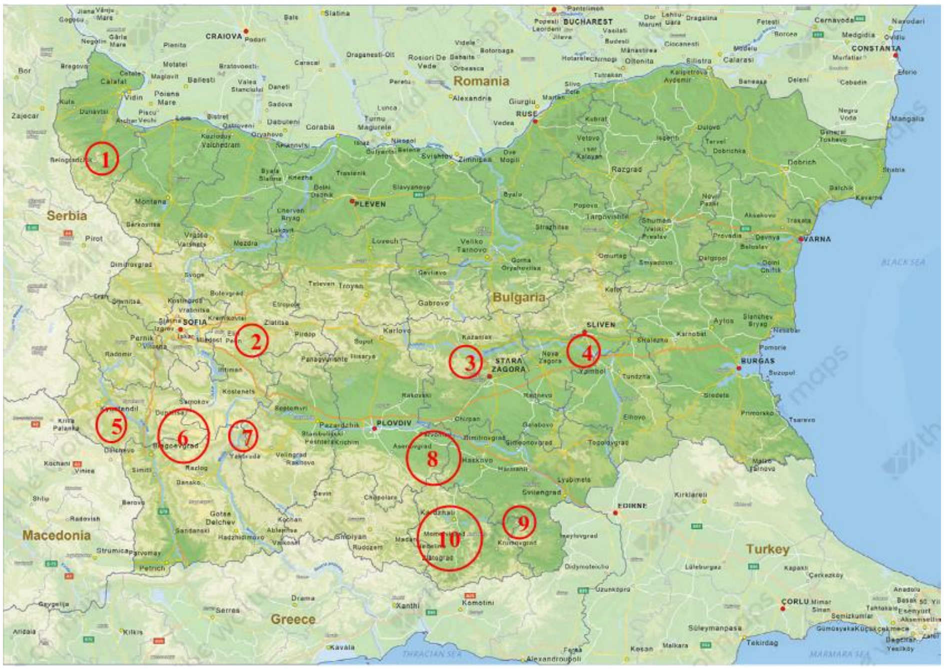

Figure 2. Location of the studied rock-cut monuments with astronomical meaning on the territory of today's Bulgaria: 1—Magura cave, 2—Bailovo cave, 3—Buzovgrad, 4—Zaychi vrah, 5—Lilyach, 6—Markov Kamak and Tsarevi Porti, 7—Kozi Kamak, 8—Belintash, Parmakla Kaya cave and Angel Voyvoda, 9—Kovil, 10—Harman Kaya, Tangardak Kaya cave and Tatul.

Prehistoric observatories show the skills of their makers to build such facilities, to conduct astronomical observations and to apply them. Generally, we can find them in high places. There is usually a spring around, and they are near populated areas. Prehistoric observatories take the form of megalithic structures such as sanctuaries and tombs. Very often, images of astronomical objects and phenomena (the Sun, the Moon, bright stars, comets, eclipses) can be found in these places. Solar, lunar and stellar images and solar calendars have been found in the cave complexes near the villages of Baylovo and Lipnitsa, Sofia district and the village of Tsarevets, Mezdra municipality; in the Topchika cave, Asenovgrad municipality; and in the Magura cave near the village of Rabisha, Belogradchic municipality [10–14].

Exploring the prehistoric observatories, we get an idea of the astronomical knowledge and observations, of the customs and beliefs, and of the art, the worldview and the values of the people and societies that lived in the ancient Bulgarian lands [15–27].

3.1. Methodology of Archaeoastronomical Investigations

The methodology of archaeoastronomical research examines the ways, methods and aims of investigation in the field of archaeoastronomical reconstructions [16].

3.1.1. Methodology for the Detection and Study of Structural Orientations in Rock-Cut Monuments (Method of "Horizon" Astronomy)

The basis of the methodology for finding the coincidences of terrain markers (structural orientations) with the points on the horizon at which the Sun rises (or sets) for an observer from a selected place is the assumption that prehistoric people empirically recorded these positions within the tropical year (the time between two identical positions of the sun at sunrise or sunset), which makes it possible to make a calendar. To restore the mechanism of ancient observations, we need to measure the azimuth of the point of sunrise (sunset) from the prehistoric monument and the specific place of observation needed for determining the declination of the sun by the formula

$$\sin\delta = \sin\varphi \sin h + \cos\varphi\cdot\cos h\cdot\cos A \tag{1}$$

where A and h are the azimuth and the height of the Sun above the true horizon at the moment of sunrise (sunset). The latitude is denoted by φ and the declination of the Sun—by δ. The height of the visible horizon is measured with a Theo 010 theodolite, with a centi-centigrade accuracy. When the horizon line is more than 5–8 km away, the curvature of the earth's surface is taken into account, as well as the refraction and parallax of the observed object. The sum of all these factors gives the following formula:

$$h = h_{hor} - r_{terra} + \pi - R \tag{2}$$

where h is the real height, h_{hor}—the apparent height of the horizon, r_{terra}—correction for the curvature of the earth's surface, π—parallax and R—the refraction of the luminary [17].

Obtaining the values of h allows us to find the azimuth of that point on the horizon, where the center of the Sun's disk will fall, with the horizon line dividing it into two equal parts. For the moment of the first touch of the disk to the line of the visible horizon, we must add 0.25°. Since the apparent diameters of the Sun and the Moon are the same, the corrections used in determining sunrises (sunsets) are the same for both bodies.

3.1.2. Methodology for the Detection and Study of Light and Shadow Effects in Rock-Cut Monuments (Method of Meridional Culminations)

The methodology for studying light calendar effects is related to the detection and precise documentation of the main lines (horizontal and vertical, orientations) forming the projection hole. Observing and measuring a "light" spot on a dark surface is easier than directly observing the sun's disk on the horizon line [18]. This procedure is facilitated when the spot has the correct geometric shape and is designed on appropriate "reception markers"—elements of the rock relief or the framework of the monument. By definition, "light projection" in a calendar sense means the coincidence of a selected edge of a light projection with a deliberately constructed "reception" marker [19]. Only two celestial bodies, the Sun and the Moon, have great enough intensities of incident light to produce such effects. The "effects" are studied empirically at characteristic points. The following constants for the facility need to be measured and calculated in advance:

1. Astronomical azimuth of the object (A—most often this is the main axis of the facility (the cave) or other auxiliary directions);
2. Latitude (φ—interpolated by map or accurate GPS);
3. Height of the Sun (h—from the characteristic "receiving markers"; dimensions and orientation of the projection opening are also needed.

With the resulting A, φ and h (the latter is adjusted by +16′ to correspond to the lowest point of the Sun relative to the horizon), according to formula (1), we calculate the declination δ of the Sun and find in the astronomical calendar the corresponding day of the year on which this light projection is realized.

According to the formula:

$$\cos A = (\sin\delta - \sin\varphi\cdot\sin h)/\cos\varphi\cdot\cos h \tag{3}$$

we calculate the azimuth A of the sunrise on the eastern horizon during the equinoxes and solstices.

In the process of research, it is quite possible also to detect a characteristic lunar declination (minimum = [−(ε − 5°9′)], or maximum = [+(ε + 5°9′)]), where ε is the inclination of the ecliptic and 5°9′ is the inclination of the moon's orbit relative to the ecliptic.

The hypothesis of the presence of light calendar effects in a monument is always related to the position of the Sun (or Moon) relative to the axis of the facility, between the centers of two entrances, or exactly in the axis of a corridor (gallery). This axis is marked from the middle of the lower outer edge of the lintel (the upper threshold of the hole to be projected) at the desired lower point—the middle of the lower threshold of the step or rock carving constituting the artificial marker. By selecting appropriate "reception markers" that must meet certain objective criteria, it is quite possible to detect calendar relationships with the annual movement of the Sun. Moreover, in certain cases, it is possible to astronomically date the chronological boundaries of the object's existence along the height of the Sun in culmination during the winter solstice.

Due to the lack of archaeoastronomical research on a larger number of monuments of this type, it is not known whether one, two or more calendar dates were used. If we assume that the date "remembered" by a marker was only one, the most significant—for example, the solstice—we can assume that the other dates are determined by movable screens in the contour of the opening. From the previous archaeoastronomical studies of rock-cut monuments and cult caves [3,4,10–27], we can conclude that the height of the Sun, designated as a shadow or light spot, is much more important than the horizontal orientation of the near and far benchmarks to sunrise or sunset.

Facilities for observing the Sun have been found at the following rock-cut monuments: *Belintash*, near the village of Mostovo, Plovdiv district, *Zaychi vruh* (Figure 3), near the village of Kabile, Yambol district; *Tatul*, near the village of Tatul, Momchilgrad municipality; *Tangarduk Kaya* (Figure 4), Kurdjali district; *Harman Kaya* (Figure 5), near the village of Dolna Chobanka, Momchilgrad municipality; *Buzovgrad* (Figure 6), Kazanluk municipality; *Tzarevi porti*, the village of Kovachevitsa, Garmen municipality; *Markov kamak*, Blagoevgrad municipality, *Lilyach*, Kyustendil municipality; *Kovil*, Krumovgrad municipality, *Baylovo*, Gorna Malina municipality; *Magura*, Belogradchik municipality and *Parmakla Kaya*, near the village of Nochevo, Asenovgrad municipality [14–27].

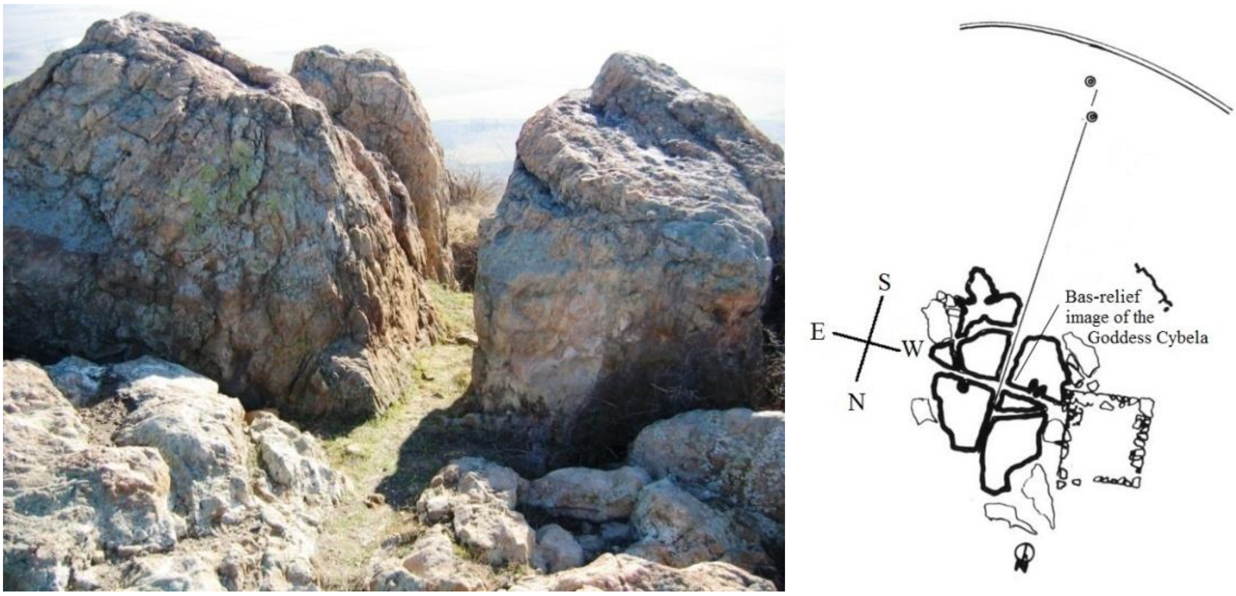

Figure 3. Zaychi vruh (Cabyle). Artificially hewn out of the rock trenches, oriented East–West and North–South, used for observations of the sun during equinoxes and culminations of bright luminaries. An additionally leveled rock, located in the northeast, allows determination of the summer solstice. This device could be used for measuring time intervals longer or shorter than a day, after [25].

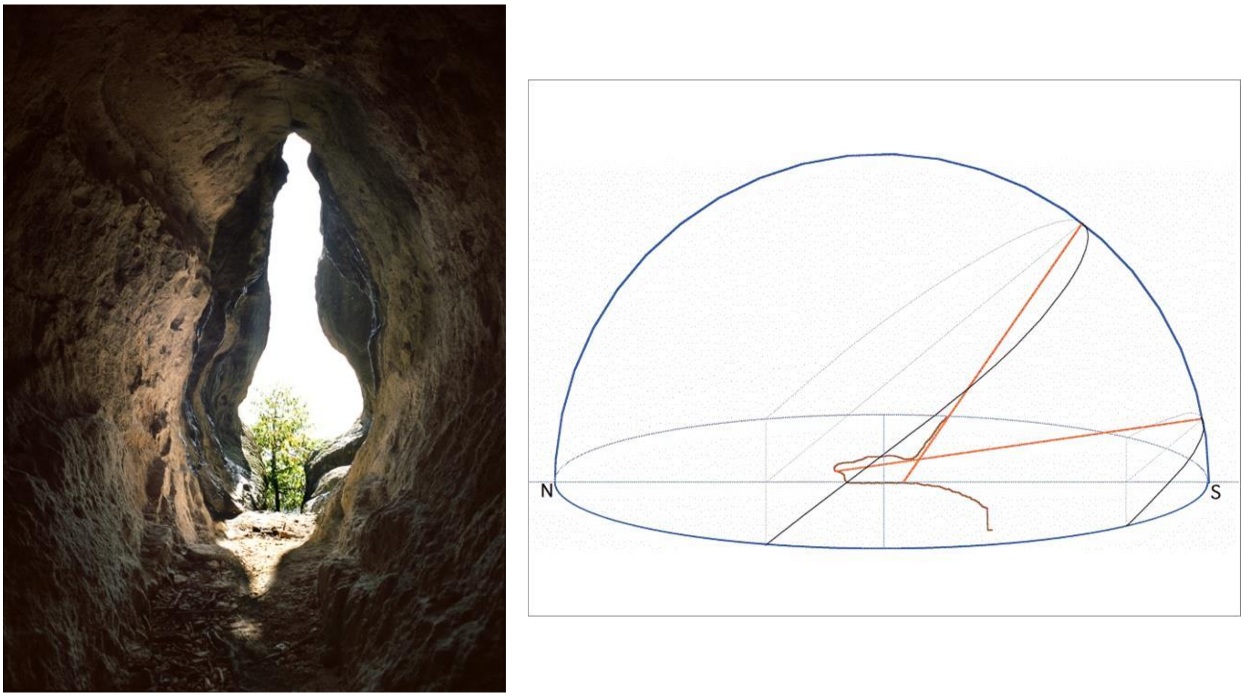

Figure 4. Tangarduk Kaya cave sanctuary. The additionally processed gallery of the natural cave is oriented North–South, and it is convenient for observation of Sun culminations. The light projection of the entrance could be used for defining the summer and winter solstices or for determining the longest and the shortest day of the year, after [19].

Figure 5. Harman Kaya rock-cut monument. Observations of the Sun from the northeastern, artificially leveled site of the rock complex. The eastern peripheral part offers convenient reliefs which, after a little further processing, were used as sighting devices. This is a typical system for observations of sunrises and sunsets (during solstice or equinox), which coincide with characteristic points of the local horizon(1—summer solstice, 2—spring and autumn equinox, 3—winter solstice), after [26].

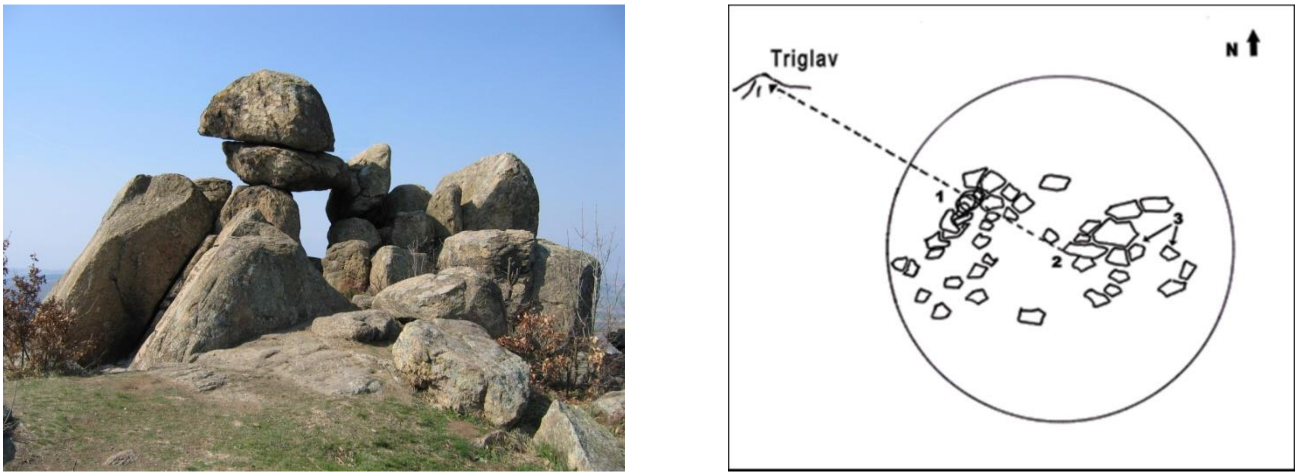

Figure 6. Buzovgrad rock sanctuary. Scheme of the basic structural elements of the sanctuary: 1—trilith, 2—"throne", 3—"sacrificial altars". The Triglav peak seen through the megalith's aperture. It is supposed that observations of the solar disc during sunset on the day of the summer solstice were made when solar disc touched the line of the visible horizon, after [20].

Figures 3–6 give several examples of facilities for observation of the sun (rises and sets) in its extreme positions on the visible horizon (solstices and equinoxes) and meridian culminations.

According to Ruggles [28], the rising and setting positions of the sun, moon and planets are not affected by the precession of equinoxes (or only the precession) but do change over time, by a smaller amount, owing to the fact that the obliquity of the ecliptic (ε) changes slowly with time. Over the past few millennia, it has been slowly decreasing, from about 24.15° in 5000 BCE to 23.45° now (27, [28] Table 31.3), but over a longer timescale (of about 41,000 years), it oscillates between limits of about 24.4° and 22.2°. A maximum was reached in about 6000 BCE, and a minimum will be reached in about 14,000 CE. Compared with the shifts in the stellar rising and setting positions due to precession, the differences in the sun's rising and setting position are small: for example, in temperate zones around 2000–6000 BCE, the sun rose and set further north at the June solstice, and the same amount further south at the December solstice, than now. The corresponding azimuth difference is about 1°.

The archaeoastronomical dating of the studied rock-cut monuments associated with long-term astronomical observations is made using the rising and setting positions of the sun in its extreme point (solstice and equinox). The maximal height of the sun in culmination during solstices (where the solar declination δ is at its maximum, and equals the obliquity of the ecliptic ε) is calculated by the formula:

$$hmax = 90 - \varphi + \varepsilon \tag{4}$$

Using the Equations (1)–(4), we calculate the obliquity of the ecliptic ε for every studied object. The period of creation and operation of the rock-cut monument is determined by the comparison of the derived obliquity of the ecliptic ε with the values presented in Table 1.

Table 1. The obliquity of the ecliptic, after [28].

Years	5000 BCE	4000 BCE	3000 BCE	2000 BCE	1000 BCE	CE 1/1 BCE	1000 CE	2000 CE
ε	24.15°	24.1°	24.0°	23.9°	23.8°	23.7°	23.55°	23.45°

Table 2 presents the rock-cut monuments associated with long-term astronomical observations and astronomical practices (prehistoric astronomical observatories), their orientations towards astronomically significant points on the visible horizon, as well as the observed phenomena—the rise, set or noon culmination of the observed object—and archaeoastronomical dating.

Table 2. Prehistoric astronomical observatories, orientation of the astronomical facilities there, supposed astronomical phenomena observed on the visible horizon—the rise, set or noon culmination of the observed object—and archaeoastronomical dating.

No	Rock-Cut Monument Type of Observations	Orientation of the Facility	Observed Phenomenon	Archaeoastronomical Dating
1.	Belintash [15] horizon observations	Summer solstice	Sunrise	2000 BCE
2.	Zaychi vruh (Cabyle) [25] horizon observations meridional culminations	Summer solstice and equinoxes	Sunrise, sunset, stellar and solar culminations	2200 BCE
3.	Tatul [27] horizon observations	Winter solstice and equinoxes	Sunrise	2200 BCE
4.	Tangarduk kaya cave [19] meridional culminations	Winter solstice	Solar culminations	3000 BCE
5.	Harman kaya [26] horizon observations	Summer and winter solstices and equinoxes	Sunrise, sunset	2500 BCE
6.	Buzovgrad [20] horizon observations	Summer solstice	Sunset	1800 BCE
7.	Tsarevi porti [22] horizon observations	Summer solstice	Sunrise	2000 BCE
8.	Markov kamak [21] horizon observations	Summer solstice	Sunrise	2200 BCE
9.	Lilyach [24] horizon observations meridional culminations	Summer and winter solstices and equinoxes	Sunrise, sunset, stellar and solar culminations	2200 BCE
10.	Kovil [23] horizon observations	Summer solstice and equinoxes	Sunrise	2800 BCE
11.	Baylovo cave [3] horizon observations	Summer and winter solstices and equinoxes	Sunrise	3000 BCE
12.	Magura cave [14] horizon observations	Summer and winter solstices and equinoxes	Sunrise	3000 BCE
13.	Parmakla kaya cave [19] meridional culminations	Winter solstice	Solar culmination	3000 BCE

Two groups of rock-cut monuments used for astronomical observations have been identified. We see that, in the first group of prehistoric observatories (Belintash, Zaychi vrah (Cabyle), Tatul, Harman Kaya, Buzovgrad, Tsarevi Porti, Markov Kamak, Lilyach, Kovil, Bailovo cave and Magura cave), ancient observers used the **method of "horizon" astronomy**. In the second group (Zaychi vrah (Cabyle), Tangarduk kaya cave, Lilyach and Parmakla kaya cave), they used the **method of meridional culminations** of the same celestial bodies. From Table 2, it is evident that these are the earliest prehistoric observatories (dated to about 3000 BCE).

4. Paleoclimate

After the dating of the studied prehistoric astronomical observatories, in order to find out if the astroclimate was suitable for astronomical observations, we make an assessment of the paleoclimate in the relevant era in the Bulgarian lands.

Paleoclimate is the climate of the Earth in an individual region, at a particular geological or prehistoric time. Paleoclimatology is the science of studying the climate in the past. It is a very interesting and relevant, multidisciplinary field combining history, anthropology, archaeology, chemistry, physics, geology and atmospheric and oceanic sciences. Paleoclimate studies use the geological and biological evidence preserved in sediments, rocks, tree rings, corals, ice sheets and other climate archives to reconstruct past climates in terrestrial and aquatic environments around the world [29]. Clues about past climate conditions are obtained from *proxy indicators*, which are indirect forms of evidence that can be used to infer the climate [30,31]. These include:

- Isotopic Geochemical Studies: the study of isotopic ratios in rocks, bubbles from ice cores, deep-sea sediments, etc. [32,33];
- Dendrochronology: the study of tree ring growth;
- Pollen Distribution: the study of plant types during the relevant climatic era and the distribution of pollen found in sediments, ice, rocks, caves, etc.;
- Study of lake sediments (Lake Varves): (like dendrochronology, but with lake sediments-a varve is an annual layer of mud in the sediment);
- Coral Bed Rings;
- Fossils in different geological and historical layers: studies of geological settings, etc. [34];
- Historical documents and artifacts that testify to the emergence and development of civilizations, etc.

Radiocarbon dating is one of the most useful absolute dating methods used in archaeology, geology, sedimentology and many other sciences. The ability to date minute samples via accelerator mass spectrometry (AMS) means that paleobotanists and paleoclimatologists can use radiocarbon dating directly on pollen purified from sediment sequences, or on small quantities of plant material or charcoal. The dating of organic material recovered from strata of interest can be used to correlate strata in different locations that appear to be similar on geological grounds. Dating material from one location gives date information about the other location, and the dates are also used to place strata in the overall geological timeline [35]. Radiocarbon dating measurements produce ages in “radiocarbon years”, which should be converted to calendar ages by a process of **calibration**.

As an example, we consider the calibration of the beginning of Holocene, the current geological epoch, which is determined to have begun about 11,700 years ago [36].

A sample from the Two Creeks Fossil Forest, Wisconsin was used in an interlaboratory test (the work of over 70 laboratories). These tests produced a median age of 11,788 $\pm$ 8 BP (2σ confidence) which, when calibrated, gives a date range of 13,730 to 13,550 cal BP or 11,730 to 11,550 BCE [37]. The Two Creeks radiocarbon dates are now regarded as a key result in developing the modern understanding of North American glaciation at the end of the Pleistocene [38].

Because the information needed to convert radiocarbon ages to calendar ages is constantly being improved, it was decided that radiocarbon ages and not calendar ages would become the standard method of recording results. This has the advantage that the thousands of dates published in articles prior to any given update do not have to be re-calculated.

The astroclimate is a set of meteorological and climatic conditions that determine the possibility of the observation of cosmic bodies. In fact, this set of atmospheric conditions mainly affects the quality of astronomical observations. The most important of them are the transparency of the air, the degree of its homogeneity (influencing the “sharpness” of the image of objects), the amount of background glow of the atmosphere, the daily temperature drops and the strength of the wind. In modern astronomy, the astroclimate is a combination of factors that distort the shape of the wave front emitted by celestial objects passing through the Earth’s atmosphere.

4.1. Data from Cave Speleothems

It is well established that variations in the total amount of solar radiation at the Earth’s surface (insolation) produce global changes in the climate. It has been proven in many ways that global climate change is due to variations in the total solar radiation reaching the earth's surface (earth's surface insolation or ***solar insolation***—the amount of electromagnetic energy (solar radiation) falling on the earth's surface) [39,40].

Past climate conditions can be estimated by studying the evolution of secondary Karst formations as speleothems, secondary mineral deposits formed in caves that serve as natural records of the solar insolation over very long time spans [39,41]. The obtained time series have durations of hundreds of thousands of years and should be calibrated using instrumental records. Thus, a large number of global change parameters can be reconstructed [39,42]. Speleothems provide high quality, well preserved and undisturbed records, but they are typically interrupted by numerous hiatuses caused by the disappearance of the infiltrating water solutions that produce speleothem growth due to droughts, etc. Speleothems that grow continuously for tens of thousands of years are exceptionally rare, while those that grow continuously for hundreds of thousands of years are unique. Such a speleothem is the one from the Duhlata Cave in the village of Bosnek region of Bulgaria [43], which produced the record on Figure 1.

Temperature, past precipitation, the nature of the soil and the vegetation cover, pollution, air composition, glaciation, fluvial erosion and deposition and groundwater flows can be usually read from the luminescence of cave speleothems and deposits.

Luminescence is the property of cave minerals most sensitive to depositional conditions [41]. Many speleothems exhibit luminescence when exposed to ultraviolet (UV) light sources or other high-energy beams. Depending on the excitation source, there are specific kinds of luminescence: "Photoluminescence" (excited by UV and other light sources), "X-ray luminescence" (by X-rays), "Cathodoluminescence" (by electron beam), "Thermoluminescence" (by heat), "Candoluminescence" (by flames) and "Triboluminescence" (by crushing). Different types of excitation may excite different luminescent centers—electron defects of the crystal lattice; admixture ions substituting ions in the crystal lattice or incorporated in cavities of that lattice; inclusions of other minerals; or fluid inclusions, molecules, ions or radicals adsorbed inside of the lattice [36]. Some or all of them may exist in a single speleothem. If the emission proceeds only during the excitation, then it is called "fluorescence", if it proceeds after the termination of the excitation then it is called "phosphorescence". Some luminescent centers produce only fluorescence, but others produce both fluorescence and phosphorescence.

Calcite speleothems frequently display luminescence, which is produced by the calcium salts of the humic and fulvic acids derived from the soils above the cave.

The method of Laser Luminescent MicroZonal Analysis [43] gives information about changes in the mineral-forming conditions and gives high resolution records of the annual rainfalls and annual temperatures in the past, allowing for the reconstruction of climate and solar activity variation.

The intensity of speleothem luminescence shows a direct connection with ***solar insolation***: The luminescence of calcite speleothems precipitated in caves depends exponentially upon the soil temperatures, which are determined primarily by solar infrared radiation in the case when **the cave is covered only by grass** or by air temperatures where there is **forest or bush cover**. In the first case, the microzonality of the luminescence detected in speleothems can be used as an indirect solar insolation index, and, in the second, as a paleotemperature proxy. Thus, in terms of the dependence on cave site conditions, we may speak about "solar sensitive" and "temperature sensitive" paleoluminescence in speleothem records, as in tree ring records.

Figure 7 shows part of the ***solar insolation luminescence proxy record*** from the Duhlata Cave, located in the region of the village of Bosnek, Pernik municipality, Bulgaria [43], which is still the only available experimental record of past solar insolation in Europe covering the last 20,000 years. The cave is covered only by grass, and the soil temperature there reaches 55 °C during the summer time, which means that this speleothem luminescence record represents only the solar insolation. It demonstrates a dramatic minimum of insolation after the Holocene maximum, from 7000 ± 2000 years ago (7000 ± 2000 BP or radiocarbon years before 1950 CE) [44]. From 4200 BCE to 600 CE, the insolation levels were below the levels during the Younger Dryas event (Figure 7), which is considered to be the end of the Last Glacial Period (LGP), a return to glacial conditions in the period 12,900–11,700 years BP [45], after which Pleistocene ended and Holocene, the current geological epoch, began with a sharp climatic warming [37]. However, it did not lead to corresponding minima of the temperatures in the region as recorded in the paleotemperature reconstructions for Bulgaria for the same period [46,47], showing that, from 5000 BCE to 100 BCE, the mean annual temperatures in Bulgaria were higher than today (Figure 8).

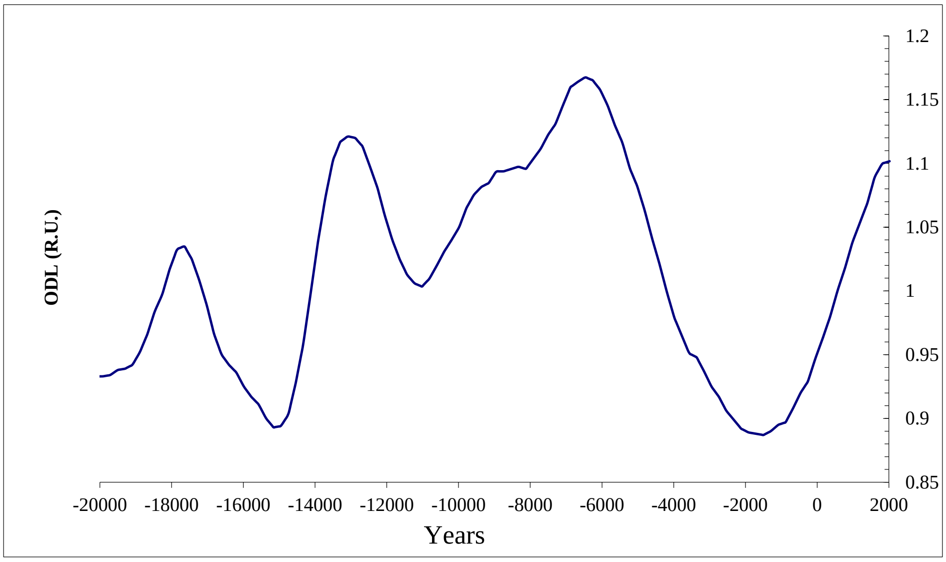

Figure 7. Luminescence proxy record of the Solar Insolation (Duhlata Cave, Bulgaria) (Optical Density of Luminescence (ODL) in decimal logarithm relative units (R.U.) depending on time, after [43].

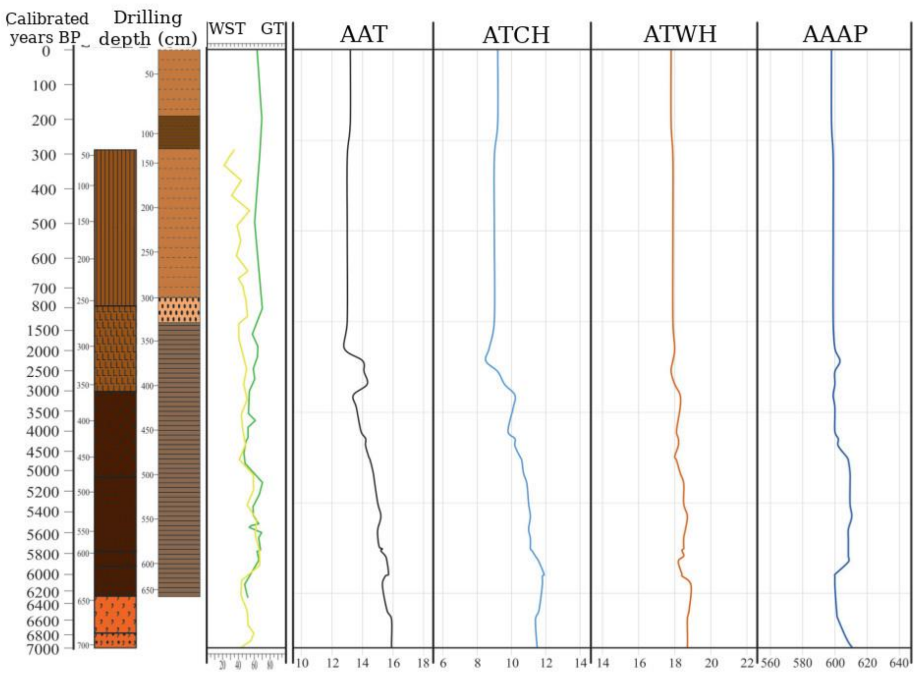

Figure 8. Reconstruction of paleoclimatic variables: WST-wood and shrub taxa (%), GT—grass taxa (%); AAT—average annual temperature (°C); ATCH—average temperature of the cold half of the year (°C); ATWH—average temperature of the warm half of the year (°C); AAAP—average annual amount of precipitation (mm/m^2), after [46].

4.2. Paleogeological and Pollen Data

Glaciers appeared in Northern Eurasia during the Pliocene, 4–5 million years ago, but the climate of the Eastern Mediterranean remained warm. A permanent drought was also recorded in Southeastern Europe at the end of the Pliocene. According to floristic data, it has been proven [48] that the average July temperature in the last 4 million years in Eastern Europe has decreased by approximately 7 °C. As a result, at the end of the Pliocene, the height of the snow line in the region decreased by 750 m. Although the climate as a whole began to change towards the cooling and strengthening of its continental character, at the beginning of the Pleistocene, the territory of today's steppe zone in southern Europe still had a Pliocene-dominated forest-steppe landscape. The territory of today's Bulgaria fell into the wide transitional zone between the periglacial areas and the pluvial belt, due to which the influences of both periglacial and warmer and wetter climatic conditions alternated rhythmically during the Quaternary period on its territory.

The Holocene epoch started about 9700 BCE, when the glacial cycle of the Pleistocene ended. According to the data from a number of geographical locations, and in particular from drilling cores in the Greenland ice sheet [49], the Pleistocene-Holocene boundary reflected the first significant warming after the end of the Younger Dryas. During the Holocene, in the so-called Holocene maximum, the average annual temperatures in North-East Bulgaria from 5000–3800 years BCE were 2–3 °C higher in comparison to the modern ones [46].

According to pollen data, the Holocene climate in Bulgaria was warmest around 5000–4500 BCE. This warm weather covered the transition from the Neolithic to the Eneolithic in Bulgaria. Subsequently, the climate became colder and wetter, and the Black Sea level dropped by 4–5 m at 3500–2000 BCE [50]. During the Holocene, in the period 4000–3000 BCE, forest cover of the lands predominated over the steppes, followed by an advance of grasslands in N-E Bulgaria. During the last 2000 years, all climatic parameters have remained without significant variations in the region [49]. However, due to the Mediterranean influence in the Rhodope, Pirin, Osogovo and Sredna Gora mountains, the amount frosty weather is 20–30% less than in the Balkan Mountains. The average duration of frost-free time (without negative temperatures) in the plains and hills of Bulgaria was 180–225 days per year.

5. Astroclimate

In prehistory, in the absence of optical instruments, the astroclimate is mainly influenced by the number of cloudless days and nights, the dust in the atmosphere due to volcanic eruptions, forest fires, stormy winds and, of course, the levels of solar activity and cosmic rays.

By definition, the astroclimate is a set of environmental conditions that determine the quality of astronomical observations. Basic and mutually independent conditions for determining the astroclimate are:

- The purity and transparency of the atmosphere;
- The light pollution of the natural environment;
- The seismicity of the region [51,52].

The first two of these conditions form a background glow in the sky, depending on the composition and amount of pollution in the atmosphere (dust, aerosols, moisture) and the amount of light pollution in it. On the other hand, the factors that affect the astroclimate are both natural and artificial (anthropogenic).

Natural factors include microclimate and meteorological conditions, the presence of clouds, fog, lightning, atmospheric pressure, temperature and humidity, the system of local and prevailing winds, temperature anomalies in the air and on the land surface, terrain, natural seismic activity and natural sources of air pollution. The natural factors determining the astroclimate exist as a given and, in some cases, can be weakened or strengthened by human activity.

Anthropogenic factors include artificial light sources, heat, artificial inhomogeneities of the area (areas with different albedo and heat capacity), artificial sources of air pollution, electromagnetic interference and seismic noise and artificial obstacles to air flow (due to land reclamation, land afforestation, etc.). Anthropogenic factors are usually negative, degrading the quality of the astroclimate and reducing the quality of astronomical observations.

Finally, we can make the conclusion that, around 8000 BCE, the climate in our lands was very favorable. During this period, the average annual temperature on the Balkan Peninsula and in particular in Bulgaria was about 2–2.5 °C higher than today [53]. This climate provides very good astroclimatic conditions for observations of the Sun, Moon, planets and bright stars, increases the effectiveness of observational data in determining the time of sunrises and sunsets (extreme positions of celestial bodies on the horizon) and noon culminations.

6. Conclusions

Here we examine 13 prehistoric astronomical observatories using the methods of archaeoastronomy in order to determine the period of their operation. In choosing sites for the construction of oriented stone complexes for astronomical observations, prehistoric people were interested in the number of clear days and nights within the tropical year. The aim of our investigation is to make an assessment of the paleoclimate in the relevant era in the Bulgarian lands in order to find out if it was suitable for astronomical observations. The estimations are made according to the geological data and solar insolation luminescence proxy records of the evolution of cave speleothems from the Duhlata cave in the village of Bosnek, Pernik municipality.

Two groups of rock-cut monuments used for astronomical observations have been identified. In the first group of prehistoric astronomical observatories (Belintash, Zaychi vrah (Cabyle), Tatul, Harman Kaya, Buzovgrad, Tsarevi Porti, Markov Kamak, Lilyach, Kovil, Bailovo cave and Magura cave), ancient observers used the **method of "horizon" astronomy** because of the climatic optimum (stable average annual temperature and low humidity), with good visibility of the Sun, the Moon and bright stars on the horizon line at sunrise and sunset. In the second group (Zaychi vrah (Cabyle), Tangarduk kaya cave, Lilyach and Parmakla kaya cave), observers used the **method of meridional culminations** of the same celestial bodies, as it was difficult to observe sunrises and sunsets on the horizon due to the high humidity, precipitation and the predominance of cloudy days. From Table 2, it is evident that earliest prehistoric observatories (dated about 3000 BCE) were designed for the observation of meridional culminations. This can be explained by the results from the reconstructions of the average annual temperatures and the average annual amounts of precipitation over the last 7000 years [46]. During this period of the emergence of prehistoric observatories in Bulgarian lands, the temperatures and precipitation levels were comparatively higher, as was the air humidity, and observations were only possible at noon and midnight.

The dynamics of climatic variables (temperature, humidity, sunshine) for several climatic periods has been investigated using paleogeological data [48], pollen analysis [46,47] and the analysis of cave speleothems from the territory of Bulgaria [43]. The solar insolation luminescence proxy record from the Duhlata Cave, placed in the region of the village of Bosnek, Bulgaria, is derived using the method of Laser Luminescent MicroZonal Analysis [43], and it is still the only available experimental record of past solar insolation in Europe covering the last 20,000 years. Climatic parameters for the last 8000 years are reconstructed, and shorter time intervals absolutely attached to the chronological boundaries of the historical periods established by archaeological excavations are defined from them. From about 5000–3800 years BCE, the average annual temperatures in Bulgaria were 2–3 °C higher in comparison to modern ones. Such a climate gives very good astroclimatic conditions for observations of the Sun near the horizon and allows increased accuracy in determining the time of occurrence of its extreme positions on the horizon.

Author Contributions: Conceptualization, A.S., P.M. and Y.S.; methodology, A.S., Y.S. and P.M.; software, O.O.; investigation, A.S., P.M., Y.S., O.O. and L.R.; data curation, A.S. and Y.S.; writing—original draft preparation, A.S., P.M., Y.S., O.O. and L.R.; visualization, A.S., P.M. and Y.S.; supervision, A.S. and P.M.; project administration, Y.S.; funding acquisition, Y.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Ministry of Education under the National Program on "Protection of the environment and reducing the risk of unfavorable events and natural disasters", WP I.6.10 "Geological records of Quaternary climate change".

Data Availability Statement: Not applicable.

Acknowledgments: We thank everyone who gave us information about the rock-cut monuments and all the participants in the archaeoastronomical expeditions to study the sites.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Liritzis, I.; Vlachos, A. Skyscape impact to cultural astronomy. *Sci. Cult.* **2022**, *8*, 131–155.
2. Bellwood, P. *First Farmers: The Origins of Agricultural Societies*; Blackwell Publishing: Oxford, UK, 2005; ISBN 0-631-20565-9.
3. Stoev, A.D.; Maglova, P.V. Astronomy in the Bulgarian Neolithic. In *Handbook of Archaeoastronomy and Ethnoastronomy*; Ruggles, C.L.N., Ed.; Springer Reference; Springer: New York, NY, USA, 2015; ISBN 978-1-4614-6140-1. [CrossRef]
4. Maglova, P.V.; Stoev, A.D. Thracian Sanctuaries. In *Handbook of Archaeoastronomy and Ethnoastronomy*; Ruggles, C.L.N., Ed.; Springer Reference; Springer: New York, NY, USA, 2015; ISBN 978-1-4614-6140-1. [CrossRef]
5. Hajdas, I.; Ascough, P.; Garnett, M.H.; Fallon, S.J.; Pearson, C.L.; Quarta, G.; Spalding, K.L.; Yamaguchi, H.; Yoneda, M. Radiocarbon dating. *Nat. Rev. Methods Primers* **2021**, *1*, 62. [CrossRef]
6. Smith, D.; Lewis, D. Dendrochronology. In *Encyclopedia of Quaternary Science*; Elsevier: Amsterdam, The Netherlands, 2007; pp. 459–465. [CrossRef]
7. Harmon, R.S.; Schwarcz, H.P.; Gascoyne, M.; Hess, J.W.; Ford, D.C. Paleoclimate Information From Speleothems: The Present As A Guide To The Past. In *Studies of Cave Sediments*; Sasowsky, I.D., Mylroie, J., Eds.; Springer: Dordrecht, The Netherlands, 2007; pp. 199–226. [CrossRef]
8. Todorova, H.; Vaysov, I. *New Stone Age in Bulgaria*; Nauka i Izkustvo: Sofia, Bulgaria, 1993; 287p. (In Bulgarian)
9. Todorova, H. *The Stone-Copper Age in Bulgaria (Fifth Millennium BC)*; Nauka i Izkustvo: Sofia, Bulgaria, 1986. (In Bulgarian)
10. Stoev, A.; Stoytchev, T. Lunar Observatories on the Bulgarian Lands. *Interdiscip. Stud.* **1991**, *18*, 137–144. (In Bulgarian)
11. Gerassimova–Tomova, V.; Stoytchev, T.; Stoev, A. Astronomical Symbolism at Rock-Cave Art of Painting. *Interdiscip. Stud.* **1991**, *18*, 203–213. (In Bulgarian)
12. Stoytchev, T.; Stoev, A. Astronomical Interpretation of Some Graffiti from the Bulgarian Caves. *Interdiscip. Stud.* **1991**, *18*, 194–202. (In Bulgarian)
13. Muglova, P.; Stoev, A.; Stoeva, M. Research on Drawings Representing Celestial Phenomena and Cosmological Elements from Cave Sanctuary from the Neolithic. In Proceedings of the 12th International Congress of Speleology, La Chaux de Fonds, Switzerland, 10–17 August 1997; Symp. 2: Archaeology and Paleontology in Caves. Volume 3, pp. 95–96.
14. Maglova, P.; Stoev, A.; Spasova, M. Eneolithic solar calendar in the Magura cave near the village of Rabisha, Belogradchik municipality, Bulgaria. In *Harmony and Symmetry. Celestial Regularities Shaping Human Culture, Proceedings of the SEAC 2018 Conference in Graz*; Draxler, S., Lippitsch, M.E., Wolfschmidt, G., Eds.; Tredition: Hamburg, Germany, 2020; pp. 45–53. ISBN -978-3-347-14632-7.
15. Muglova, P.; Stoev, A.; Radoslavova, T. Thracian rock sanctuary "Belintash" near Mostovo village, Plovdiv district—A model of an ancient solar observatory. *Interdiscip. Stud.* **1990**, *17*, 156–167.
16. Potemkina, T.M.; Maglova, P.V.; Stoev, A.D. On the methodology of archaeoastronomical research, Worldview of ancient and traditional societies of Eurasia. In *Memory of V.N. Chernetsov, Collection of Articles, Russian Academy of Sciences, Institute of Archeology*; TAUS Publishing House: Moscow, Russia, 2006; pp. 189–197. ISBN 5-903011-04-7.
17. Kulikov, K.A. *A Course in Spherical Astronomy*; Nauka: Moscow, Russia, 1974; 232p. (In Russian)
18. Ruggles, C.L.N. Pushing Back the Frontiers or Still Running Around in the Same Circles? 'InterpretativeArchaeoastronomy' Thirty Years On. *Proc. Int. Astron. Union* **2011**, *7*, 1–18. [CrossRef]
19. Stoeva, P.; Stoev, A.; Spasova, M. Late Chalcolithic solar-chthonic rock-cut structures for time measuring in the Eastern Rhodopes, Bulgaria, In Mediterranean Archaeology and Archaeometry, special issue dedicated to the proceedings of SEAC 2015 conference "Astronomy in past and present cultures" Rome, 9–13 November 2015. *Mediterr. Archaeol. Archaeom.* **2016**, *16*, 401–406. [CrossRef]
20. Stoev, A.; Muglova, P.; Spasva, M. Sun in the cult practices on the territory of the megalithic sanctuary "Buzovgrad". In Proceedings of the First International Symposium "Ancient cultures in South-East Europe and the Eastern Mediterranean. Megalithic Monuments and Cult Practices", Blagoevgrad, Bulgaria, 11–14 October 2012; pp. 207–216.
21. Stoev, A.; Maglova, P. Astronomical markers and orientations of the rock-cut monument "Markov Kamak" in the Tsarev Peak region, Rila Mountain. In *"Boundaries of Cultural Studies"-Collection of Works on the Occasion of 15 Years Since the Foundation of the*

Specialty "Cultural Studies" at South-West University "Neofit Rilski"; Neofit Rilski University Press: Blagoevgrad, Bulgaria, 2010; pp. 72–92. ISBN 978-954-680-693-2.
22. Stoev, A.; Maglova, P.; Markov, V.; Spasova, M. Prehistoric rock sanctuary with arch near the village of Kovachevitsa, Bulgaria: Spatial orientation and solar projections. *Mediterr. Archaeol. Archaeom.* **2016**, *16*, 413–419. [CrossRef]
23. Maglova, P.; Stoev, A.; Spasova, M.; Benev, B. Eneolithic Projection System for Astronomical Observations on the Territory of Megalithic Sanctuary near the Village of Kovil (Municipality of Krumovgrad, Kurdzhali District). In Proceedings of the Second International Symposium "Megalithic Monuments and Cult Practices", Blagoevgrad, Bulgaria, 12–15 October 2016; pp. 55–64.
24. Stoev, A.; Maglova, P.; Markov, V.; Spasova, D.; Genov, A. Structure of the sacred space, astronomical orientation and functional evolution of the rock-cut monument near the village of Lilych, Kyustendil region, Bulgaria. In *Harmony and Symmetry. Celestial Regularities Shaping Human Culture, Proceedings of the SEAC 2018 Conference in Graz*; Draxler, S., Lippitsch, M.E., Wolfschmidt, G., Eds.; Tredition: Hamburg, Germany, 2020; pp. 39–44. ISBN -978-3-347-14632-7.
25. Stoev, A.D.; Varbanova, Y. Positional systems for solar and lunar observations in the archaic cultures in Bulgaria. In *Astronomical Traditions in Past Cultures, Proceedings of the First Annual General Meeting of the European Society for Astronomy in Culture (SEAC), Smolyan, Bulgaria, 31 August–2 September 1993*; IA-BAS: Sofia, Bulgaria, 1996; pp. 93–100.
26. Stoev, A.; Maglova, P.; Stoeva, M.; Tashev, Y.; Videnov, B.; Velkov, R.; Velkov, V. An archaeoastronomical investigation of theHarman kaya rock-cu tmegacomplex in the region of Dolna Chobanka village, Momchilgrad municipality. In *Thracia 15 in Honour of Alexander Fol's 70th Anniversary*; Institute of Thracology, BAS, Tangra TanNakRa Publhing House: Sofia, Bulgaria, 2003; pp. 333–339.
27. Stoeva, P. Ancient Solar Observations from Rock Sanctuaries at East Rhodopes, Bulgaria. In Proceedings of the International Conference under the Patronage of UNESCO "Astronomy and World Heritage: Across Time and Continents", Kazan, Russia, 19–23 August 2009; Marov, M., Ed.; Publishing House of Kazan University: Kazan, Russia, 2016; pp. 145–152, ISBN 978-5-00019-618-2.
28. Ruggles, C.L.N. Long-Term Changes in the Appearanceof the Sky. In *Handbook of Archaeoastronomy and Ethnoastronomy*; Ruggles, C.L.N., Ed.; Springer Science+Business Media: New York, NY, USA, 2015. [CrossRef]
29. Bradley, R.S. *Palaeoclimatology*, 2nd ed.; Academic Press: San Diego, CA, USA, 1999.
30. Available online: https://www.globalchange.umich.edu/globalchange1/current/lectures/kling/paleoclimate/index.html (accessed on 10 October 2022).
31. Available online: https://www.usgs.gov/programs/climate-research-and-development-program/science/paleoclimate-research (accessed on 12 October 2022).
32. Bowen, R. *Isotopes in the Earth Sciences*; Elsevier: London, UK, 1988; 662p, ISBN 1-85166-145-X.
33. Rollinson, H. *Using Geochemical Data, Evaluation, Presentation, Interpretation*; Routledge: London, UK, 1993; eBook Published 1 October 2013. [CrossRef]
34. Garrison, E. *Techniques in Archaeological Geology*, 2nd ed.; Springer: Berlin, Germany, 2016.
35. Godwin, H. The Croonian Lecture: Radiocarbon dating and Quaternary history in Britan. *Proc. R. Soc. Lond. B Biol. Sci.* **1961**, *153*, 287–320. [CrossRef]
36. Heaton, T.J.; Blaauw, M.; Blackwell, P.G.; Ramsey, C.B.; Reimer, P.J.; Scott, E.M. The IntCal20 approach to radiocarbon calibration curve construction: A new methodology using Bayesian splines and errors-in-variables. *Radiocarbon* **2020**, *62*, 821–863. [CrossRef]
37. Taylor, R.E.; Bar-Yosef, O. *Radiocarbon Dating*, 2nd ed.; Left Coast Press: Walnut Creek, CA, USA, 2014; ISBN 978-1-59874-590-0.
38. Macdougall, D. *Nature's Clocks: How Scientists Measure the Age of Almost Everything*; University of California Press: Berkeley, CA, USA, 2008; ISBN 978-0-520-24975-2.
39. Shopov, Y.Y.; Stoykova, D.; Tsankov, L.; Sanabria, M.; Lundberg, J.; Georgiev, L.; Forti, P.; Georgieva, D. Verification of the Causes of Glaciations and Sea Level Changes Using the Records of Calcite Speleothems. *Int. J. Speleol.* **2000**, *29*, 71–75. [CrossRef]
40. Liritzis, I.; Galloway, R.B. Solar-Climatic effects on Lake/Marine sediment radioactivity variations. In: Holocene Cycles. Climate, Sea Levels, and Sedimentation. *J. Coast. Res.* **1995**, *10*, 63–71.
41. Tarashtan, A.N. *Luminescence of Minerals*; Naukova Dumka: Kiev, Ukraine, 1978. (In Russian)
42. Shopov, Y.Y.; Stoykova, D.; Tsankov, L.; Sanabria, M.; Georgieva, D.; Ford, D.; Georgiev, L. Influence of Solar Luminosity over Geomagnetic and Climatic Cycles as Derived from Speleothems. *Int. J. Speleol.* **2004**, *33*, 19–24. [CrossRef]
43. Stoykova, D.; Shopov, Y.Y.; Gabreva, D.; Tsankov, L.T.; Yonge, C.J. Origin of the Climatic Cycles from Orbital to Sub-Annual. *J. Atmos. Sol. Terr. Phys.* **2008**, *70*, 293–302. [CrossRef]
44. Marcott, S.A.; Shakun, J.D.; Clark, P.U.; Mix, A.C. A reconstruction of regional and global temperature for the past 11,300 years. *Science* **2013**, *339*, 1198–1201. [CrossRef]
45. Rasmussen, S.O.; Andersen, K.K.; Svensson, A.M.; Steffensen, J.P.; Vinther, B.M.; Clausen, H.B.; Siggaard-Andersen, M.-L.; Johnsen, S.J.; Larsen, L.B.; Dahl-Jensen, D.; et al. A new Greenland Ice core chronology for the last glacial termination. *J. Geophys. Res.* **2006**, *111*, D06102. [CrossRef]
46. Vergiev, S.; Filipova-Marinova, M. Pollen-based paleoclimate reconstructions of North-Eastern Bulgaria during the last 7000 years using modern analog technique (MAT). *Rev. Bulg. Geol. Soc.* **2020**, *81*, 155–157. [CrossRef]
47. Vergiev, S. Pollen-based paleoclimate reconstructions of Beloslav Lake (Northeastern Bulgaria) during the last 6000 years using modern analog technique (MAT). *Rev. Bulg. Geol. Soc.* **2021**, *82*, 132–134. [CrossRef]
48. Evlogiev, J. The boundary Neogene-Quaternary and stratigraphy of the Early Pleistocene in the Tethys, the CentralParathetys and Ocean. *Rev. Bulg. Geol. Soc.* **1995**, *56*, 87–104. (In Bulgarian)

49. Walker, M.; Johnsen, S.; Rasmussen, S.O.; Steffensen, J.P.; Popp, T.; Gibbard, P.; Hoek, W.; Lowe, J.; BjoËrck, S.; Cwynar, L.; et al. The Global StratotypeSection and Point (GSSP) for the base of the Holocene Series/Epoch (Quaternary System/Period) in the NGRIP ice core. *Episodes* **2008**, *31*, 264–267. [CrossRef]
50. Filipova-Marinova, M. Archaeological and paleontological evidence of climate dynamics, sea-level change, and coastlinemigration in the Bulgarian sector of the Circum-Pontic Region. In *The Black Sea Flood Question: Changes in Coastline, Climate, and Human Settlement*; Yanko-Hombach, V., Gilbert, A.S., Panin, N., Dolukhanov, P.M., Eds.; Springer: Dordrecht, The Netherlands, 2007; pp. 453–482.
51. Kucherov, N.I. Astroclimate, Znanie ed.: Moscow, Russia, 1962; pp. 10–24.
52. Rozenberg, E. *Twilight: A Study in Atmospheric Optics*; translated from Russian; Plenum: New York, NY, USA, 1966; 358p.
53. Baltakov, G.; Kenderova, R. *Quaternary Paleogeography*; Maleo: Varna, Bulgaria, 2003; 324p. (In Bulgarian)