Archaeoastronomical study of the megalithic site of Göbekli Tepe, Turkey

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1. Introduction

Göbekli Tepe is the oldest megalithic site in the world. It stands on the summit of a hill of 780 m in height and probably was built during the second half of the tenth millennium B.C. (9800-8700 B.C. - Dietrich 2011). The site is made up of about 20 rings or enclosures. The first enclosures to be found were assigned the letters A, B, C, D, E and F, according to the order of their discovery. The main feature they have in common is the presence, at the centre of each, of two enormous, T-shaped monolithic pillars surrounded by other pillars of the same shape but not as tall as the central ones, set out around the enclosure wall. Enclosures E and F only have the couple of central pillars.

The archaeoastronomical relevance of the site has been recently evidenced by Collins (2013), according to whom the central pillars in four of the enclosures are oriented toward the setting point of the star Deneb (α Cyg). The author obtained an astronomical dating for the various enclosures which agrees rather well with the one obtained by Dietrich (2011) with the technique of carbon-14.

In the present paper, the careful evaluation of the effects caused by atmospheric extinction has enabled us to verify that the central pillars of the studied enclosures are in fact turned to face the setting point of Deneb, but these alignments occurred in epochs, still in agreement with the ones obtained by Dietrich (2011), but different from those proposed by Collins (2013). We have also individuated, for the first time, the probable astronomic alignments of two other enclosures at Göbekli Tepe, i.e. enclosures F and A.

2. Checking the alignments towards Deneb (α Cygni) of enclosures D, C, E and B

Taking into consideration the effects of the proper motion and the precession of the equinoxes on the position of Deneb in the course of the time, Collins (2013) has proposed the dating presented in Table 1 for the enclosures D, E C and B. He has based his calculations on a value of the angle of extinction of Deneb fixed at 2 degrees, including the corrections for the refraction by means of the Stellarium astronomical software.

These orientations and the relative dating proposed by Collins (2013) have been verified in this work by means of the application of a new archaeoastronomical procedure. The study is based mainly on a careful evaluation of the effects that atmospheric extinction has on the coordinates of a star, a factor which is often neglected in many works of archaeoastronomical subject, thus leading to results which are often completely misleading (Schaefer, 1993). The procedure we have followed to determine the new dating can be summarized into five basic steps (for the details, see De Lorenzis, 2013):

1. calculation of the extinction coefficient using data regarding humidity in the observation site;
2. calculation of the air mass passed through by the starlight and its extinction caused by the earth's atmosphere;
3. determination of the height of prime visibility (HPV) of Deneb by means of the use of Bouguer's law of attenuation;
4. checking of the possible presence of reliefs in the directions where the enclosures are oriented;
5. search for the date when the calculated value of HPV of Deneb is observed.

The last point has been addressed by means of the Cartes du Ciel (CDC) software which, unlike Stellarium, rightly takes into consideration the effects of the precession of the equinoxes and the stars' proper motions on the celestial coordinates even in very remote epochs. The new dating obtained by this method is reported in Table 1. If we attribute an error $\Delta(\mathrm{AZ}) = \pm 1^\circ$ to the azimuth measurements reported by Collins (2013), we are able to define the period (obtained again by means of CDC software), in which it was possible to see Deneb set at an azimuth that fell within the angular interval considered. This period is reported in Table 1 where it is compared with the dating obtained by Dietrich (2011) by means of analysis of carbon-14.

The results obtained and reported in Table 1 allow us to affirm that, very probably, the builders of Göbekli Tepe would have wanted to celebrate their cosmological beliefs by orienting the central

Table 1
Data relative to the four enclosures oriented towards Deneb. In the last column we see the time interval within which the setting azimuth of Deneb is found within a range of ±1° from the theoretical value.

Enclosure	Azimuth (°)	Year Collins (B.C.)	Year CDC (B.C.)	HPV CDC (°)	Radiocarbon dating (B.C.)	CDC dating (B.C.)
D	353	9400	9590	1.65	[9745; 9314]	[9620; 9550]
E	350	9290	9463	1.65	[9500; 8500]	[9510; 9410]
C	345	8980	9156	1.67	[9500; 8500]	[9230; 9080]
B	337	8245	8409	1.72	[8306; 8236]	[8520; 8210]

pillars of the Enclosure D, E, C and B towards Deneb, as also suggested by Collins (2013).

3. The alignment of enclosure F towards the Sun

The only information available on the orientation of enclosure F comes by way of Collins (2013), who indicates a disposition of the central pillars of the enclosure towards east-northeast or towards west-southwest. These directions, according to the author, are very close to that of the Sun rising (azimuth equal to about 67°-68°, N67.5°E) at the summer solstice or setting at the winter solstice (azimuth about 247°-248°, S67.5°W), respectively. On looking for the day of the year when, in the present epoch, the Sun rises (or sets) at an azimuth of about 67° (or 247°), it is possible to find an important date, associated with the Harvest Festival which sanctioned the moment of the year's first harvest (Keating, 1861). Today this feast is celebrated on 1st August, that is about 41-42 days after the summer solstice and is collocated approximately halfway between the summer solstice and the autumn equinox. Therefore, we have supposed that the central pillars of enclosure F are aligned in the direction of the sunrise on this celebration. To evaluate this hypothesis, we have developed the following procedure (for details, see De Lorenzis 2013):

1. individuation of the day on which the summer solstice took place in past epochs (by means of the CDC astronomic software);
2. individuation of the day of the Harvest Festival in the epochs studied;
3. determination of the azimuth of the rising Sun on the day of the Harvest Festival (obtained by the JPL Horizons routine, see below);
4. reconstruction of the secular trend of the Sun's azimuth on the day of the Harvest Festival;
5. extrapolation of the azimuth datum to the epoch of the building of enclosure F.

The reconstruction of the change over the centuries of the rising azimuth of the Sun on the day of the Harvest Festival has been the result of careful research carried out by means of the generation of ephemerides by means of the Horizons routine supplied by the NASA JPL. The time interval covered by the research ranges from 3000 B.C. to 2505 A.D., registering the rising azimuths of the Sun every 275 years starting from 3000 B.C.. This epoch, in fact, represents the earliest limit for which we can calculate the ephemerides of the Sun (and of the Moon) in all the available astronomical routines (for details, see De Lorenzis & Orofino, 2015). In absence of theoretical indications about the long-term secular trend of the declination (and of the rising azimuth) of the Sun, we have decided to interpolate and then extrapolate the collected data about the rising azimuth of the Sun on the Harvest Festival by using three laws which best fit the data: constant, linear (slightly) decreasing and parabolic. This extrapolation gives an estimate of the rising azimuth at 8400 B.C. in the range 66.2°- 67.6°, with a most likely value of 67.6°. By means of Google Earth, it has been established that in this direction there is a relief of about 2116 m that means the field of vision of the horizon surrounding the site is not free anymore. Thus, the estimate for the azimuth of the sunrise at 8400 B.C., corrected for the effect of the topography surrounding the site, is somewhere between 66.4° and 67.8°, with the latter which represents the most likely value. Collins (2013) proposes an alignment of the central pillars towards the Sun's rising point on the day of the summer solstice. However, currently, on the day of the summer solstice the rising azimuth of the Sun for a free horizon is equal to about 59.3°. By making the opportune extrapolation (as before), we arrive at an azimuth value at the summer solstice in 8400 B.C. of between 59.0° and 60.4° with a most likely value of 60.4°. Remembering that the orientation of the central pillars of enclosure F is quantified as N67.5°E, it can be affirmed that the possible alignment pro-

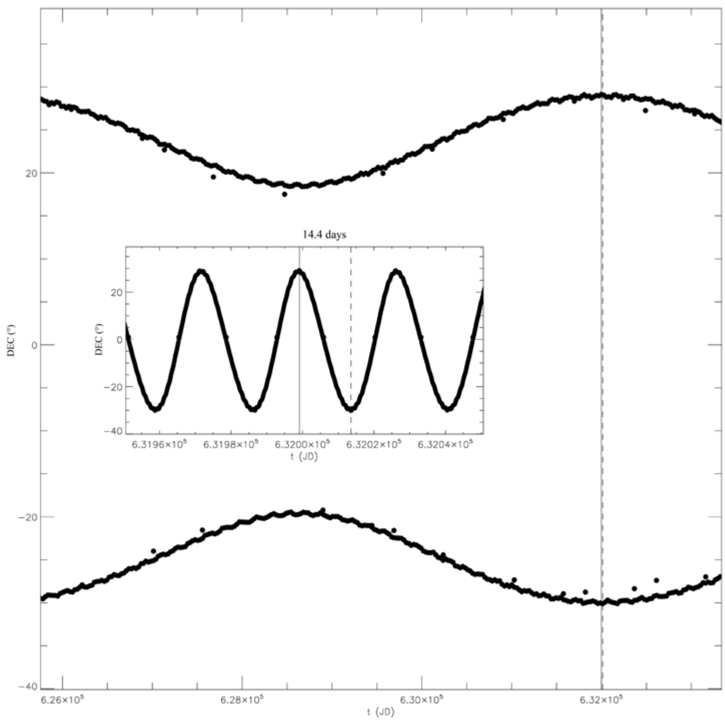

Figure 1. Trend of the lunar declination in function of time between 3000 B.C. and 2980 B.C. for the first lunar standstill after 3000 B.C.. The declination, on the vertical axis, is expressed in degrees, while the time, on horizontal axis, is in Julian Days (JD). The typical quasi-sinusoidal pattern is shown in the central inset where all the positions of the Moon from 1st March to 30th June 2983 B.C. are plotted. In this period, the absolute maximum (continuous vertical line) and the absolute minimum (dotted vertical line) of declination are found at a distance of about 14 days each other. Graphics created using IDL.

posed by Collins (2013) towards this direction is to be considered unreliable, considering the large difference observed between the values reported above. On the contrary, the values of the rising azimuth of the Sun on the day of the Harvest Festival, found by means of the extrapolation, are much closer to the datum relative to the orientation of enclosure. Our alternative hypothesis, although based on an extrapolation, seems more reasonable than that of Collins (2013).

4. The alignment of enclosure A towards the lunar standtsills

To complete the picture of the probable alignments present at Göbekli Tepe, enclosure A remains to be analyzed, since in literature there is no information about the possible celestial objectives of the central pillars. They are set almost exactly from north-west towards south-east or vice-versa with azimuths equal to 132° and 312° (Collins, 2013). We have assumed as reference date for the construction of this enclosure the one proposed by Dietrich (2011) of 8500 B.C. by means of analysis with carbon-14.

We have verified the possibility that the central pillars of enclosure A were erected towards the position of the Moon when it was in its extreme lower (minor) standstill. The lunar standstill chosen is consistent with the orientations of the central pillars of the various enclosures. The technique adopted to find the presumed alignment of enclosure A towards the minor lunar standstill can be summarized in the following steps:

1. collection of data regarding the lunar position over the years by means of the Horizons routine;
2. elaboration of the data by means of a script translated into IDL, for the individuation of the minor lunar standstill, through the reconstruction of the progress of the Moon during the Metonic cycle, i.e. the passage from one lunar standstill to the next of the same kind;
3. reconstruction of the secular trend of the declination of the Moon when it is at the minor lunar standstill;
4. extrapolation of the lunar declination at the epoch of the presumed construction of the enclosure, in order to individuate the rising azimuth on the day in which, at that epoch, the Moon was at its minor standstill.

By taking advantage of the periodicity of the cycle of lunar standstills (equal to about 18.6

years), we have calculated the typical trend of the lunar declination in function of the time, as shown in Figure 1.

The chosen sample was made up of 147 equally spaced minor lunar standstills, starting from the first one in 2983 B.C. to the last one in 2674 A.D.. This number is large enough to be considered statistically significant. In order to evaluate the secular trend of the available data, we have interpolated them by means of the linear law

$$\delta = st + d$$

where δ is the declination of the Moon at its minor standstill, t is the time in Julian Days (JD), while s and d are two constants. Extrapolating the data, the value of -30.82° has been thus found for the declination of the Moon on the day of its minor standstill at 8500 B.C.. From this value, it is possible to find the relative rising azimuth of the Moon when it was at his minor standstill, equal to 130°. Unlike in the case of enclosure F oriented towards the Sun, it has been found, by means of Google Earth, that there is an absence of reliefs in that direction, at least for a distance of about 350 km.

The agreement between the azimuth measured at Göbekli Tepe for enclosure A, equal to 132° (Collins, 2013), and that obtained by our analysis, equal to 130°, is to be considered quite satisfactory, also considering the large error margin (of the order of some degree) which can be attributed to both the quantities. It is, then, possible to conclude that the very probable direction towards which the central pillars of enclosure A are pointing is that of the Moon rise on the day in which it was at its minor standstill.

5. Conclusions

It is reasonable to think that the builders of Göbekli Tepe, by creating the site, wanted to transmit some of their cosmological beliefs to future generations and that, in particular, they intentionally oriented the central pillars of the enclosures towards some astronomical object. For more details, see De Lorenzis & Orofino (2015).

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