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Alignment of the Western and Eastern Passage Tombs at Knowth Tomb 1

Frank Prendergast
Technological University Dublin, frank.prendergast@tudublin.ie

Tom Ray
Dublin Institute for Advanced Studies, tr@cp.dias.ie

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APPENDIX 2

Alignment of the Western and Eastern passage tombs at Knowth Tomb 1

Frank Prendergast[1] and Tom Ray[2]

[1]*College of Engineering and Built Environment, Dublin Institute of Technology*
[2]*School of Cosmic Physics, Dublin Institute for Advanced Studies*

REFERENCE

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Section and figure numbers in the paper adhere to those used in the forthcoming volume. Readers should note that Fig. 2.10 referred to in the text is part of Chapter 2 of the volume. However, the detail shown in that illustration is largely duplicated here in Fig. A2.1 and in the cover illustration.

ABSTRACT

This report presents a summary account of two surveys undertaken by the authors to determine and interpret the alignments of the western and eastern passage tombs at Knowth, Co. Meath. The findings indicate that contrary to earlier suggestions, the eastern passage and the western passage (inner and outer) are not aligned towards sunrise and sunset respectively at the period of the vernal and autumnal equinoxes.

A2.1 Introduction

The passage tomb complex at Knowth, Co. Meath consists of the main kerbed mound known as Tomb 1 surrounded by twenty smaller tombs. The large mound contains two burial tombs – a cruciform chamber opening to the east, and an undifferentiated tomb accessed by an angled passage and which opens to the west. The complex therefore has evidence for a total of 21 mounds and 22 tombs. Recent research on the structure of the large mound as well as the location and placement of the internal art, now suggests that it had two phases of construction termed Tomb 1B and Tomb 1C (Eogan, 1998; see Chapter 2). As proposed, the circumference of the earlier Tomb 1B cairn may have coincided with the bend of the western passage and this could partially explain its angled morphology. It should be noted however, that due to concerns with structural stability, the excavation cutting on the western side was shorter than on the eastern side and consequentially, the former did not actually detect the relationship between the inner core cairn and the bend of the western passage (see Fig. 2.10). Construction of the second phase, Tomb 1C, extended and maintained the orientation of the eastern passage of Tomb 1B. By merging the most recent survey of the complex (commissioned by the National Monuments Service of the Office of Public Works) with our orientation surveys, and also with the plans of the tomb produced during excavation, we obtain a spatially correct planimetric representation of the eastern and western passages and chambers relative to the other components of the complex (Figure A2.1). In addition, we have incorporated the outline limits of both phases of tomb construction in the plan but with the caveat that uncertainty pertains to the delineation of Tomb 1B on its western side as previously explained.

Since excavations first began at Knowth in 1962, there has been some confusion regarding the orientation of the whole complex and thus the direction of the passages in the published plans (Eogan 1986, 23, 31; Stout 2002, 50; Waddell 1998, 63). This could be attributable to the selective use or interpretation of different north points (magnetic or true) used to orientate the archaeological detail and / or to the lack of an explicit statement as to which north point type was adopted on a particular plan. Arising out of the archaeological need and concern for a precise definition and clarification of this issue and the wider cultural and public interest in the possible alignment of the eastern and western passages in an astronomical sense, we address the key question of whether or not, a link may have existed between the Tomb 1 passages and the direction of the rising / setting sun at the equinoxes[1] as first proposed by Eogan (1986, 178; see below).

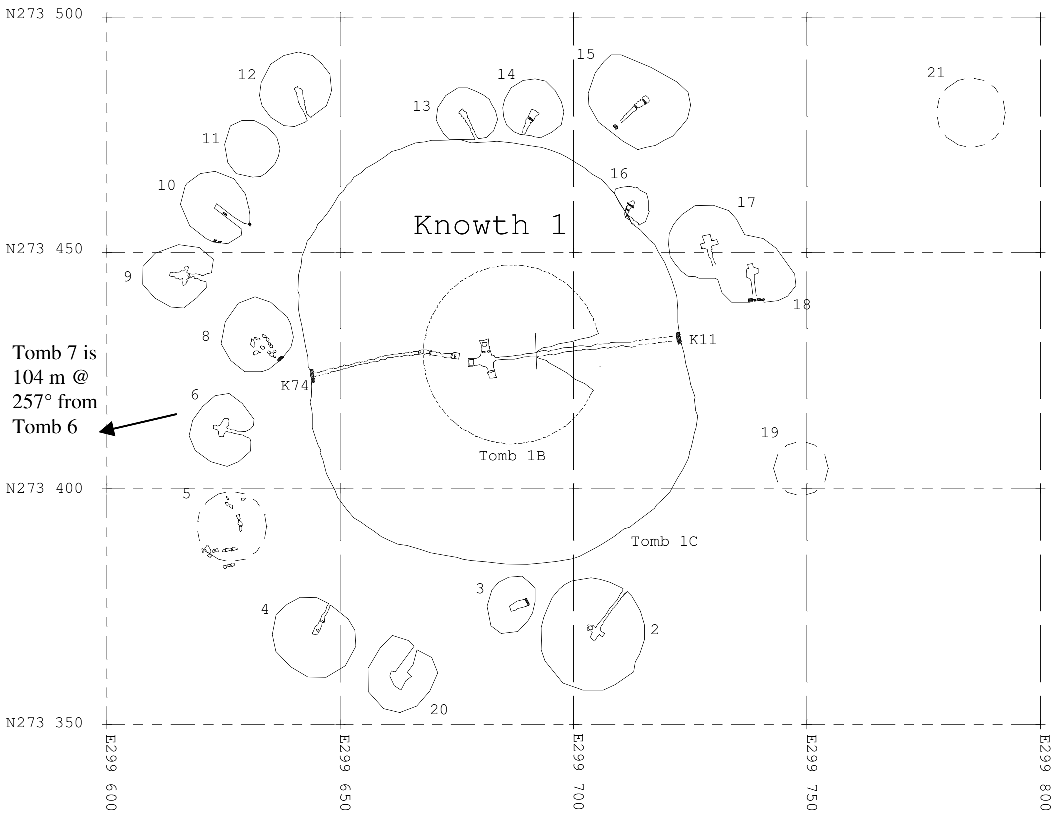

Fig. A2.1: Plan of the passage tomb complex at Knowth. The coordinates are in metres on the Irish Grid shown in the plan and the grid interval is 50 m. True north is 1°.2 west of grid north (plan is based on a survey supplied by the National Monuments Service of the Office of Public Work with additional archaeological detail from Dr. Kerri Cleary). The western limit of Tomb 1B is an estimate only.

[1] The moment when the Sun, which moves along the ecliptic, crosses the vernal equinox while moving from south to north and crosses the autumnal equinox while moving from north to south. Expressed differently, the sun will rise and set approximately due east and west respectively, provided the horizon is at 0° altitude (see discussion at end of paper).

A2.2 Western Chamber and Passage

During conservation work on the western passage and chamber of Tomb 1 in 1997, visual observations by W. Cummins of the Office of Public Works indicated that direct sunlight entered the passage on the 23rd September 1997 at *c*.18:20 (UTC +1)[2] and that the illumination reached beyond the first sill stone as far as orthostat 38 (Figure A2.2).

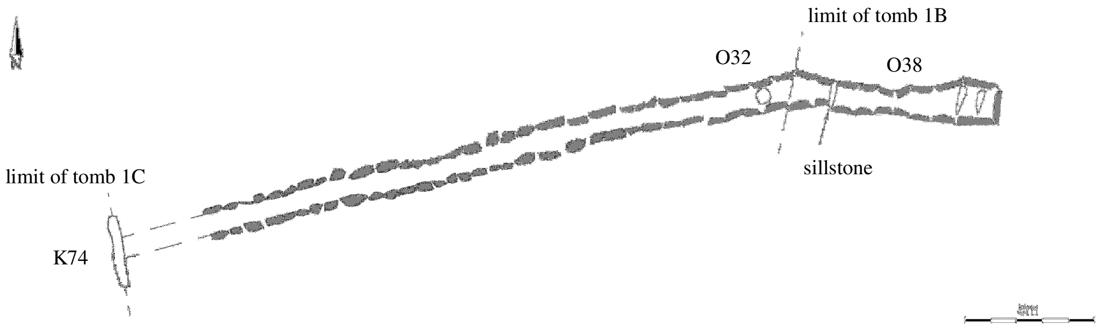

Fig. A2.2: Tomb 1 western passage and chamber
True north is shown on the plan.

At that time, the capstones were removed from the outer section of the passage as part of the conservation works being undertaken in conjunction with the excavation. The earliest reference by Prof. Eogan (1986, 178) to a possible astronomical alignment of the eastern and western passages states "At Knowth, however, the orientation of Tomb 1 suggests that there could have been two ceremonies at different times, the vernal equinox on 20th or 21st March and the autumnal equinox on 21st or 22nd September." Thus, the phenomenon observed by Cummins raised several potentially important questions in relation to the alignment of the western tomb. Was the illumination of the outer passage and part of the inner passage facilitated by the temporary unroofed condition of the outer passage? Could such illumination continue to occur when the capstones and mound material were reinstated? Was the alignment astronomically significant, as is the case for the main passage tomb at Newgrange?

[2] Coordinated Universal Time (UTC) was formerly known as Greenwich Mean Time (GMT).

Given that the observed event had occurred at the autumnal equinox, albeit *circa* one hour before sunset, it was proposed by the authors to determine the precise orientation of the passage and thus investigate any possible astronomical alignment, similar to that claimed for Newgrange (Patrick 1974; Ray and O'Brien 1989). At the request of Prof. Eogan, a survey was undertaken by the authors on the 27th of November 1997 prior to the reinstatement of the capstones and the covering mound material.

A2.2.1 Methodology: western tomb survey

A baseline defined by two ground survey stations was established in the outer passage - the first was located just inside the entrance kerbstone K74 and the second was located at the bend in the passage on its northern side in the vicinity of orthostats 33 / 34 (see Figs A2.1 and A2.2). The baseline closely coincided with the axis of the outer passage over most of its length. The azimuth[3] of the baseline was observed using a gyro-theodolite[4]. Our survey also measured the angular deflection between the outer and inner sections of the passage and this was found to be 19°.4. In addition, the slope of the line from the existing floor level at the bend in the passage to the top of the entrance kerb stone was determined using a theodolite. This provided the necessary lower limit of angular altitude of the visible sector of sky that could be seen from the bend in the passage for use in the computation of astronomical declination[5]. A summary of the survey data and computations is given in Appendix A2.I below.

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[3] Azimuth is the horizontal angular distance measured clockwise from true north to any specified target or object.

[4] A surveying instrument that precisely determines the direction of the local meridian (true north). By measuring the horizontal angle between the meridian direction and the reference baseline, the azimuth or true bearing of that baseline is found.

[5] A celestial object's angular distance north or south of the celestial equator. Declination is one of the two coordinates in the equatorial coordinate system (the other is right ascension and is not relevant to this study). At the equinoxes, the sun's declination is *c*. 0° at any epoch.

A2.2.2 Results and Discussion

Allowing for refraction, we calculated that when Cummins recorded his observations on the 23rd of September 1997 at 18:20 UTC+1, the sun had an azimuth of 258°.0 and an altitude of +8°.3 (Table A2.1). This was very close to the instant of equinox which occurred on the 22nd of September at 23:56 UTC.

Table A2.1: Horizon coordinates for sun at Knowth (W6° 29' 26", N53° 42' 04", Elev. 78m)

Date	Time	Altitude	Azimuth
1997 Sep 23	18:20 UTC+1	8°.3	258°.0

Computed using Multiyear Computer Almanac (U.S. Naval Observatory 2005).

Interpretation of the data in Table A2.1 indicates that when the illumination of the passage was observed by Cummins at the equinox, the sun was about one hour before actual sunset and thus some 12° south of due west and 8°.3 above the horizon. The computed azimuth value agrees well with the passage alignment as determined using the gyro-theodolite (see Appendix A2.I) and is also confirmed by the timed observations provided by Cummins. Significantly, the sector of the sky that is visible from within the passage in the vicinity of orthostats 33 and 34 has a lower angular altitude limit of *c*. +1°. With the capstones in-situ however, the upper angular altitude limit of the visible sector of sky is estimated to be not greater than *c*. +1°.5, thus creating a small aperture in the vertical. Because the altitude of the sun at that date and time was +8°.3, it follows that direct sunlight could not have penetrated anywhere near the sill stone on the 23rd of September 1997 (at the equinox) and instead it seems likely that what was observed was reflected light (e.g. from a pool of water in the passage). Due to the inward leaning of some of the passage orthostats, there is also considerable restriction on the amount of direct light that can enter into the passage. The temporary absence of the capstones however, may well have played a role in allowing direct sunlight to penetrate further up the passage than normal, where it was then reflected beyond the bend.

We found that a small sector of the sky centred on an azimuth of 258° and with altitude limits of between *c*. +1° and +1°.5 could be viewed by an observer positioned anywhere in the outer passage *i.e.* from the entrance kerbstone K74 to orthostats 33 and 34. This area of sky should be visible irrespective of the presence of the capstones. When the setting sun is coincident with this azimuth and altitude (in early March and October) there is, however, a significant horizontal shift in its apparent position by as much as one solar diameter (or 0°.5) per day. Accordingly, there will only be a brief period, occurring twice a year and lasting a day or two at most, when direct light from the setting sun will penetrate as far as orthostats 33 and 34 (see Table A2.2).

From the results of the astronomical survey (see Appendix A2.I), we conclude that neither the outer nor the inner section of the western passage was aligned on the setting sun at the equinoxes. A summary of the results of the computations is presented in Table A2.2 and includes the azimuths, astronomical declinations, and significant dates for the alignment of the inner and outer sections of the western passage.

Table A2.2: Knowth western passage: astronomical declinations and dates for the horizontal and vertical alignment of the passages (inner and outer)

Passage	Azimuth	Altitude	Solar Declination δ	Calendar Dates
Western (outer)	258° 34'	+1° 03′	-6° 12'	March 4 October 9
Western (inner)	278° 14'	+1° 00′	+5° 18'	April 3 September 8

Interpretation of the data in Table A2.2 indicates that the expected equinoctial solar declination of *c*. 0° is not present. Accordingly, the outer passage obviously does not correspond to an equinoctial alignment on the setting sun on the local horizon; instead the setting sun will directly illuminate the outer passage as described above, approximately seventeen days after the autumnal equinox, or equivalently, seventeen days before the vernal equinox. The alignment of the inner section of the western passage (Tomb 1B) is 8° (or 16 solar diameters) north of the direction of sunset at the equinox. The relevant dates are given in Table A2.2.

Note that the change in the tilt (obliquity) of the earth's axis over time has no effect on the direction of sunrise at the equinoxes at any given place and will remain constant. This is in contrast to the effect of obliquity on the direction of sunrise and sunset at the solstices. Consequently, over the 5000 years that have elapsed since Tomb 1 was built, the direction of sunrise at the equinoxes has not changed.

A photographic survey was conducted on the 23rd of September 2008 and the 8th of October 2008 to verify the findings of the above computations. On both dates, the alignment of the western passage was extended outside the tomb with the aid of ranging poles and this provided the observer with an external definition of the passage axis. This simple methodology allowed a visual comparison between the direction of the setting sun and the outer passage alignment. The data provided the additional confirmation that:

- at the equinox (declination $\delta = 0°$), the western passage (outer) is not aligned on the setting sun but is instead aligned on the sun while it is still about 12° (or 24 solar diameters) south of its azimuth at sunset and 8° (or 16 solar diameters) vertically above the horizon (Plate A2.1);
- when the sun is setting on the orientation of the outer passage (Tomb 1C), its declination is -6° 12′ and azimuth is 258° 34′ and therefore the passage orientation has no association with the equinox. This spectacle is, however, visually obscured by the large tree and hedgerow (see Plate A2.2).

On both of the above dates, an observer was also positioned within the passage to confirm that at the equinox, only a few metres of the southern sidewall of the passage nearest the entrance were illuminated. We note also that the calculated lunar declinations for the orientations of the western passage in Table A2.2 indicate a lack of any association with the major standstill positions of the moon.

Plate A2.1: The elevated sun viewed from close to the entrance of the western passage at the equinox (23rd September 2008, 18:50 UTC+1). For a short period of time, only the southern side of the outermost section of the passage is illuminated. By sunset at *c*. 19:20 UTC+1, the sun will have moved significantly to the north (right) in azimuth, decreased in altitude, and is no longer in alignment with the outer passage (Photo: F. Prendergast).

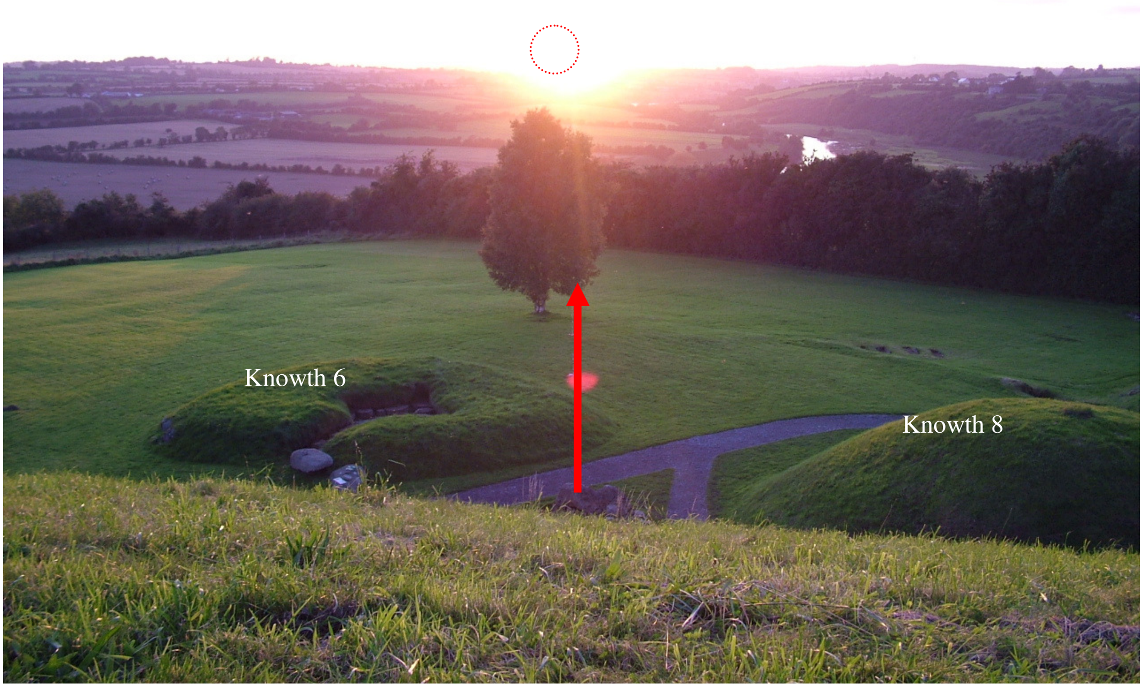

Plate A2.2: The setting sun (seventeen days after the autumnal equinox) on the 8th October 2008 (18:40 UTC+1) as viewed from the mound of Tomb 1C and when aligned with the outer section of the western passage. The extended axis of the western passage (outer) is delineated by ranging poles that are just visible to the left of the arrow, and these coincide with the direction of sunset (Photo: F. Prendergast).

In summary, neither the outer (Tomb 1C) nor the inner (Tomb 1B) sections of the western passage are aligned towards any of the solstitial or equinoctial points on the horizon, although light from the setting sun could penetrate far into the passage on the specific dates as described (the spectacle is blocked by the large tree and high hedgerow to the west of the entrance as illustrated in Plate A2.2). Nor is there any apparent link with the moon at its major standstill positions. Any potential significance of the passage orientation in a wider national context of such tombs is addressed elsewhere by one of the authors (Prendergast 2011).

A2.3 Eastern Chamber and Passage

The construction of Tomb 1C extended the passage alignment of the earlier phase Tomb 1B to its present limit (see Figure A2.1). The bend that is evident in the western passage is not replicated in the morphology of the eastern passage which is comparatively straight and level over its entire length (Figure A2.3).

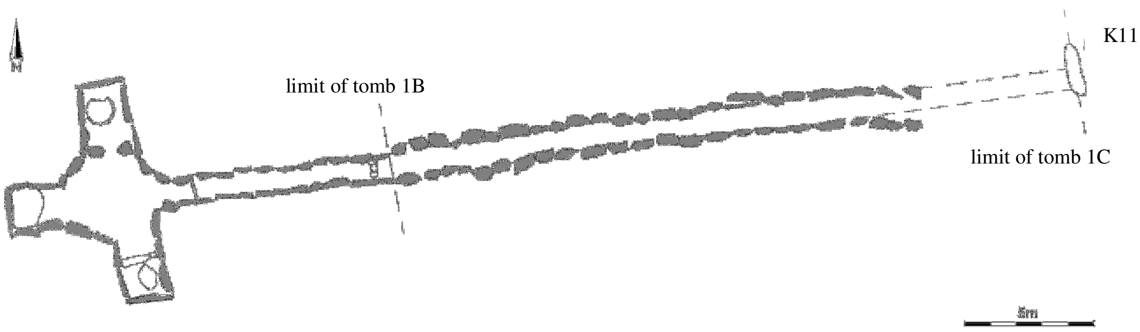

Fig. A2.3: Tomb 1 eastern passage and chamber
True north is shown on the plan.

There are several reasons why we consider it unlikely that a clear view of the horizon and sky would ever have been possible from the burial chamber following the construction of Tomb 1C. The significant increase in the length of the passage - from *c*. 9 m for phase 1B to a total length of *c*. 35 m (including the chamber) following the addition of phase 1C, makes it twice that of the passage at Newgrange 1, and thus even more susceptible to the view being restricted by the irregular profiles of the orthostats forming the passage. The problem is further compounded by the erection of kerbstone 11 which would have considerably narrowed the size of the apparent aperture at the entrance, in a geometric sense. Accordingly, we estimate the angular limits of the apparent aperture to be less than 1°.4 horizontally and significantly less in the vertical, thus making any penetration of the chamber by direct sunlight unlikely. Regardless of these structural changes to the tomb, the alignment of the passage has always remained a key question in relation to the archaeological importance and the wider cultural meaning of the monument and the following section of the report examines this question.

A2.3.1 Methodology: eastern tomb survey

In June 1985, K. Mooney and F. Prendergast undertook a commissioned photogrammetric survey of the corbelled roof of the eastern chamber of Tomb 1 at the request of Prof. Eogan. As part of that process, the azimuth of the central axis of the eastern passage was also measured by gyro-theodolite. The baseline for that task was similarly defined by two ground survey points located in the centre of the passage at its east and west terminals respectively. A summary of the survey data and the computations are given in Table A2.3 and Appendix A2.II.

Table A2.3: Knowth eastern passage: astronomical declinations and dates for the horizontal and vertical alignment of the passage.

Passage	Azimuth	Altitude (based on the slope of the passage floor)	Solar Dec. δ	Assoc. Dates
Eastern	85° 08'	0°	+2° 12'	March 26 September 16

Interpretation of the data in Table 3 indicates that the expected solar declination δ of *c*. 0° for the equinox is not present in the data. Accordingly, the passage obviously does not correspond to an equinoctial alignment on the rising sun.

A2.3.2 Results and discussion

At the equinox, the sun will rise approximately due east, provided the angular altitude of the horizon is 0°. At Knowth, the altitude of the eastern local horizon is about +1°. As a result, the sun would rise a little further to the south of east at the equinox. Consideration of the data in Table A2.3 and Appendix A2.II indicates that the azimuth of the eastern passage is *c*. 85° 08´. Such an alignment is therefore north of east by about 5° and further north again of actual sunrise at the equinox because of the elevated angular altitude of the horizon. This is the equivalent of about 10 solar diameters away from the equinox, *i.e.* six days after the vernal equinox or equivalently six days before the autumnal equinox. In other words, the elevation of the horizon makes our azimuth determination and angular difference even less favourable for an equinox hypothesis for the eastern passage (Prendergast and Ray 2002).

A2.4 Conclusions

It is evident from the literature relating to Tomb 1 that the equinoctial alignment hypothesis for the east and west passages is accepted either as probable or as a *de facto* proven case (e.g. Kelley and Milone 2005, 168-169}. Such acceptance may have been partially driven by the initial suspicions of Prof. Eogan as cited above. Confusion in the literature between magnetic north and true north has compounded this belief. A site survey may be referenced to magnetic north but this needs to be made explicitly clear on the plan. The date on which the survey was done also needs to be given to account for magnetic variation. Over time, the drift in the magnetic pole will alter the relationship between magnetic north and either true or grid north and this can be significant (Moran, 2001; Appendix A2.III). For example, magnetic north was west of true north by 6° 30' in 1997 and this deviation is dynamically changing over time. The same value in 1970, when the first plans for Knowth were published, was *c*. 11° *i.e.* at that time the western passage would have been almost aligned with magnetic west. Currently (2014) it is 3° 48' and decreasing systematically. In addition, true north is west of grid north by a constant 1° 13' for the geographic location of the passage tomb. A clear understanding of the nature of these different north points is therefore a critical issue when attempting to make inferences on an alignment, solely on the basis of information portrayed on an archaeological plan. The recently commissioned survey of the complex by the National Monuments Service of the Office of Public Works, which is orientated with respect to national grid north, will significantly help to remove such ambiguities in the future.

We conclusively demonstrate here that neither of the tombs within the large mound was precisely aligned on the horizon position of the sun at the equinoxes and we have shown that such a phenomenon could not and does not occur. Were such an alignment ever intended by the tomb builders, we would expect to see a much higher precision in the goodness of fit to this astronomical event, given that the apparent daily shift in the azimuth of the rising or setting sun at that time of the year is about one solar diameter. These findings are consistent with wider studies relating to passage tomb alignment, both published and forthcoming, which show little evidence of any specific interest by prehistoric societies in the exact event of equinox. Significantly, amongst the corpus of Irish passage tombs, there are just four instances out of a total of 122 tombs with extant passages that have an apparent alignment on sunrise or sunset at the equinox and this suggests mere chance (Prendergast 2011). In the wider context, extensive research conducted by others on the axial alignment of prehistoric tombs throughout the British Isles and Europe has similarly found little evidence of an interest in the equinox (e.g. Ruggles 1997). The debate is perhaps best summed up by Ruggles (2005, 151) who states "The equinoxes, perhaps more than any other astronomical concept, demonstrate the dangers of applying Western concepts too readily and uncritically in interpreting the material remains of human cultures in the past."

Unlike the winter and summer solstice sunrise and sunset positions - which are discernible, observable and unique astronomical events with proven cultural, agricultural and ritual relevance - the equinoxes *per se* are more a product of historic and modern society's knowledge, understanding and concern with the precise regulation of time and calendars. Arguably, such ideas had little relevance to the agrarian or ceremonial needs of Neolithic people. That argument is not to exclude the possibility that passage alignment towards the east or the west may be reflective of a more generalised but less precise interest in the event (rather than a precise date) of sunrise or sunset at these times of year. Prof. Eogan's assertion of ceremonies being conducted at the site on dates defined by the alignment of the passages may well have credence, but such dates are not those of the equinox. Further research on passage tomb alignment is continuing, and when the above data are incorporated into, and contextualised with, the larger sample of tomb data, new findings and interpretations for the alignments of the east and west passages of Tomb 1 may emerge and be offered in due course.

References

Eogan, G. (1986) *Knowth and the passage-tombs of Ireland*. London: Thames and Hudson.

Eogan, G. (1998) 'Knowth before Knowth'. *Antiquity*, 72 (275): 162-72.

Kelley, D. H. & Milone, E. F. (2005) *Exploring ancient skies : an encyclopedic survey of archaeoastronomy*. New York; London: Springer.

Moran, E. (2001) The Secular Variation of Magnetic Declination in Ireland. Valentia Observatory: *Met Éireann (The Irish Meteorological Service).*

Patrick, J. (1974) 'Midwinter sunrise at Newgrange'. *Nature*, 249: 517-19.

Prendergast, F. (2011) Linked Landscapes: *Spatial, Archaeoastronomical and Social Network Analysis of the Irish Passage Tomb Tradition*. PhD Thesis. University College Dublin.

Prendergast, F. & Ray, T. (2002) 'Ancient astronomical alignments: fact or fiction?' *Archaeology Ireland*, 16:2 (60): 32-35.

Ray, T. P. & O'Brien, T. (1989) 'The winter solstice phenomenon at Newgrange, Ireland: accident or design?' *Nature*, (342): 958.

Ruggles, C. N. (1997) 'Whose Equinox?' *Archaeoastronomy 22 (supplement to Journal for the History of Astronomy)*, 28: S45-S50.

Ruggles, C. N. (2005) *Ancient astronomy: an encyclopedia of cosmologies and myth*. Santa Barbara, Calif. ; Oxford: ABC Clio.

Stout, G. (2002) *Newgrange and the Bend of the Boyne*. Cork: Cork University Press.

U.S. Naval Observatory (2005) *Multiyear interactive computer almanac, 1800—2050*. Richmond, Va.: Willmann-Bell.

Waddell, J. (1998) *The prehistoric archaeology of Ireland*. Galway: Galway University Press.

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APPENDIX A2.I

Western passage survey data by F. Prendergast and T. Ray

Azimuth survey determined with Wild GAK1 Gyro-theodolite using the reversals method.
Survey Date: 1997, November 27th

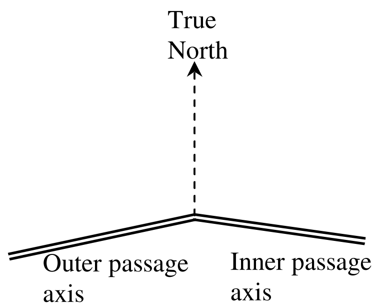
Gyro Left Reversal	Gyro Right Reversal	Gyro Mean Centre (U)	Baseline (face left)	Baseline (face right)	Baseline (Mean)
118° 16'			205° 47'	25° 46'	205° 47'
	136° 04'	127° 13'			
118° 27'		127° 13'			
	135° 54'				

Azimuth of Baseline = Baseline (mean) – U (Mean) = 205° 47' – 127° 13' = 78° 34'

Outer Passage Azimuth (inwards) 78° 34'
Outer Passage Azimuth (outwards) 258° 34'

Angle of bend in passage 199° 40' (clockwise exterior)
160° 20' (clockwise interior)
Deflection angle of passage 19° 40'

Inner Passage Azimuth (inwards) 98° 14'
Inner Passage Azimuth (outwards) 278° 14'



Inclination Survey

Height of Floor inside Kerb	0.00 m (an assumed datum)
Height of Floor @ bend in Passage	0.72 m (not true floor)
Height of top of Kerb Stone	1.21 m
Distance from Kerb to Bend	26.7 m

Vertical angle from floor at bend in passage to top of entrance kerb stone +1° 03'

APPENDIX A2.II

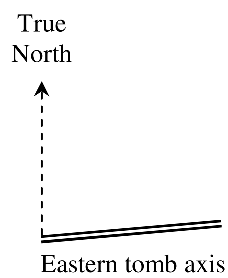
Eastern passage survey by F. Prendergast

Azimuth survey determined with Wild GAK1 Gyro-theodolite using the reversals method.
Survey Date: 1985 June 24th

Left Reversal	Right Reversal	Mean Centre (U)	Baseline (face left)	Baseline (face right)	Baseline (Mean)
315° 20'			45° 30'	225° 29'	45° 30'
	325° 22'	320° 22'			
315° 23'					

Azimuth of Baseline = RO (mean) – U (Mean) = 45° 30' – 320° 22' = 85° 08'

Eastern Passage Azimuth (out) 85° 08'



APPENDIX A2.III

The magnitudes and relationships between Magnetic North, Projection (or Grid) North and True North at Knowth

A. Magnetic Declination (D)

Absolute values of magnetic declination (D) *i.e.* the angular difference between true and magnetic north are computed from linear equation [1] supplied by Moran (2001) for Ireland and for epoch 2001.

$$D_{2001}(\phi, \lambda) = 11.81 - 0.281\phi + 0.455\lambda \qquad [1].$$

Here, φ and λ are latitude and longitude of the position, respectively. Extrapolation back in time (to 1980) with negligible error can be done using a second equation from Moran (2001). In particular, the annual change in D (expressed in arc minutes) is dD/dt, computed from linear equation [2] where

$$\frac{dD(\phi, \lambda)}{dt} = 5.247 + 0.059\phi - 0.147\lambda \qquad [2].$$

For the latitude and longitude of Knowth I, and by combining equations [1] and [2] we obtain the magnetic declination for the epoch of the survey of the western tomb as:

$$D_{\text{January 1997}} = -6° \ 30'.$$

B. Meridian Convergence (C)

The relationship between true north and grid north is obtained from equation [3]:

$$C \approx \Delta\lambda \times \sin\phi \qquad [3].$$

where $\Delta\lambda$ is the longitude difference between the central meridian (at 8° West for the Irish Transverse Mercator map projection) and the longitude of the site. For Knowth 1, C = 1° 13'.

Relationship between True North, Magnetic North and Grid North

Adopting Grid North as the vertical on the map (this is the convention), both True North and Magnetic North are left (west) of Grid North by the angular amounts already computed. This is visualised below but not drawn to scale for diagrammatic clarity.