International Journal of Geometric Archaeology and Ancient Civilization

GLINT OPEN ACCESS

Volume 1, Issue 1

Research Article

Date of Submission: 27 April 2026
Date of Acceptance: 01 June 2026
Date of Publication: 10 June 2026

The Bush Barrow Gold Lozenge, the Solar Hexagon, and the Polar Threshold: A Formal Astronomical Comparison

Hrvoje Zujic, M.Sc.E.Eng*
Independent Researcher, Croatia

***Corresponding Author:** Hrvoje Zujic, Independent Researcher, Croatia.

Citation: Zujic, H. (2026). The Bush Barrow Gold Lozenge, the Solar Hexagon, and the Polar Threshold: A Formal Astronomical Comparison. *Int. J. Geom. Archaeol. Anc. Civ.,* 1(1), 01-23.

Abstract

The Bush Barrow gold lozenge, excavated in 1808 from an Early Bronze Age burial near Stonehenge, has been interpreted either as a solar-observation instrument tuned to the southern British horizon or as a calendrical tally. This paper tests an alternative hypothesis: that the artefact preserves a six-point solar hexagon defined by the four solstitial extremes plus two cardinal eastern and western points, and that this geometry contracts toward a quasi-rhombic form in the polar-threshold zone.

We conduct a latitude sweep from 51° N (Stonehenge) to 71° N and examine the hexagon at two critical thresholds: polar-day onset (PDonset, φ = 65.504° N) and polar-night onset (PNonset, φ = 66.638° N). At PDonset, the W/E vertex angle is 98.71°, close to Thom's ~99° obtuse angle. At PNonset, using the disk-centre horizon criterion ($h_0 = -0.566°$), the polar-day interval terminates on the thirty-sixth calendar day (day 1 to day 36), matching the lozenge's thirty-six perimeter zig-zag units (nine per side).

These three primary correspondences — quasi-rhombic form at PNonset, ~99° vertex angle at PDonset, and thirty-sixth-calendar-day alignment at PNonset — do not establish polar manufacture or use. They do indicate a structured convergence, raising the possibility that a British Bronze Age object encodes a high-latitude solar geometry whose closest formal and numerical counterparts lie near the Arctic Circle.

Keywords: Bush Barrow Lozenge; Solar Hexagon; Archaeoastronomy; Polar Day; Polar Night; Stonehenge; Stonehenge Gold; Zig Zag; Zig-Zag; Arctic Circle

Introduction

Bush Barrow (Wilsford G5) is one of the richest Early Bronze Age burials in Britain, situated on Normanton Down approximately 1 km southwest of Stonehenge. Current archaeological reassessment places the Bush Barrow burial and its gold lozenge in the early second millennium BCE (approximately 2000–1700 BCE), based on the wider Normanton Down cemetery sequence and associated material culture [1]. Excavated in 1808 by William Cunnington, the burial contained the remains of a tall man accompanied by status objects including a bronze dagger, a mace with bone zig-zag mounts, and — placed on the man's chest — a large gold lozenge of exceptional craftsmanship. Because this is a British elite object deposited in the Stonehenge landscape, its astronomical interpretation has normally been sought against the southern British horizon; that local expectation forms the starting point of the present enquiry [1,2].

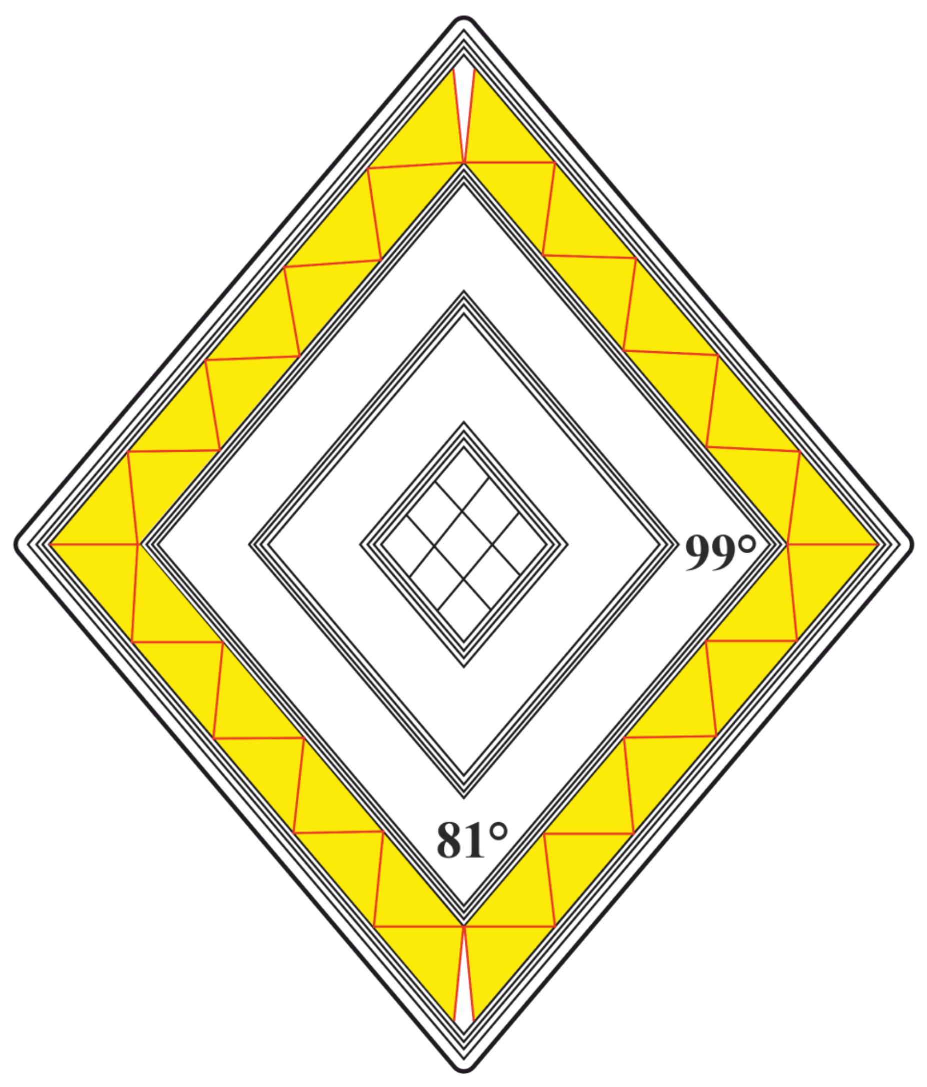

Figure 1. The Bush Barrow gold lozenge — author's sketch based on direct observation of the artefact. The outer band highlights the continuous series of thirty-six zig-zag units, while concentric rhomboid frames emphasise the artefact's rhombic basis. Note the two pairs of divergent lines emanating from the acute-angle vertices. Inner angles of the rhombus: acute ~81°, obtuse ~99° (after Thom et al.).

The lozenge has an obtuse vertex angle of approximately 99° and an acute angle of approximately 81°, with concentric rhomboid frames defined by finely inscribed parallel grooves. Its outer band carries a continuous series of thirty-six zig-zag units (nine per side). These published geometric values are used in the present comparison [3]. See Figure 1.

The placement of the lozenge on the chieftain's chest, together with its extraordinary precision, suggests that the object was not merely decorative but carried symbolic or functional significance. This paper tests whether the lozenge's angular geometry, perimeter count, and outer zig-zag band are formally compatible with a solar horizon framework and whether that scheme becomes geometrically distinctive at the transition into polar-day and polar-night regimes. Two principal astronomical interpretations have been proposed.

Background

Thom, Ker and Burrows (1988): A Solar and Lunar Calendar

Thom, Ker and Burrows proposed that the Bush Barrow lozenge was a calendrical device designed for use at the latitude of Stonehenge ($\varphi \approx 51.17°$ N). Their hypothesis held that the lozenge, bonded to a flat piece of wood and used horizontally at eye level with an alidade, functioned as a plane-table instrument. With the shorter diagonal aligned on the local meridian (north–south), sight-lines radiating from specific intersection points of the zig-zag pattern would indicate the azimuths of sunrise and sunset at sixteen epochs of the year, following Alexander Thom's proposed prehistoric sixteen-month calendar [3].

Using photogrammetric measurements of the lozenge and astronomical calculations for circa 1900–1600 BCE, Thom et al. reported an average discrepancy of 0.58° between the lozenge-derived and calculated solstitial azimuths. They emphasised that the acute angle of approximately eighty-one degrees — which equals the angular separation between the summer and winter solstice sunrise (or sunset) azimuths at the latitude of Stonehenge — was a fundamental design parameter. Additional sight-lines were identified as corresponding to lunar standstill risings and settings.

This interpretation was later questioned by North, who argued that the lozenge's small size and fragility would not permit precise azimuth determination, and by Ruggles, who noted that several proposed alignments fell between the markings rather than on them. Ruggles also raised the objection that if the lozenge had an astronomical function, other lozenges of the same type should exist [4,5].

Mauméné (2017): A Calendrical Encoding of Planetary Cycles

Mauméné, published in Culture and Cosmos, proposed a fundamentally different calendrical reading. Rather than treating the lozenge as a physical observing instrument, Mauméné interpreted the decorative elements — zig-zag units, concentric rhomboid frames, and the central cross pattern — as a system for encoding the number of days in synodic planetary cycles, primarily that of Venus [6].

The core argument proceeds as follows. Each side of the lozenge presents nine zig-zag units (triangles), giving a perimeter total of $4 \times 9 = 36$ days. Four concentric rhomboid frames yield $4 \times 36 = 144$ days per group, and four such groups produce $4 \times 144 = 576$ days. Adding the eight (or nine) small lozenges in the central cross pattern gives $576 + 8 = 584$, closely matching the mean synodic period of Venus (583.9 days). Mauméné extended this analysis to the Clandon Barrow lozenge and the Upton Lovell golden button, finding consistent encodings of lunar months, and the synodic periods of Mars and Jupiter.

Mauméné's interpretation highlighted the deliberate departures from perfect symmetry in all three artefacts as evidence of intentional numerical encoding, arguing against a purely ornamental function. The central number thirty-six — days per perimeter revolution — serves as the fundamental counting unit in his system.

Methods

Research Design and Problem Definition

Across Bronze Age Europe south of the Arctic Circle, solar marking on circular monuments commonly focuses on four solstitial horizon events: summer-solstice sunrise and sunset, and winter-solstice sunrise and sunset. The design problem addressed here is straightforward: if those four rise/set azimuths cease to exist at and beyond the Arctic Circle, what observable horizon markers could replace them?

Given this background, the absence of polar-regime interpretations in mainstream archaeoastronomy is methodologically striking: although many Irish and British Bronze Age gold artefacts are interpreted in solar terms, almost none are systematically tested against Arctic-circle solar phenomena (midnight sun, polar night, and their onset/termination horizon thresholds). The implication is direct: progress on this problem may not require discovery of new artefacts, but re-interpretation of established artefact corpora with polar-aware solar models.

This question is not detached from a British context. Britain, Ireland, and Scandinavia were connected by long-distance exchange networks in later prehistory, making transmission of cosmological ideas plausible. Pytheas of Massalia (late fourth century BCE) also reported that Thule lay six days' sail north of Britain, where around the summer solstice there was no true night, preserving a direct ancient testimony that extreme northern light regimes were imagined in relation to Britain [7,8].

In this study, we formalize a circular stone-ring horizon model with six marker points. The four solstitial markers are treated as the stable baseline, while the two intermediate E/W points are defined by the cardinal axis rather than by a presumed astronomical equinox. This follows long-standing methodological cautions that naked-eye equinox determinations are ambiguous, whereas the north-south line can be established from the shortest noon shadow and E/W then constructed as perpendiculars [9-11].

At polar thresholds, the solstice still exists astronomically but no longer yields sunrise/sunset azimuths, because the Sun becomes circumpolar. We therefore test a polar substitute for the southern four-point scheme: the edge directions at the onset and termination of polar day and polar night. These four transition-edge directions are evaluated as functional analogues of the four solstitial rise/set markers used farther south.

Because the target context is Bronze Age naked-eye practice, the computation is intentionally an observer-level robust algorithm rather than an instrument-grade timestamp detector of solar events. We use $\Delta\varphi = 0.001°$, temporal sampling $dt = 5$ min, and persistence checks across neighbouring latitude samples. This deliberately prioritises reproducibility and archaeological plausibility over sub-minute formal precision. The comparative latitude sweep (51–71° N) then tests how this substitution changes the solar hexagon geometry and whether the resulting form and counts converge on the Bush Barrow lozenge metrics.

Solar-Hexagon Definition

We define a six-point solar hexagon on the horizon circle using only two types of observational input available to a Bronze Age observer:

(a) **Solstitial extremes.** By watching the horizon over the course of a year, the observer marks the four extreme positions of sunrise and sunset: the northernmost sunrise and sunset (summer solstice) and the southernmost sunrise and sunset (winter solstice). These four points define the angular limits of solar motion on the horizon. Within the polar circle, where the sun becomes circumpolar at the summer solstice, the classical solstitial rise and set azimuths are replaced by the gate-edge azimuths defined in Section 3.1: the sunrise on the first day of polar day, the sunset on the last day of polar day, and their polar-night counterparts. In this paper, the term 'gate' is used as a descriptive shorthand for the paired limiting azimuths that bound the visible solar regime at a threshold latitude. It is intended as a geometric label only and carries no symbolic implication.

(b) **Intermediate eastern and western points.** The two remaining vertices are fixed operationally at due east (90°) and due west (270°), obtained as perpendiculars to the gnomon-defined north-south meridian discussed in Section 3.1.

These six points are labelled using descriptive solar names that indicate the astronomical event defining each position on the horizon:

- Summer Solstice Sunrise (SSRise) = northernmost sunrise azimuth
- East (E) = due east (≈ 90°)
- Winter Solstice Sunrise (WSRise) = southernmost sunrise azimuth
- Winter Solstice Sunset (WSSet) = southernmost sunset azimuth
- West (W) = due west (≈ 270°)
- Summer Solstice Sunset (SSSet) = northernmost sunset azimuth

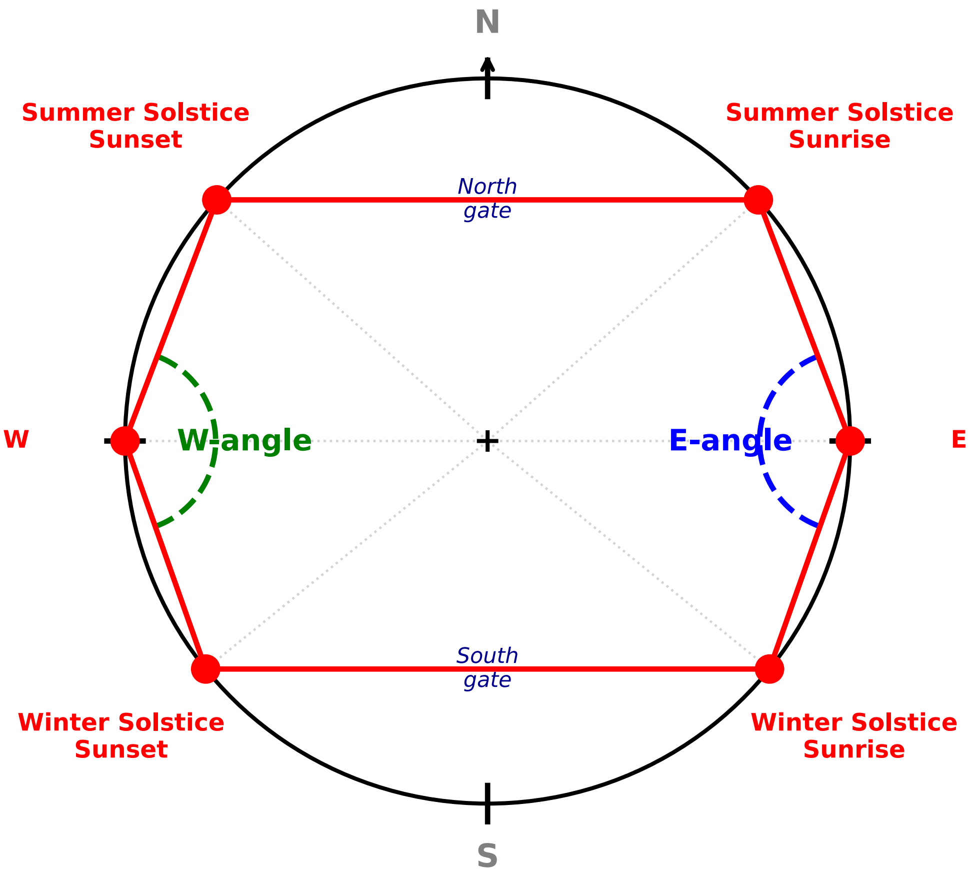

Figure 2. The solar hexagon on the horizon circle: six points defined by solstitial extremes (summer solstice sunrise, winter solstice sunrise, winter solstice sunset, summer solstice sunset) and cardinal directions east (E ≈ 90°) and west (W ≈ 270°). Calculated for Stonehenge (φ = 51.17° N, 2000 BCE, h_0 = −0.833°) using the Meeus solar ephemeris.

Connecting these six points in order around the horizon circle (SSRise → E → WSRise → WSSet → W → SSSet) produces the solar hexagon. The construction therefore requires only two observational operations: recording the solstitial extremes and deriving E/W from the north-south meridian (Figure 2).

The following analysis tracks how this six-point construction changes with latitude and threshold definition.

Two vertex angles are of particular interest:

- E-angle = the angle at vertex E (≈90°), between rays toward SSRise and WSRise (the 'eastern' vertex angle).
- W-angle = the angle at vertex W (≈270°), between rays toward WSSet and SSSet (the 'western' vertex angle).

By symmetry of the construction, E-angle = W-angle at all latitudes.

The inscribed-angle theorem provides a key mathematical safeguard: the vertex angles at E and W are determined solely by the arc between the two adjacent solstitial points, and are independent of the exact position of the vertex on that arc. Whether the intermediate points are taken as due east and due west, as azimuthal midpoints, as temporal midpoints, or as equinoctial directions, the E-angle and W-angle remain identical. The present model is therefore not dependent on any particular equinoctial interpretation, even though it adopts the cardinal axis operationally [9]. The hexagon is thus defined by observable horizon positions and elementary geometry, accessible without formal astronomical instruments.

Latitude Range and Comparative Scope (51°–71° N)

The latitude range is bounded by two archaeologically motivated limits: φ = 51° (southern England, Stonehenge/Bush Barrow context) and φ = 71° (Nordkapp, northern continental Europe).

Within this frame, the northernmost confirmed Bronze Age settlement in Scandinavia is Sandvika near Tromsø (φ ≈ 69.6° N, c. 1000–800 BCE), while Nordkapp serves as the continental upper bound for plausible overland Bronze Age observation. The analysis is therefore confined to φ = 51°–71°.

Computational Procedure

Solar Ephemeris

For each time t expressed as Julian Day (JD), apparent geocentric solar coordinates (α, δ) are computed via a standard Meeus-style chain: mean longitude and anomaly, equation of centre, aberration and nutation corrections, obliquity of the ecliptic ε, and conversion to equatorial coordinates. From (α, δ) and GMST, local sidereal time is obtained for a chosen longitude. Longitude only sets the clock and does not affect boundary azimuths, which are governed by local geometry [12].

The computation uses apparent (aberration- and nutation-corrected) geocentric declination throughout. No topocentric parallax correction is applied: for the Sun, the geocentric-topocentric difference is below 0.003°, negligible against refraction uncertainty. Delta T (TT-UT) is interpolated from Meeus's historical table for the target epoch; its effect on declination at a fixed calendar date is below 0.001°. In the robust v8 implementation, latitude scanning for polar-regime detection uses a uniform step $\Delta\varphi = 0.001°$.

Horizon Transformation

For geographic latitude φ, altitude h and azimuth A are computed from the standard spherical-astronomy relations assuming a flat (sea-level) horizon. Azimuth follows the convention 0° at north, increasing clockwise. Solstitial sunrise/sunset azimuths are obtained analytically from the solstitial declination δ_s and the chosen horizon threshold h_0.

Horizon Threshold h_0

The standard astronomical definition of sunrise/sunset uses $h_0 = -0.833°$ (upper limb tangent to the horizon under average refraction). We adopt $h_0 = -0.566°$ (disk-centre with mean refraction) as the primary operational threshold, and report results for $h_0 = -0.833°$ for comparison. The physical motivation for preferring the disk-centre criterion at polar latitudes — principally the unreliability of the upper limb under polar refraction anomalies — is developed in 'Why $h_0 = -0.566°$ is not an ad hoc choice'.

Robust Polar-Regime Detection

Polar regimes are detected with a day-level procedure rather than by sub-daily extrema at a single solstice instant. For each tested latitude phi, solar altitude is sampled every dt = 5 min over each UTC calendar day. A polar-day day is defined as a day with no sunset crossing (altitude never falls below h_0), and a polar-night day analogously as a day with no sunrise crossing. PD_days and PN_days are then counted as consecutive calendar-day blocks within the seasonal windows. PDonset is defined as the first latitude where PD_days >= 1, and PNonset analogously where PN_days >= 1. To suppress one-step numerical jitter, onset is accepted only when the condition persists across k = 3 consecutive latitude samples. For $h_0 < 0$, PNonset lies at a higher latitude than PDonset.

Results

Onset Latitudes of Polar Day and Polar Night

For 2000 BCE with $h_0 = -0.566°$, the onset of polar day occurs at $\varphi_{PD} = 65.504°$ and the onset of polar night at $\varphi_{PN} = 66.638°$. The angular separation is $\Delta\varphi = 1.134°$. The corresponding ground distance, computed as a WGS84 meridian arc, is approximately 126.45 km (using integral M(phi) $\Delta\varphi$ with $M(\phi) = a(1-e^2)/(1-e^2 \sin^2\phi)^{(3/2)}$, a = 6378.137 km, $e^2 = 0.006694$). Across the epoch range 2500–1500 BCE, threshold drift remains small relative to this fixed 2000 BCE reference geometry, confirming that the choice of h_0 (not epoch) is the decisive parameter (Figure 3).

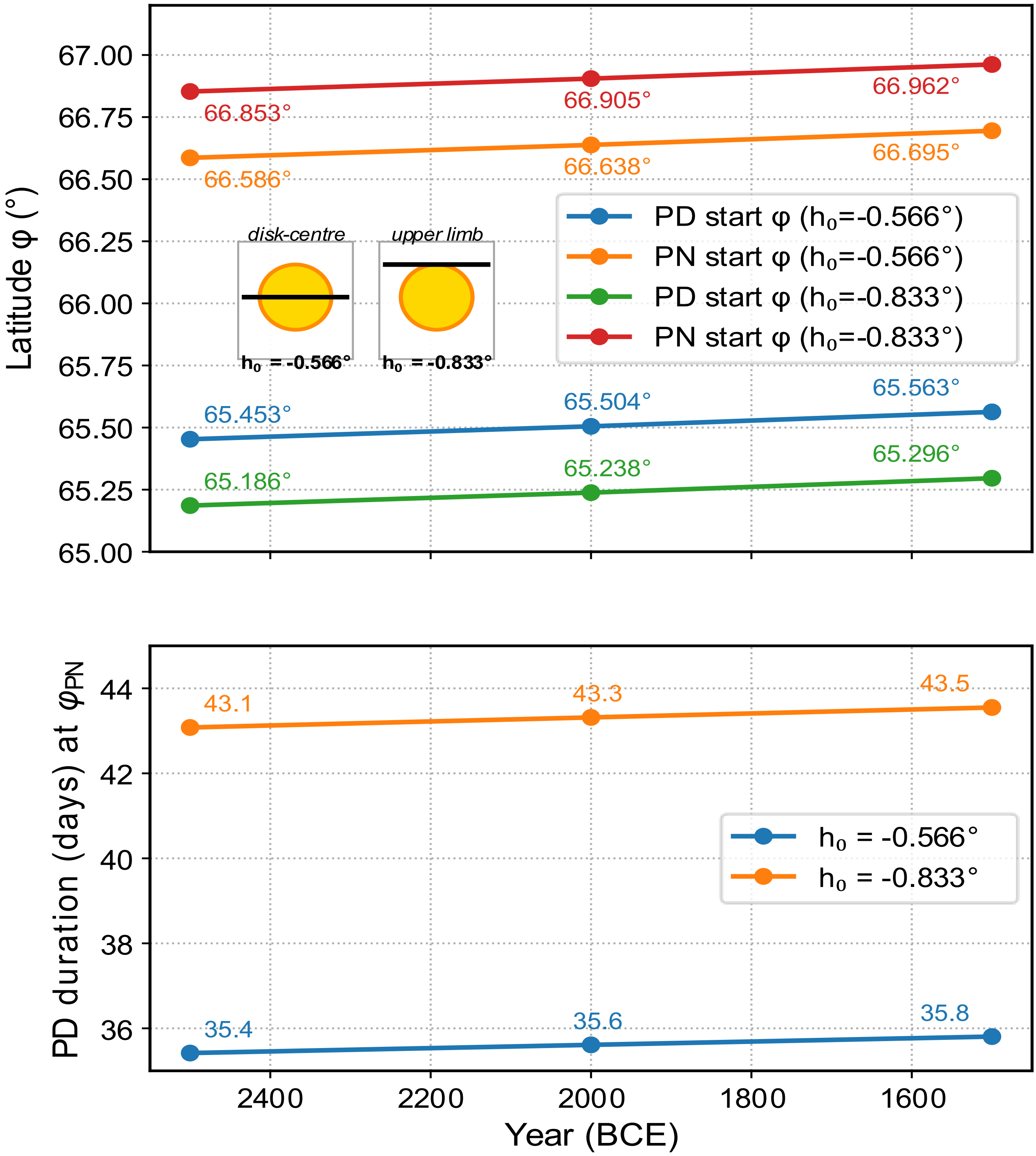

Figure 3. Top: onset latitudes of polar day (PD) and polar night (PN) during 2500–1500 BCE, for $h_0 = -0.566°$ and $h_0 = -0.833°$ (dt = 5 min). Bottom: polar-day duration (days) at the latitude where polar night begins, same epoch and thresholds.

Polar-Day Duration at the Polar-Night Threshold

The bottom panel of Figure 3 presents the central quantitative result of this study. At the fixed polar-night onset reference latitude ($\varphi\_PN = 66.638°$ for $h_0 = -0.566°$), the cumulative polar-day duration ranges from 35.417 days (2500 BCE) to 35.806 days (1500 BCE), with a value of 35.610 days for 2000 BCE (Figure 3, bottom). Across 2500–1500 BCE, the value remains close to 35.4–35.8 days, i.e. within the thirty-sixth day. Since the first polar day begins further south ($\varphi\_PD = 65.504°$), a traveller moving northward accumulates polar days before reaching φ_PN. At the latitude where the sun first fails to rise at winter solstice, that observer is entering the thirty-sixth day of continuous summer sunlight — the same count as the lozenge's thirty-six perimeter zig-zag units. Put in plain counting terms: for 2000 BCE and $h_0 = -0.566°$ at φ_PN, if the first polar-day calendar day is day 1, the last day of the interval is day 36. For clarity, the perimeter count is compared to calendar-day ordinality (day-number sequence), not to an integer multiple of 24-hour days: the continuous no-sunset duration is ~35.61 days, which terminates within the thirty-sixth calendar day.

For $h_0 = -0.833°$ (the standard astronomical limb criterion), the corresponding interval reaches the forty-fourth calendar day at φ_PN, with no numerical match to the lozenge's thirty-six. Put in plain counting terms: for 2000 BCE and $h_0 = -0.833°$ at φ_PN, if the first polar-day calendar day is day 1, the last day of the interval is day 44.

The Zig-Zag Signature at Polar-Regime Entry

At the transition into the polar domain, the solstitial gate-edge azimuths (SSRise, WSRise, WSSet, SSSet) develop a characteristic saw-tooth ('zig-zag') form. The underlying cause is the discreteness of calendar days combined with a continuously varying latitude. Solar declination is a continuous function of time, but the gate-edge azimuth is determined by whichever calendar day first becomes circumpolar — that is, the day whose declination first exceeds the critical threshold $\delta^* = \arccos(-\sin h_0) - \varphi$. As latitude increases continuously, δ* changes continuously, but the set of available daily declinations is discrete: each calendar day carries a fixed declination. Each time the rising threshold δ* crosses from one calendar day to the next, the gate-edge azimuth jumps discontinuously — the last circumpolar day shifts from day D to day D−1 (one day further from solstice), whose lower declination places the gate-edge azimuth further from north, suddenly widening the gate. Between successive jumps, the gate narrows continuously as latitude increases. The growing amplitude of successive teeth reflects the increasing declination difference between consecutive days further from solstice.

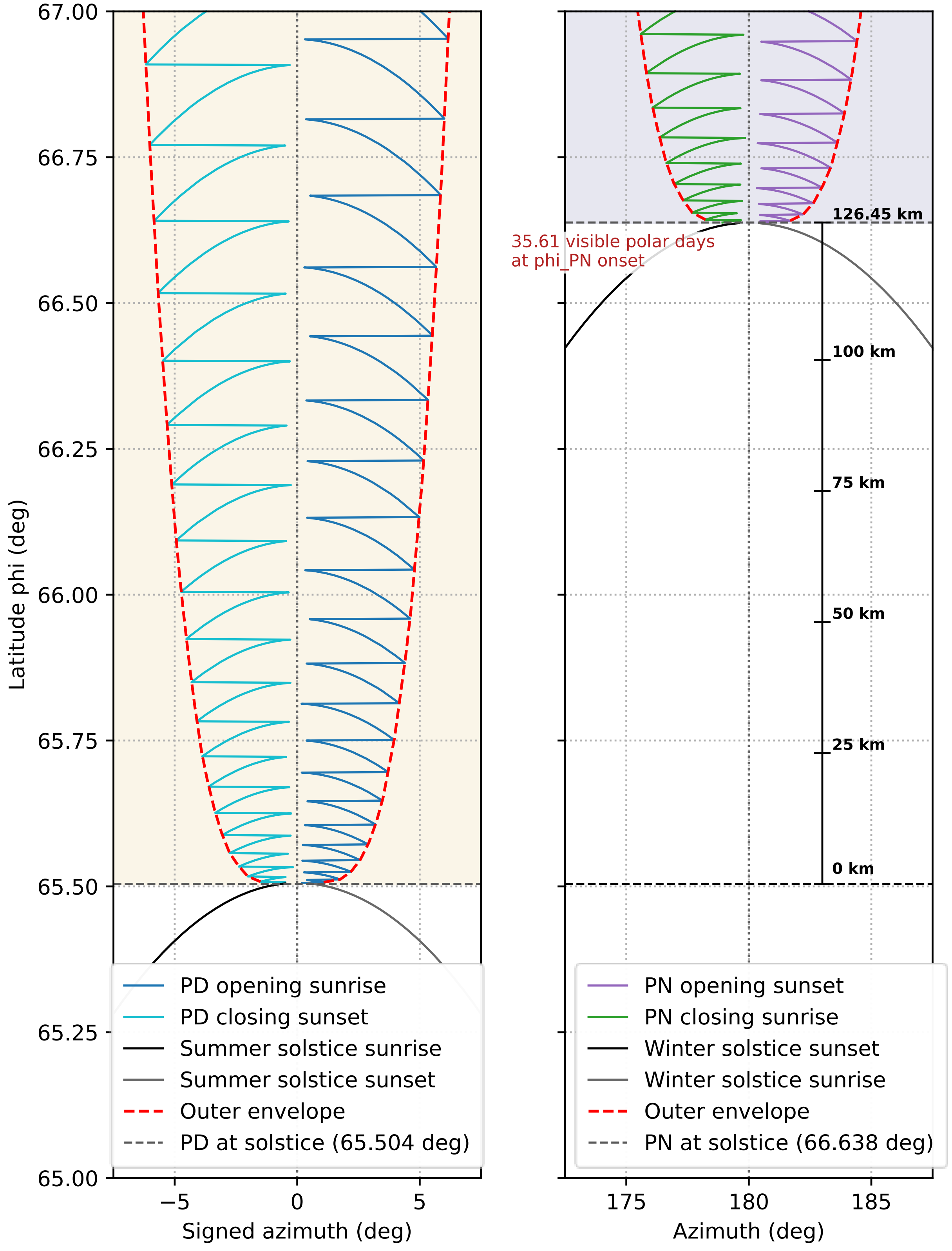

Figure 4. Northern and southern solstitial gates, 2000 BCE, $h_0 = -0.566°$, $\varphi = 65°–67°$. Left panel: polar-day gate — solstitial sunrise azimuths (SSRise, WSRise) near the polar-day threshold, with zig-zag signature and envelope (dashed). Right panel: polar-night gate — solstitial sunset azimuths (WSSet, SSSet) near the polar-night threshold, with zig-zag signature and envelope (dashed). The distance scale on the right panel marks the 126.45 km meridian arc separating the polar-day onset from the polar-night onset latitude.

Figure 4 also shows the envelope curves (dashed) obtained by interpolating through the outer peaks of each saw-tooth series. The envelope represents the gate width as a smooth, monotonically increasing function of latitude: with each successive polar day (or polar night), the angular opening of the gate widens. Because the envelope is computed at high spatial resolution ($\Delta\varphi = 0.001°$, dt = 1 day), it filters out the discrete zig-zag jumps and reveals the underlying trend. The progressive widening of the envelope — slow near the onset latitude and accelerating further into the polar domain — is the quantitative expression of what a northward-travelling observer would perceive as the polar gate opening ever wider.

The E-Angle and W-Angle Across Latitude

The E-angle ($\angle SSRise - E - WSRise, vertex\ at\ E\ \approx\ 90°$) and W-angle ($\angle WSSet - W - SSSet, vertex\ at\ W\ \approx\ 270°$) are computed as functions of latitude for 2000 BCE. By construction, E-angle = W-angle at all latitudes.

At mid-latitudes ($\varphi \approx 51°$), the angles are wide (approximately 140°). With increasing latitude, they decrease monotonically as the solstitial extremes widen on the horizon (Figure 5).

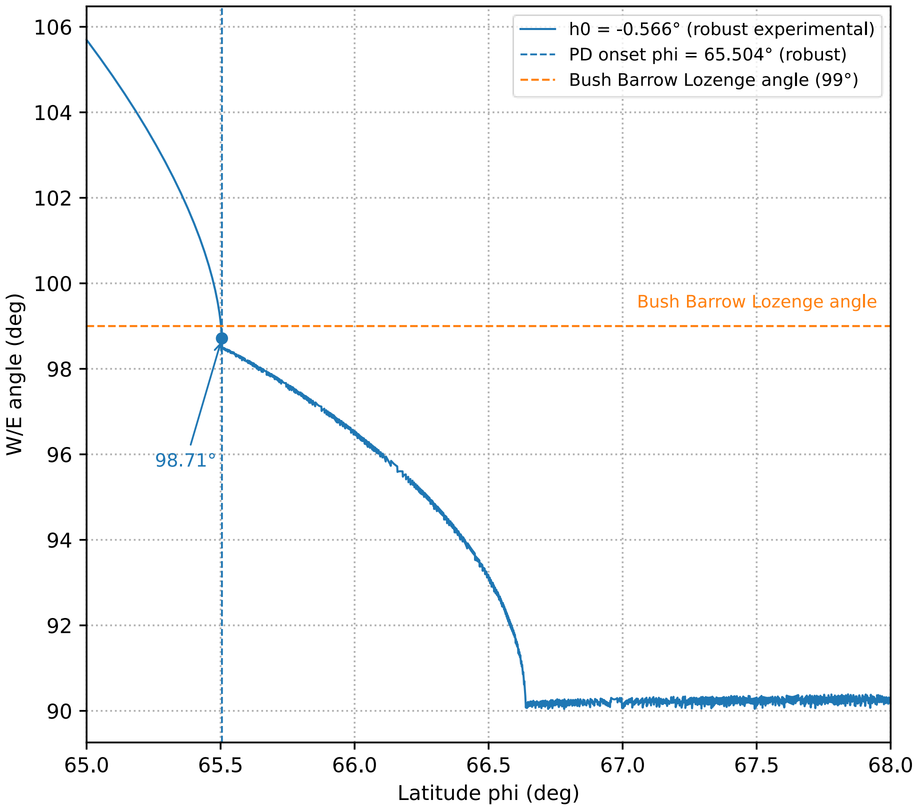

Figure 5. E-angle (= W-angle) as a function of latitude for 2000 BCE, $\varphi = 65°–68°$, $h_0 = -0.566°$ (disk-centre criterion). The filled circle marks the W/E angle at the polar-day onset latitude: 98.71° at $\varphi = 65.504°$.

At the polar-day onset latitude ($\varphi\_PD = 65.504°$), the disk-centre criterion ($h_0 = -0.566°$) gives a W/E angle of approximately 98.71°. Figure 5 shows the full dependence of this angle on latitude.

Morphological Evolution of the Solar Hexagon: 51°–71°

Figure 6 presents a twenty-panel collage (4×5 grid, 2000 BCE, $h_0 = -0.566°$) tracing the morphological evolution of the solar hexagon across $\varphi = 51°–71°$. Row 1 ($\varphi = 51°–63°$, 3° steps) shows the hexagon at temperate latitudes: a broad, nearly equilateral figure. Rows 2–3 resolve the polar-threshold zone (65°–66.638°) in fine steps: the panel at $\varphi = 65.504°$ (PD onset, row 2) carries the W/E vertex angle 98.71°, and the panel at $\varphi = 66.638°$ (PN onset, row 3) marks the onset of the quasi-rhombic form. From PN onset onwards all panels are filled with gold: both polar gates are nearly zero degrees wide, so to a Bronze Age observer the figure would have appeared indistinguishable from an ideal rhombus. Row 4 ($\varphi = 66.8°, 67°, 68°, 69°, 71°$) shows the deepening of the quasi-rhombic form as both polar gates widen.

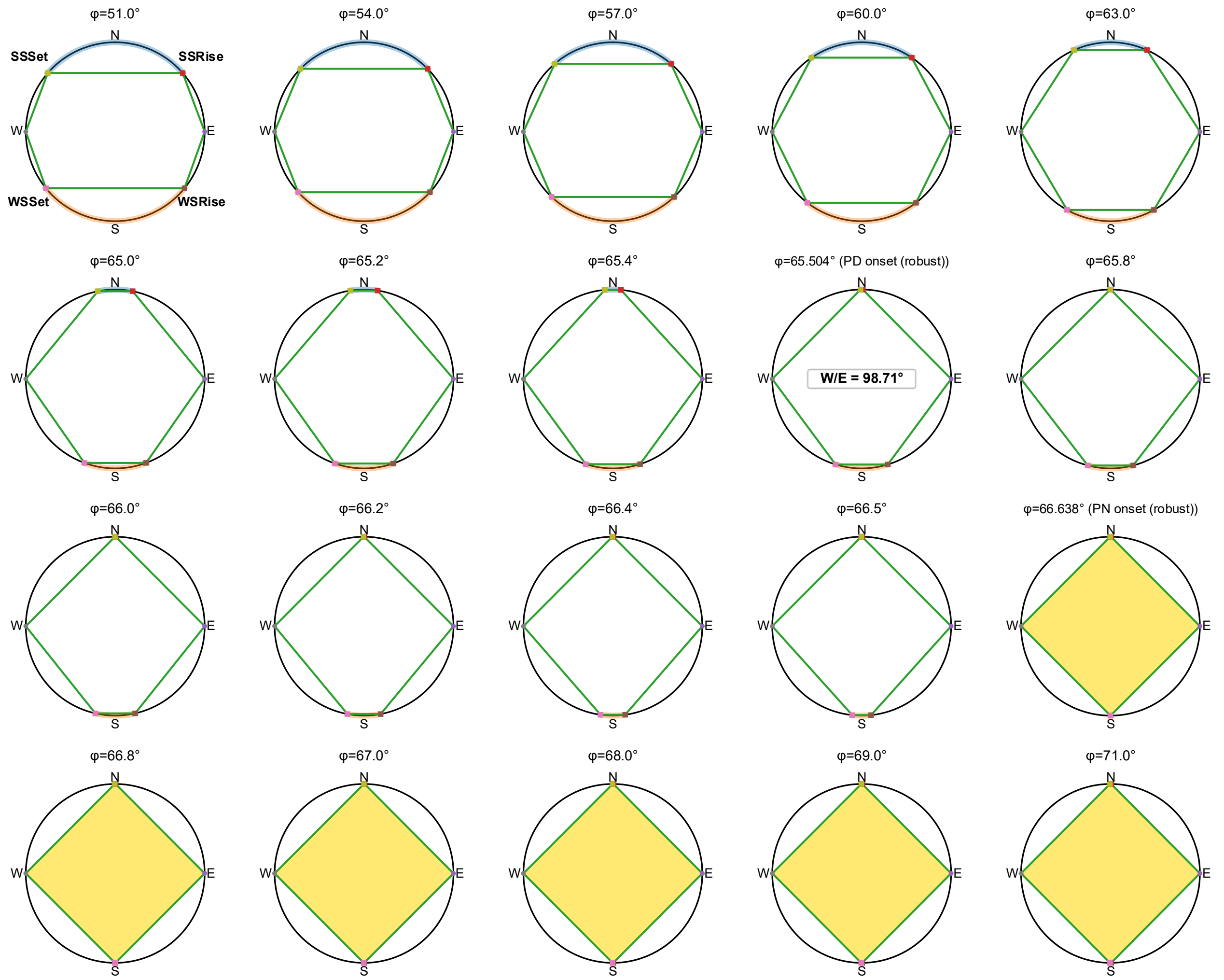

Figure 6. Morphological evolution of the solar hexagon (4×5 grid, $\varphi = 51°–71°$, 2000 BCE, $h_0 = -0.566°$). Each panel shows the six-point polygon SSRise–E–WSRise–WSSet–W–SSSet on the unit horizon circle. Row 1: 3° steps (51°–63°). Rows 2–3: fine steps through the polar-threshold zone (65°–66.638°), with PD onset ($\varphi = 65.504°$, W/E = 98.71°) in row 2 and PN onset ($\varphi = 66.638°$) in row 3. Row 4 ($\varphi = 66.8°, 67°, 68°, 69°, 71°$). Gold fill: $\varphi \geq 66.638°$ (quasi-rhombic form).

To test whether this morphology depends on how the two intermediate western/eastern points are defined, Figure 7 overlays three constructions at PD and PN onset for both $h_0 = -0.566°$ and $h_0 = -0.833°$: (i) the cardinal axis (E/W), (ii) astronomical-equinoctial sunrise/sunset, and (iii) temporal-midpoint equinoctial sunrise/sunset on the calendar day at the time-midpoint between summer and winter solstice (typically about 92 days after winter solstice). In all four onset panels, the polygons are nearly coincident: differences are confined to very small offsets near W and E, visualized in side insets placed west of W and east of E, while N and S effectively overlap. Quantitatively, the PD-onset panels give W/E = 98.71° for h_0 = −0.566° and W/E = 100.47° for h_0 = −0.833°. The PN-onset panels annotate terminal calendar-day numbers and their continuous solar-declination crossing offsets around summer solstice: day 36 with SS −17.89 d and SS +17.73 d for h_0 = −0.566°, and day 44 with SS −21.78 d and SS +21.54 d for h_0 = −0.833°. The key geometric outcome is therefore robust: choosing different intermediate-point definitions does not significantly change the hexagon form at polar thresholds.

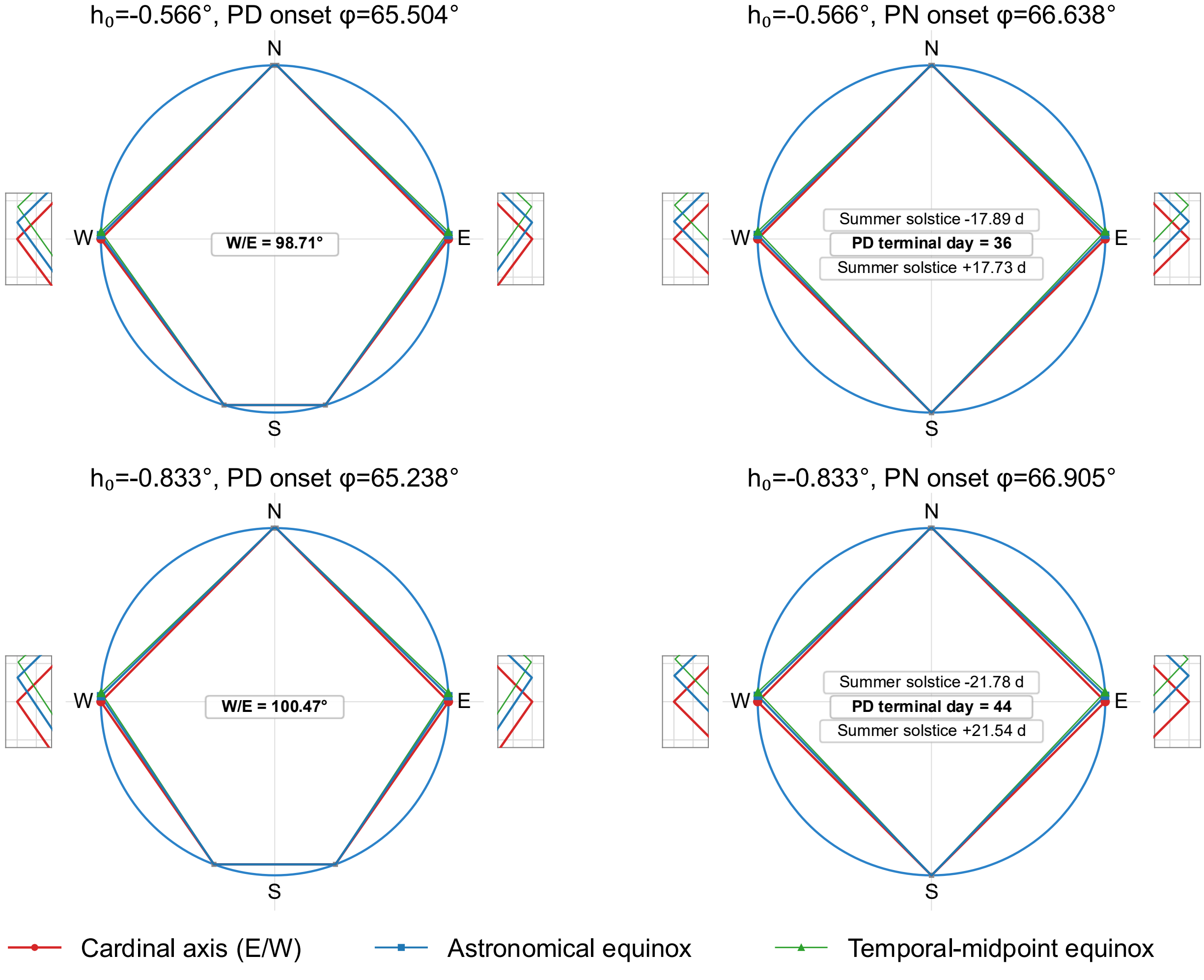

Figure 7. Robustness of hexagon morphology to intermediate-point definition at polar thresholds (2000 BCE). Four panels show PD and PN onset for h_0 = −0.566° and h_0 = −0.833°. Each panel overlays three polygons with identical solstitial vertices but different intermediate-point definitions: cardinal axis (E/W), astronomical equinox, and temporal-midpoint equinox (sunrise/sunset on the calendar day at the time-midpoint between summer and winter solstice). Insets west of W and east of E magnify the small separations near those vertices; overlap near N and S remains effectively complete. PD panels annotate W/E values (98.71° for h_0 = −0.566°; 100.47° for h_0 = −0.833°). PN panels annotate terminal calendar-day numbers and continuous-offset splits relative to summer solstice: day 36 with SS −17.89 d and SS +17.73 d (h_0 = −0.566°), and day 44 with SS −21.78 d and SS +21.54 d (h_0 = −0.833°).

Interpretation

Table 1 summarises the five internally coupled correspondences between the Bush Barrow lozenge and the solar hexagon at the polar threshold, together with an assessment of the robustness of each.

Table 1: Summary of Formal Correspondences Between the Bush Barrow Lozenge and the Solar Hexagon at the Polar Threshold

Feature	Lozenge	Solar Hexagon Model	Comment	Strength
Overall shape	rhombic	broad hexagon at 51°–60°; quasi-rhombic only at $\varphi \approx 67°$	form incompatible with British latitudes	strong
Obtuse angle	~99° (after Thom et al.)	98.71° at φ_{PD}	model output, not fitted	strong
Perimeter count	36 zig-zag units	≈36 polar days at φ_{PN}	for $h_0 = -0.566°$	conditional
Zig-zag motif	zig-zag band on perimeter	saw-tooth gate-edge azimuths at polar onset	formal analogy	supportive
Divergent lines	two pairs from acute vertices	envelope of gate width	widens with latitude	supportive

Comparison with the Bush Barrow Lozenge

The most direct correspondence concerns the overall shape. At the latitude of Stonehenge ($\varphi \approx 51°$), the solar hexagon is a broad, open polygon. As latitude increases through the British and Irish range (51°–60°), the hexagon gradually narrows but remains far from rhombic. Through the polar-threshold transition the figure continues to contract, but the quasi-rhombic collapse is reached at the polar-night onset latitude ($\varphi_{PN} = 66.638°$), where both north and south gates are near closure (Figure 6). The lozenge's rhombic form is therefore incompatible with the solar hexagon at any latitude in Britain or Ireland, but formally compatible with the hexagon at polar latitudes. This morphological transition is visually obvious and requires no instruments to perceive.

A second, independent correspondence is angular: at PDonset ($\varphi_{PD} = 65.504°$), the model gives W/E = 98.71° with no fitted free parameter. The quasi-rhombic shape criterion, by contrast, is evaluated at PNonset.

The Number Thirty-Six and Polar-Day Duration

The lozenge's perimeter carries a continuous sequence of thirty-six zig-zag units (nine per side). In Mauméné's reading, these represent thirty-six successive days forming the base counting unit for planetary-cycle encodings [6].

In the present framework, the number thirty-six acquires a different but equally specific meaning: the polar-day season at the latitude where polar night begins ($\varphi_{PN} = 66.638°$) falls within the thirty-sixth day for $h_0 = -0.566°$. This correspondence is threshold-dependent: for $h_0 = -0.833°$, the polar-day duration at φ_{PN} reaches the forty-fourth day, breaking the match. The number thirty-six therefore selectively favours the disk-centre refraction model ($h_0 = -0.566°$).

It is important to note that even if the thirty-six-day correspondence is threshold-sensitive, the shape transition itself is not confined to a single numeric threshold. Across tested h_0 values, the hexagon contracts progressively through the polar-threshold band and reaches its quasi-rhombic state at or very near the PN-onset latitude; only the exact latitude of this state shifts with h_0. The shape result is therefore the primary correspondence, and the day-count match is a secondary, threshold-dependent reinforcement.

The Zig-Zag and Divergent-Line Motifs

The saw-tooth (zig-zag) form of the gate-edge azimuth curves at polar-regime entry (Figure 4) offers a visual analogy with the lozenge's perimeter zig-zag ornament. While we do not claim a direct iconic mapping, the formal resemblance is notable: discrete angular changes at the threshold of a polar regime, rendered as a zig-zag band encircling the artefact.

A second visual analogy concerns the divergent line pairs at the lozenge's acute vertices. In the polar-threshold geometry these vertices correspond to the narrowing solar gates, whose envelope widens progressively with latitude even while the individual gate-edge azimuths continue their saw-tooth oscillation. The motif is therefore suggestive of the same transition, though again not demonstrative.

Accordingly, the comparison is not a re-description of the Stonehenge horizon but a higher-latitude formal analogue.

Relationship to Previous Interpretations

The present model complements Mauméné's emphasis on the number thirty-six by assigning the lozenge's perimeter count a specific polar-day meaning rather than a general calendrical one [6]. It therefore offers an astronomical context for Mauméné's intuition without displacing it.

However, the present model requires a fundamentally different orientation of the lozenge from that proposed by Thom et al. [3]. Thom placed the acute vertices (~81°) on the east–west axis, interpreting the lozenge as a calendar device calibrated to the solstitial azimuths at the latitude of Stonehenge. Ruggles and Chadburn have identified several problems with this interpretation: the difficulties of establishing north, the difficulties of using a portable object for making accurate measurements, and the fact that Thom's reference directions were 'clearly selected from a range of other possibilities'. They conclude that 'there is no convincing evidence that they were astronomical instruments or were used for establishing important calendrical dates' [13]. The present framework supports this scepticism on independent grounds and proposes a different orientation: the W-angle of the solar hexagon at polar-day onset (98.71°) places the obtuse vertices on the east–west axis and consequently the acute vertices on the north–south axis. The two pairs of divergent lines emanating from the acute vertices correspond to the northern and southern polar gates, whose separation widens toward higher latitudes (Figure 4). This 90° rotation relative to Thom's orientation is the key interpretive move: the divergent line pairs emerging from the acute vertices now point northward and southward, directly echoing the widening envelope of the polar gates with latitude (Figure 4). Under this orientation both interior angles of the lozenge acquire astronomical content simultaneously. The obtuse ~99° vertex aligns with the hexagon's W-angle at polar-day onset (98.71°), and the acute ~81° vertex is the angular opening of the divergent-line pair at the polar-gate vertex — the angle at which the two edges bounding the north (or south) polar gate diverge from one another. At PDonset, the measured W-angle is 98.71°, so its supplementary acute angle is 180° − 98.71° = 81.29°. The ~99° and ~81° matches are therefore not two independent numerical coincidences but a single coupled fit fixed by the one latitude of polar-day onset. This is consistent with Ruggles and Chadburn's scepticism concerning the ~81° value as a deliberate Stonehenge-calibrated design parameter: the acute angle in the present model carries no local solstitial function, and its near-coincidence with the solstitial azimuth difference at Stonehenge is treated as an incidental numerical encounter rather than as the controlling geometry.

The present argument is not intended to apply to all British gold lozenges indiscriminately. The small Bush Barrow lozenge and the Clandon Barrow lozenge differ substantially in angular scheme, and their omission here is deliberate: the polar-threshold model is proposed only for the large Bush Barrow lozenge, whose angle, perimeter count, and outer zig-zag motif converge in a specific way.

The Zig-Zag Motif as an Observed Phenomenon

The zig-zag pattern at polar-gate edges is not merely a mathematical artefact. An observer who records gate-edge azimuths while moving northward would see continuous narrowing interrupted by abrupt jumps at the onset of polar day and, farther north, at the onset of polar night. For a Bronze Age observer this would constitute an unexpected discontinuity at the threshold of perpetual daylight. The point remains suggestive rather than probative, but it grounds the zig-zag analogy in observation rather than in decorative resemblance alone. This saw-tooth behaviour also appears to be under-discussed in the archaeoastronomical literature.

Geographic Provenance: Three Levels of Argument

The Bush Barrow lozenge was deposited near Stonehenge ($\varphi \approx 51°$ N), so any proposed solar reading must first be tested against southern British latitudes. On that test the polar-threshold model fails locally: between 51° and 60° N the solar hexagon remains broad, shows no saw-tooth gate signature, and yields no thirty-six-day correspondence. Any fit therefore points to a higher-latitude horizon. That does not detach the argument from Britain; on the contrary, it sharpens the question of why a British artefact should encode a solar geometry that becomes formally meaningful only farther north.

The paper therefore advances three distinct claims: a computational geometric result, an archaeological analogy, and a conjectural transmission question. The first is demonstrable within the model; the second is interpretive; the third remains historically open and should not be confused with the geometric fit itself.

That third claim is not impossible within a Bronze Age northern-European context. As noted in Methods, Bronze Age habitation is attested well into northern Scandinavia, and long-distance exchange linking Scandinavia, the Baltic, and Britain is widely recognised [14,15]. Amber in elite Wessex graves and Scandinavian maritime imagery indicate exchange networks capable of carrying information as well as goods.

Classical testimony likewise shows that knowledge of the midnight sun, polar night, and Hyperborean northern regions could circulate far beyond the Arctic. Reports preserved by Homer, Herodotus, Strabo/Pytheas, and Pliny do not demonstrate Bronze Age transmission to Wessex, but they do show that polar phenomena were historically thinkable and transmissible across long cultural distances [16,17,7,8].

Historical transmission is therefore treated as an open contextual question, while the geometric fit is evaluated on its own internal consistency.

Why This is Not a Claim of Polar Manufacture
This model does not require that the Bush Barrow lozenge was manufactured in the Arctic, nor that the individual buried at Bush Barrow personally travelled to the polar circle. What is demonstrated here is a formal geometric correspondence, which remains compatible with multiple pathways: formal analogy, mediated knowledge transmission, symbolic transformation of northern phenomena, or chance convergence. The claim is therefore intentionally bounded: this is a structured interpretive framework, not proof of direct polar manufacture.

Why $h_0 = -0.566°$ is Not an Ad Hoc Choice
In practice, only three naked-eye solar horizon markers are physically meaningful: the upper limb, the centre of the disk, and the lower limb, each modified by atmospheric refraction. The upper-limb criterion is the standard convention in archaeoastronomy south of the polar circle, where the solar limb is usually a stable visual marker. At polar latitudes, however, severe refraction, flattening, ducting, and mirage effects make the upper limb less reliable. The disk-centre criterion is therefore not one arbitrary option among many, but the most robust operational proxy for a naked-eye observer under polar atmospheric conditions. It is not treated here as a fitted numerical parameter, but as the formal expression of the disk-centre horizon event under mean refraction. The lower-limb criterion is not commonly used as a practical observational marker and is not adopted here.

A critical feature of this interpretation is its sensitivity to the horizon threshold h_0. Two distinct definitions are in common use:

- **Standard astronomical: $h_0 = -0.833°$:** the standard astronomical criterion (upper limb tangent to the horizon under mean refraction). This is the conventional apparent-sunrise/sunset criterion and is appropriate for naked-eye marking under average atmospheric conditions, especially at non-polar latitudes.
- **Operational visual: $h_0 = -0.566°$:** disk-centre criterion (geometric centre of the solar disk at the horizon under mean refraction). This corresponds to the moment when the Sun is visually half-immersed in the horizon — arguably the most natural naked-eye reference.

The disk-centre criterion is not an innovation of this paper. The polar circle itself is geometrically defined as the latitude where the centre of the Sun — not the upper limb — remains continuously above or below the horizon for more than twenty-four hours at a solstice. At polar latitudes, temperature inversions, optical ducting, and image deformation make the solar limb difficult to define unambiguously; the disk-centre criterion avoids reliance on the limb and provides a more robust operational definition. The standard astronomical sunrise/sunset threshold (h_0 = −0.833°) is constructed from two components: mean atmospheric refraction at the horizon (≈34′) and the Sun's angular semi-diameter (≈16′). Removing the semi-diameter correction — that is, using the geometric centre of the disk rather than the upper limb — yields h_0 = −0.833° + 0.267° ≈ −0.566°, effectively the value adopted here. This caution is consistent with prior methodological work: Schaefer (1993) showed how near-horizon visibility depends strongly on atmospheric and perceptual limits [18], while Purrington (1988) provided a quantitative treatment of low-altitude visibility criteria in archaeoastronomical applications [19].

There is a strong physical reason why the upper-limb criterion is unreliable at polar latitudes. Under the severe temperature inversions that routinely form over ice-covered surfaces, the solar disk is subject to extreme image deformation: flattening, fragmentation into horizontal 'pancake' layers, and the well-documented Novaya Zemlya effect — an atmospheric duct that can project an image of the Sun above the horizon when the disk is geometrically well below it [20]. In Barentsz's 1597 polar expedition, the Sun was observed two weeks before its calculated return; Shackleton reported seeing the Sun seven days after it should have set. At Tuktoyaktuk (69°26′ N) in 1979, the Sun appeared above the horizon despite being geometrically 1°34′ below it [21]. Under such conditions, the upper limb of the Sun is effectively undefined: the 'rectangular sun' has no well-defined top edge. The geometric centre of the disk is a far more robust reference point, since its apparent position is less affected by the differential refraction that distorts the limb.

Forsythe et al. demonstrated that the choice of sunrise/sunset definition — upper limb versus disk-centre — can alter accumulated daylight hours by up to one week over a growing season [22]. Their daylength model explicitly treats the disk-centre case (their parameter p = 0°) alongside the standard upper-limb case (p = 0.833°), confirming that both are recognised operational definitions in the scientific literature.

Table 2 shows how the key observables vary across a range of h_0 values. Only h_0 = −0.566° simultaneously yields a W-angle within about 1° of Thom et al.'s approximately 99° obtuse angle and a terminal calendar-day value within the thirty-sixth day at the polar-night onset latitude.

An additional parameter scan was performed for years 2500–1500 BCE (step 1 year) and h_0 from −0.590° to −0.540° (step 0.001°), retaining only cases where the polar-day duration at φ_PN falls within 35.001–36.000 days. The accepted domain forms a broad continuous band (31,384 of 51,051 cells), and h_0 = −0.566° lies inside that band (Figure 8). This supports treating the result as robust over a finite parameter neighborhood, not as a single-value fit.

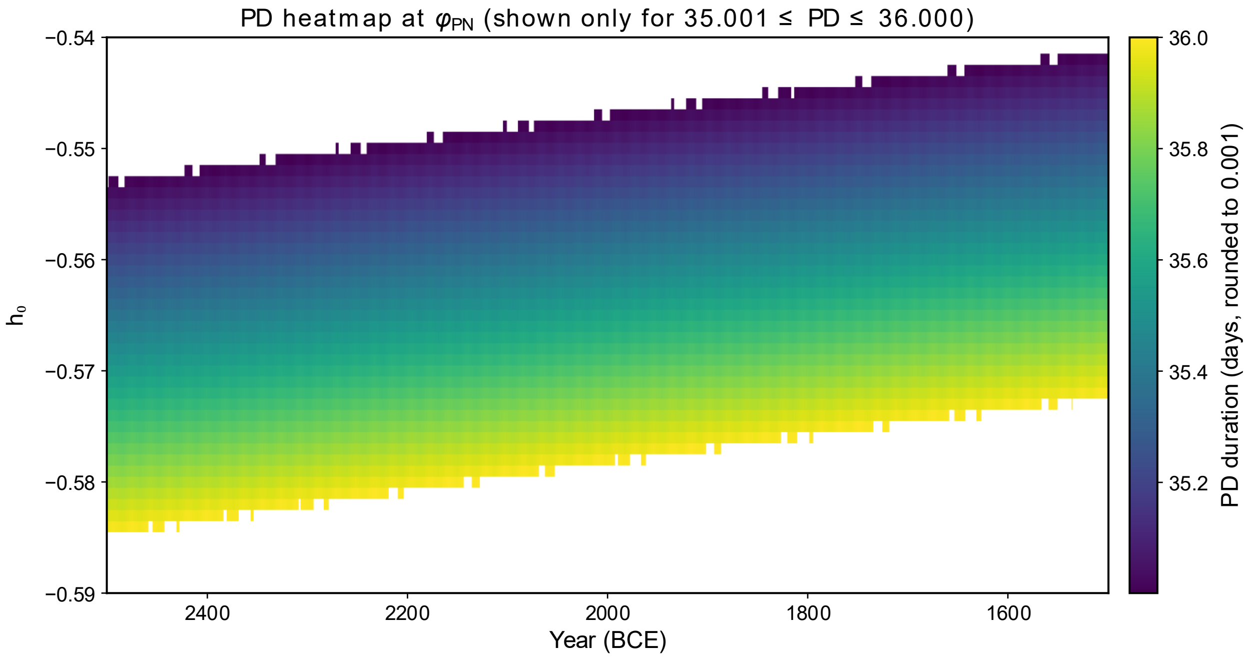

Figure 8. Parameter-space scan for the thirty-sixth-calendar-day condition. Heatmap over 2500–1500 BCE (step 1 year) and h_0 = −0.590° to −0.540° (step 0.001°), computed as polar-day duration at φ_PN and shown only where 35.001 ≤ PD ≤ 36.000 days (white = outside target range). The manuscript value h_0 = −0.566° lies within this continuous accepted band.

Figure 8 makes the robustness pattern explicit. The accepted domain is continuous across all 1001 tested years (2500–1500 BCE), with no isolated islands in parameter space. For each year, the admissible h_0 interval is broad (31–32 grid steps, i.e., about 0.031°–0.032°), and the global bounds are h_0 = −0.584° to −0.542°. The manuscript value h_0 = −0.566° lies inside this band throughout the full epoch range; the band itself shifts only gradually toward less negative h_0 from older to younger dates.

Table 2: Sensitivity of Key Observables to the Horizon Threshold h_0 (2000 BCE). Only h_0 = −0.566° Yields Both a W-Angle Within About 1° of Thom et al.'s Approximately 99° and a Terminal Calendar-Day Value Within the Thirty-Sixth Day

h_0	φ_PD	φ_PN	W at φ_PD	Terminal Day at φ_PN
−0.833°	65.238°	66.905°	100.47°	44
−0.70°	65.371°	66.772°	99.64°	40
−0.566°	65.504°	66.638°	98.71°	36
−0.40°	65.671°	66.472°	97.38°	31

Some neighbouring thresholds can approximate one observable — for example, h_0 = −0.70° yields a W-angle of about 99.64°, close to Thom et al.'s lozenge angle of about 99°, but a terminal day number of 40. Only h_0 = −0.566° simultaneously approximates both Thom et al.'s lozenge angle and its thirty-six-count perimeter.

The choice of $h_0 = -0.566°$ need not be treated as an ad hoc parameter selected only to produce the desired result. It is the physically motivated disk-centre criterion, and the convergence with the lozenge's geometry is a consequence, not a premise, of this choice.

Limitations

- The horizon threshold h_0 is the most sensitive parameter. Real refraction in polar conditions varies substantially (inversions, ducting, Novaya Zemlya effect). The precise angular and durational values depend on the assumed atmospheric model.
- A related limitation follows from this design choice: the algorithm is not intended to recover exact physical event times to modern observational precision. It is a robust threshold model calibrated to what an unaided observer could plausibly discriminate, and should be interpreted as such.
- The angular comparison uses the rounded values reported by Thom et al. (~81° and ~99°). The present argument does not depend on a sub-degree metrical reconstruction of the lozenge.
- The solar ephemeris uses a Meeus-style analytical chain. More sophisticated treatments (topocentric corrections, higher-order nutation) would introduce small corrections without affecting qualitative patterns.
- There is no direct archaeological evidence that the Bush Barrow craftsmen themselves observed polar latitudes. The comparison remains a hypothesis of formal compatibility; without independent evidence of knowledge transfer between polar-threshold observers and southern English goldsmiths, the correspondence cannot be elevated to a settled identification.
- A multiple-comparison risk must be acknowledged: among the many possible geometric readings of a richly decorated object, some correspondences may arise by chance. The present study mitigates this risk in a specific way: the five correspondences (rhombic form, vertex angle, day count, zig-zag motif, and divergent-line/polar-gate analogy) are not independently selected features but internally coupled outputs of a single one-parameter model whose sole control variable is latitude. They constitute a single-system convergence, not a collection of ad hoc matches. This distinguishes the present approach from retroactive pattern-mining, in which features are selected post hoc to fit a hypothesis.
- The zig-zag signature at polar-gate edges arises from day-count quantisation: each new circumpolar day produces a discrete jump in gate width, followed by continuous narrowing. Its visual resemblance to the lozenge's zig-zag ornament is suggestive but not probative.

Conclusion

- A six-point solar hexagon (SSRise–E–WSRise–WSSet–W–SSSet) is defined on the horizon circle using only the four solstitial extremes and two intermediate eastern and western points, fixed here to the cardinal east-west axis (E = 90°, W = 270°) from the gnomon-defined meridian, without requiring any precise determination of the astronomical equinox [9].
- Across 51°–71° N the hexagon changes from a broad mid-latitude polygon to a quasi-rhombic form reached at PN onset and maintained northward. At the latitude of the first polar day ($\varphi_{PD} = 65.504°$, $h_0 = -0.566°$), its E/W-angle is 98.71°, within approximately 0.5° of Thom et al.'s ~99° obtuse angle [3].

- The polar-day duration at the latitude where polar night begins is within the thirty-sixth calendar day (for $h_0 = -0.566°$), matching the lozenge's thirty-six perimeter zig-zag units. This count is threshold-dependent and does not survive the standard upper-limb criterion $h_0 = -0.833°$. In plain counting terms for 2000 BCE ($h_0 = -0.566°$): if polar-day day 1 is the interval start, the interval ends on day 36, matching the lozenge's 36 zig-zag units.
- The zig-zag motif formally resembles the saw-tooth azimuth signature at polar-regime entry, while the divergent line pairs are consistent with the widening gate envelope. Both motifs are supportive analogies rather than decisive proofs (Figures 4–5).
- The present model provides a possible astronomical framework that complements Mauméné's identification of the thirty-six zig-zag units as a day count, linking this number to the polar-day season at polar-night onset [6].
- However, it requires a different orientation of the lozenge from that proposed by Thom et al.: the acute vertices are placed on the north–south axis rather than on the east–west axis — a 90° rotation of Thom's reading. This orientation is supported independently by two criteria: the coupled match of the lozenge's obtuse (~99°) and acute (~81°) angles with the hexagon's W-angle (98.71°) and the supplementary N/S polar-gate vertex (81.3°) at polar-day onset, and the alignment of the divergent-line motifs with the north–south opening of the polar gates, whose envelope widens with latitude.
- Taken together, these features form a single-system convergence rather than a set of independent ad hoc matches. The argument remains a structured hypothesis, not a settled identification, and the question of historical transmission to southern Britain remains open. What the model does suggest is that a British artefact may preserve a solar geometry whose closest formal counterpart lies on a northern, near-polar horizon.

Funding
No external funding was received for this research.

Acknowledgements
No fieldwork, excavation, or institutional support was involved in this study. All computations were performed independently using open-source Python libraries. The numerical calculations, the generation of the figures, and the preparation of the supporting Python code were carried out with the assistance of AI coding tools, specifically OpenAI ChatGPT, OpenAI Codex (agentic coding assistant), and Anthropic Claude (including Claude Code). These tools were used as computational and drafting aids under the author's direction; the astronomical model, its geometric interpretation, the selection of parameters, the verification of all results, and the final text are the sole responsibility of the author. No AI system is listed as an author, and no AI system independently originated, validated, or interpreted any of the findings reported here.

Author Contributions
The author is solely responsible for the conceptualization, mathematical modelling, software implementation, figure preparation, and manuscript writing.

Conflicts of Interest

The author declares no known competing financial interests or personal relationships that could have influenced the outcomes presented in this study.

Data Availability
The computational scripts and final figures are included in the submission package as supplementary materials. Additional manuscript source files can be supplied by the corresponding author upon editorial request.

Ethics Statement
This research did not involve human participants, living animal subjects, or newly conducted archaeological fieldwork. All analyses are based on published physical measurements reported in the published literature and on computational modelling of solar geometry. No ethical approval was therefore required.

References

[1] Needham, S., Lawson, A. J. and Woodward, A. (2010). A noble group of barrows: Bush Barrow and the Normanton Down Early Bronze Age cemetery two centuries on. *The Antiquaries Journal*, 90, 1–39.
[2] Hoare, R. C. (1812). *The Ancient History of Wiltshire* (Vol. 1, Pt. 1). W. Miller.
[3] Thom, A. S., Ker, J. M. D. and Burrows, T. R. (1988). The Bush Barrow gold lozenge: Is it a solar and lunar calendar for Stonehenge? *Antiquity*, 62(236), 492–502.
[4] North, J. (1996). *Stonehenge: A New Interpretation of Prehistoric Man and the Cosmos*. The Free Press.
[5] Ruggles, C. L. N. (2005). *Ancient Astronomy: An Encyclopaedia of Cosmologies and Myth*. ABC-CLIO.
[6] Mauméné, C. (2017). The Bush Barrow and Clandon Barrow gold lozenges and the Upton Lovell golden button: A possible calendrical interpretation. *Culture and Cosmos*, 21(1–2), 31–50.
[7] Strabo. (1917–1932). *Geography* (Vols. 1–8; H. L. Jones, Trans.). Harvard University Press. (Original work composed ca. 20 CE)
[8] Pliny the Elder. (1942). *Natural History* (H. Rackham, Trans.). Harvard University Press. (Original work published ca. 77 CE)
[9] Ruggles, C. L. N. (1997). Whose equinox? *Archaeoastronomy: Supplement to the Journal for the History of Astronomy*, 28, S45–S50.
[10] González-García, A. C. and Belmonte, J. A. (2006). Which equinox? *Archaeoastronomy: Journal for Astronomy in Culture*, 20, 95–105.
[11] Belmonte, J. A. (2021). What equinox? In E. Boutsikas, S. C. McCluskey and J. Steele (Eds.), *Advancing Cultural Astronomy: Studies in Honour of Clive Ruggles* (pp. 13–33). Springer.
[12] Meeus, J. (1998). *Astronomical Algorithms* (2nd ed.). Willmann-Bell.
[13] Ruggles, C. and Chadburn, A. (2024). *Stonehenge: Sighting the Sun*. Liverpool University Press.
[14] Kristiansen, K. and Larsson, T. B. (2005). *The Rise of Bronze Age Society: Travels, Transmissions and Transformations*. Cambridge University Press.
[15] Ling, J. (2008). *Elevated Rock Art: Towards a Maritime Understanding of Bronze Age Rock Art in Northern Bohuslän, Sweden* (GOTARC Serie B, Gothenburg Archaeological Theses 49). Göteborg University.
[16] Homer. (1996). *The Odyssey* (R. Fagles, Trans.). Viking. (Original work composed ca. 8th century BCE)

[17] Herodotus. (2003). *The Histories* (A. de Sélincourt, Trans.; J. Marincola, Rev.). Penguin Classics. (Original work published ca. 430 BCE)
[18] Schaefer, B. E. (1993). Astronomy and the limits of vision. *Vistas in Astronomy*, 36(4), 311–361.
[19] Purrington, D. R. (1988). Heliacal rising and setting: Quantitative aspects. *Archaeoastronomy: Supplement to the Journal for the History of Astronomy*, 12, S72–S85.
[20] Lehn, W. H. (1979). The Novaya Zemlya effect: An Arctic mirage. *Journal of the Optical Society of America*, 69(5), 776–781.
[21] Lehn, W. H. and German, B. A. (1981). Novaya Zemlya effect: Analysis of an observation. *Applied Optics*, 20(12), 2043–2047.
[22] Forsythe, W. C., Rykiel, E. J., Jr., Stahl, R. S., Wu, H. and Schoolfield, R. M. (1995). A model comparison for daylength as a function of latitude and day of year. *Ecological Modelling*, 80, 87–95.