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A NEW STUDY OF ALL MEGALITHIC LUNAR LINES

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Introduction

In 1978 we published a paper in this *Journal* in which, by using strict terms of reference, we showed that there was a high probability that Megalithic Man had really observed the Moon and the wobble of its orbit.[1] We have several times expressed surprise at the accuracy with which the stones were set,[2] and we stated that we could not explain this. Accordingly we decided to try to find out just how these people worked. For this we needed as many observations as possible and so we discarded the strict terms of reference in the 1978 paper and decided to use all reliable lines: that is, all lines which had been reliably measured.

We propose to compare each measured declination with the expected value and then to make a study of the residuals. To do this we deduct from the measured declination the value of $(\epsilon \pm i)$ and so are left with an angle which should be near one of the values of $\pm\Delta\pm s$. We have in several publications[3] plotted a histogram of these values but L. V. Morrison of the Royal Greenwich Observatory about a year ago explained to us it would be much more satisfactory to open this histogram up into four different parts corresponding to the north and south declination at each standstill, and this we have now done (see Figure 2 below).

The whole process depends on the assumption which we have in fact shown to be correct: namely, that the backsights were placed with an accuracy of a few arc minutes. We must obviously include only lines of which the altitude and azimuth are known with this kind of accuracy.

A value for ϵ, the obliquity of the ecliptic, is needed; but this varies slowly with time and so, since archaeologists cannot give us exact dates for the sites, we must determine ϵ from the observations themselves. It is unlikely that all the sites were erected at the same time and so this perhaps produces some errors.

The Expected Declination

The monthly maxima of the Moon's declination go through a cycle from $(\epsilon+i)$ to $(\epsilon-i)$ and back in 18·6 years. In Figure 1 the curved chain-dotted lines show diagrammatically the locus of the monthly declination maxima, had there been no wobble of the orbit; and the large dots show the actual peaks at the monthly declination maxima. The curve joining these latter dots comes itself to a maximum about every 173 days. As the major standstill approached, the observers watched the gradual increase of the declination peaks and so it was natural for them to record the maximum at M (Figure 1). Similarly, for the negative declination they tended to use the minimum at M_1. At the minor standstill on the other hand they had been watching the gradual decrease in the declination hollows, and so we assume that they tended to mark the lowest at N. Similarly, for the negative case we assume they tended to use N_1.

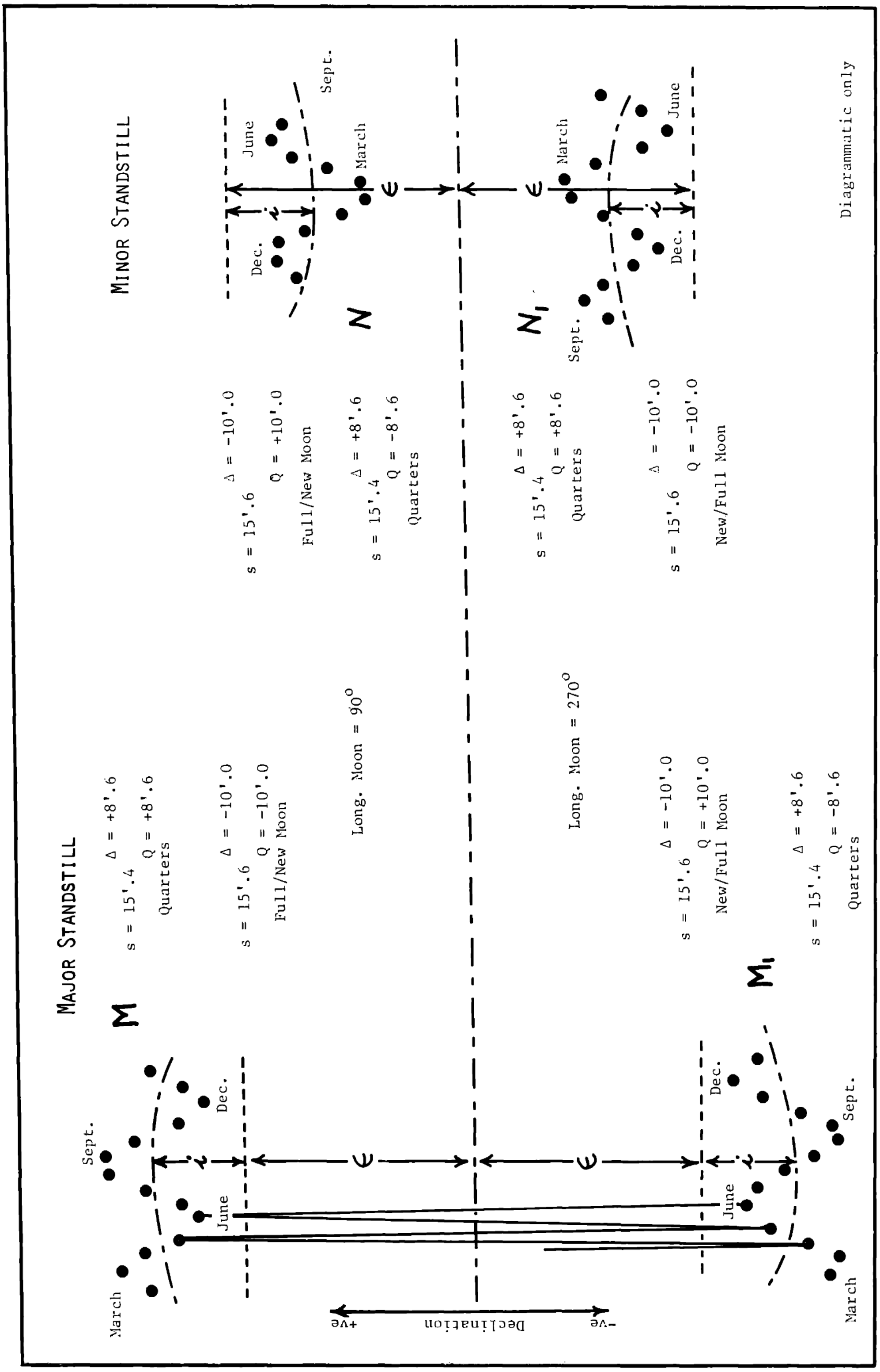

FIG. 1. Conditions at the standstills. Note that the Major and Minor Standstills are 9·3 years apart. that Δ applies to i, and that Q applies to declination.

The Perturbation

We have gone through our published books and papers and found clear indication that Megalithic Man had worked to the above rules, but the material is mixed up with those cases where by taking the mean of the solstitial and equinoctial values, in other words the mean of the top and bottom of the perturbation wobble, he recorded a value which was close to $\pm(\epsilon \pm i)$.

The perturbation values Δ have in Figure 1 the correct signs attached so that they apply to i, the inclination of the lunar orbit. These values of Δ have been calculated from

$$\Delta = 519'' \cos 2(\lambda' - \Omega) - 42'' \cos 2(\lambda - \lambda') + 39'' \cos 2(\lambda - \Omega)$$

where λ = longitude of the Moon

λ' = longitude of the Sun

and Ω = longitude of the node.

At the standstills at the equinoxes we thus find the Moon at first or third quarter with $\Delta = 8'{\cdot}6$ and at the solstices the full or new Moon with $\Delta = -10'{\cdot}0$. The above formula and values differ slightly from the values given in our book *Megalithic remains in Britain and Brittany* and were provided by L. V. Morrison. He also told us that the mean values of the horizontal parallax and semi-diameter to be used are:

56′·4 and 15′·4 at the equinoxes, and

57′·4 and 15′·6 at the solstices.

The method of finding the time of year of the phenomenon and the times of day when the Moon is on the horizon will be found in our book or in an earlier article in this *Journal*.[4] It should be remembered that at the equinoxes the major standstill occurs when the Moon is near first or third quarter and at the solstices when it is nearly new or full. Much information is contained in Figure 1 and it is recommended that this figure be studied in detail by a reader wishing to understand what comes later.

Observed Declination δ_0

We calculated again the observed declinations δ_0 starting with the azimuths and altitudes as previously published, taking the appropriate time when finding refraction and using the above mean parallax values (see Table 1, column 2). We used all the known British sites, except a few which we considered to be unreliable in that they had not been measured with sufficient accuracy. Also we omitted all sites where the position of the backsight was not accurately known. Into this latter category go Stonehenge, Haggstone Moor and Callanish V looking north. (At Stonehenge the backsight might be at one of "the stations" or at the centre.) Perhaps we should have omitted the Brogar lines to Ravie Hill as this is a small notch, low down on the horizon. We could also have removed Callanish I but we considered that the foresight to the *top of Clisham* was possibly accurately enough known from the 1-inch Ordnance Survey. All other sites dependent on the contours of this survey have been omitted except Blakeley Moss and Parc-y-Meirw. (For the latter however it must be pointed out that with such a large negative altitude, refraction is uncertain.) The 6-inch Ordnance Survey maps for the north part of the Outer Hebrides are contoured at 25ft intervals and so the mountains at the top of Loch Seaforth are also contoured

TABLE 1.

Site	δ_0	Nominal δ	Assumption 1 Q	ε 23°	β	R= |β-Q|	Assumption 2 Q	R= |β-Q|	Ref.
Brogar									
JK	-18°44'.1	-(ε-i)	- 0'.7	52'.1	+ 0'.3	1'.0	- 1'.0	1'.3	MRBB
M	-18 59.2	-(ε-i+s)	-16.2	51.7	-14.8	1.4	-16.5	1.7	MRBB
Comet	-18 50.3	-(ε-i-Δ+s)	- 6.8	52.2	- 5.9	0.9	- 7.4	1.5	MRBB
MLJ	-18 20.1	-(ε-i-Δ-s)	+24.0	52.8	+24.3	0.3	+23.4	0.9	MRBB
Kame 1	+29 24.3	+(ε+i+Δ+s)	+24.0	51.6	+22.5	1.5	+23.4	0.9	MRBB
Kame u	+29 24.8	+(ε+i+Δ+s)	+24.0	52.1	+23.0	1.0	+23.4	0.4	MRBB
L	-18 50.9	-(ε-i-Δ+s)	- 6.8	52.8	- 6.5	0.3	- 7.4	0.9	MRBB
Ravie Hill, Comet	+28 48.2	+(ε+i-s)	-16.2	55.7	-13.6	2.6	-16.5	2.9	MRBB
Ravie Hill, H	+28 52.3	+(ε+i+Δ-s)	- 6.8	50.4	- 9.5	2.7	- 7.4	2.1	MRBB
Stenness	+19 08.0	+(ε-i+Δ+s)	+25.6	51.1	+23.6	2.0	+26.2	2.6	MRBB
Callanish I	-29 12.8	-(ε+i+Δ)	- 8.6	55.5	-11.0	2.4	- 8.0	3.0	MLO H 1/1
Callanish V	-28 35.4	-(ε+i-Δ-s)	+25.6	52.3	+26.4	0.8	+26.2	0.2	MLO H 1/5
Mid Clyth A_1	-29 09.2	-(ε+i+Δ)	- 8.6	51.9	- 7.4	1.2	- 8.0	0.6	MLO N 1/1
Mid Clyth A_2	-29 27.1	-(ε+i+Δ+s)	-24.0	54.4	-25.3	1.3	-23.4	1.9	MLO N 1/1
Wormadale Hill	-29 09.5	-(ε+i-Δ+s)	- 8.6	52.2	- 7.7	0.9	- 8.0	0.3	MRBB
Ballinaby	+29 16.8	+(ε+i+s)	+14.8	53.3	+15.0	0.2	+14.5	0.5	MRBB
Ballinaby	+29 25.6	+(ε+i+Δ+s)	+24.0	52.9	+23.8	0.2	+23.4	0.4	MRBB
Kintraw	-18 20.9	-(ε-i-Δ-s)	+24.0	53.6	+23.5	0.5	+23.4	0.1	MLO A 2/5
Temple Wood S_1A_1	+28 55.4	+(ε+i+Δ-s)	- 6.8	53.5	- 6.4	0.4	- 7.4	1.0	MLO A 2/8
Temple Wood $S_{54}A_1$	+29·18.1	+(ε+i+s)	+14.8	54.6	+16.3	1.5	+14.5	1.8	MLO A 2/8
Temple Wood Q A_1	+29 01.5	+(ε+i)	- 0.7	53.5	- 0.3	0.4	- 1.0	0.7	MLO A 2/8
Temple Wood A_2	-28 48.3	-(ε+i-s)	+16.2	55.8	+13.5	2.7	+16.5	3.0	MLO A 2/8
Ballymeanach A_1	+29 12.8	+(ε+i+Δ)	+ 8.6	55.5	+11.0	2.4	+ 8.0	3.0	MLO A 2/12
Ballymeanach A_2	+29 27.7	+(ε+i+Δ+s)	+24.0	55.0	+25.9	1.9	+23.4	2.5	MLO A 2/12
Dunadd	+29 16.4	+(ε+i+s)	+14.8	52.9	+14.6	0.2	+14.5	0.1	MLO A 2/13
High Park A_1	-29 27.7	-(ε+i+Δ+s)	-24.0	55.0	-25.9	1.9	-23.4	2.5	MLO A 4/2
High Park A_2	-28 46.3	-(ε+i-s)	+16.2	53.8	+15.5	0.7	+16.5	1.0	MLO A 4/2
Skipness	-29 24.4	-(ε+i+Δ+s)	-24.0	51.7	-22.6	1.4	-23.4	0.8	AA 1
Beacharr	+29 11.1	+(ε+i-Δ+s)	+ 8.6	53.8	+ 9.3	0.7	+ 8.0	1.3	MLO A 4/5
Crois Mhic-Aoida	-28 37.2	-(ε+i-Δ-s)	+25.6	54.1	+24.6	1.0	+26.2	1.6	MLO A 4/9
Campbelltown	-28 44.8	-(ε+i-s)	+16.2	52.3	+17.0	0.8	+16.5	0.5	MLO A 4/14
Campbelltown	-28 54.9	-(ε+i+Δ-s)	+ 6.8	53.0	+ 6.8	0.0	+ 7.4	0.6	MLO A 4/14
Knockstaple	+28 52.5	+(ε+i+Δ-s)	- 6.8	50.6	- 9.3	2.5	- 7.4	1.9	MLO A 4/19
Gigha	+29 25.7	+(ε+i+Δ+s)	+24.0	53.0	+23.9	0.1	+23.4	0.5	MLO A 4/17
Dunskeig	-19 00.0	-(ε-i+s)	-16.2	52.5	-15.6	0.6	-16.5	0.9	JHA
Knockrome	-29 27.0	-(ε+i+Δ+s)	-24.0	54.3	-25.2	1.2	-23.4	1.8	MLO A 6/4
Stillaig	+28 53.4	+(ε+i+Δ-s)	- 6.8	51.5	- 8.4	1.6	- 7.4	1.0	MLO A 10/5
Glen Prosen	-28 55.1	-(ε+i+Δ-s)	+ 6.8	53.2	+ 6.7	0.1	+ 7.4	0.7	MLO P 3/1
Lundin Links	-18 59.7	-(ε-i+s)	-16.2	52.2	-15.3	0.9	-16.5	1.2	MLO P 4/1
Fowlis Wester	+29 17.0	+(ε+i+s)	+14.8	53.5	+15.2	0.4	+14.5	0.7	MLO P 1/10
Parc y Meirw	+18 19.6	+(ε-i-Δ-s)	-24.0	52.3	-24.8	0.8	-23.4	1.4	MLO W 9/7
Blakeley Moss	+28 45.8	+(ε+i-s)	-16.2	53.3	-16.0	0.2	-16.5	0.5	MLO L 1/16

MRBB: *Megalithic remains in Britain and Brittany* (see ref. 2).
MLO: *Megalithic lunar observatories* (see ref. 3).
AA 1: *Archaeoastronomy* (supplement to *JHA*), no. 1 (1979).
JHA: "A Reconsideration of the Lunar Sites in Britain", *JHA*, ix (1978), 172-3.

$\beta = \delta_0-(\varepsilon\pm i)$; $Q = \delta_e-(\varepsilon\pm i)$, where δ_e is the nominal or expected declination; R is the residual and equals β-Q irrespective of sign; r is the r.m.s. of R; ε (for example) for major standstill and positive declination is given by $\varepsilon = \delta_0-i-Q$. Mean i = 5°8'.7.

From the above 42 values of β, r = 1'.34 for Assumption 1 and 1'.53 for Assumption 2. In Assumption 1 the observers had determined their position over a span of about 179 years; for this c_s would be zero (first seven columns). In Assumption 2 the observers had determined the position of the stone from *one* standstill. For this c_s may be 0'.3 or 0'.6 (columns 8 and 9; see also text). The broad-shafted (0'.6) and narrow-shafted arrows (0'.3) in Fig. 2 purport to show to scale the corrections involved.

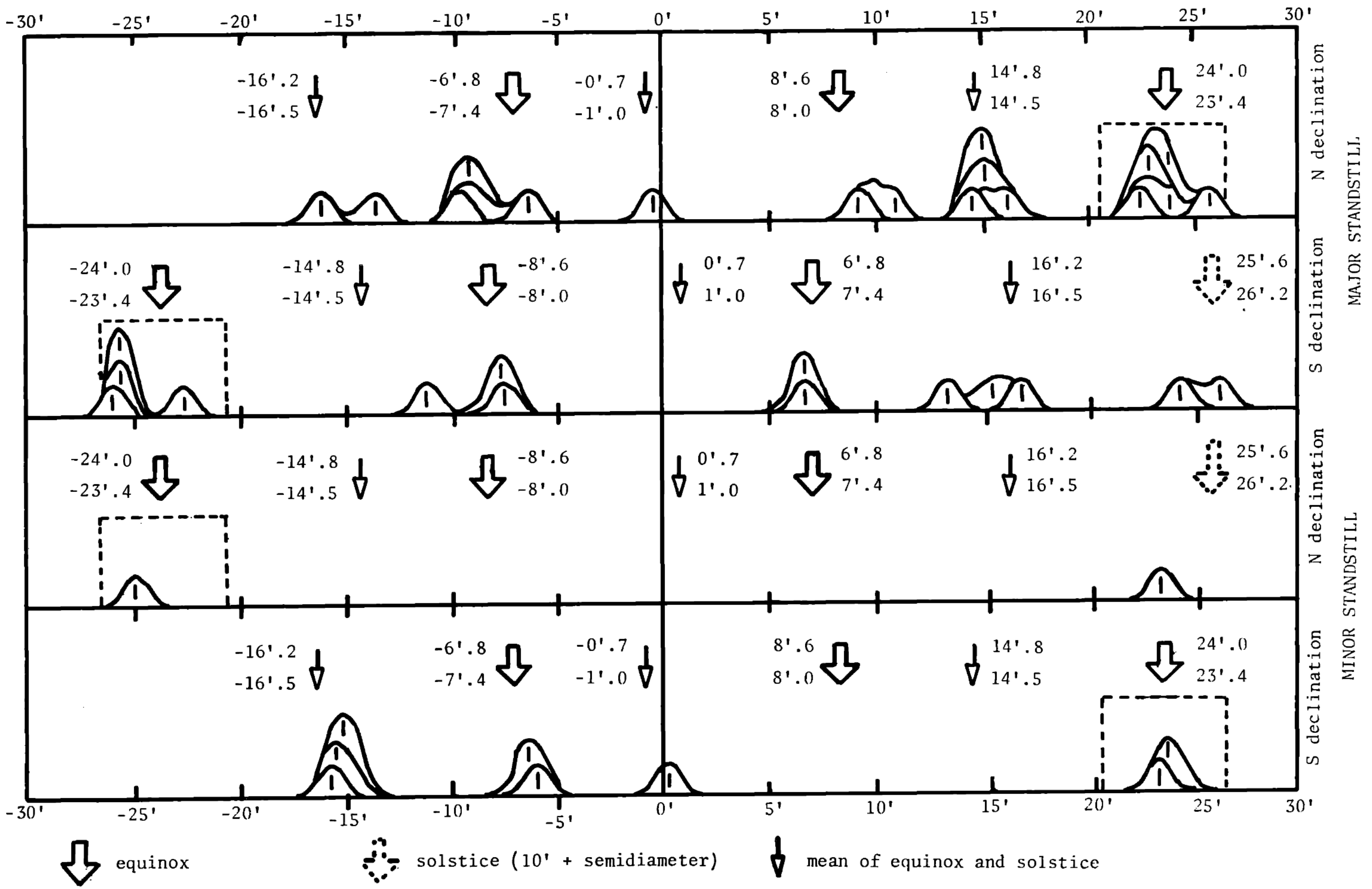

FIG. 2. Four histograms of β values, where $\beta = \delta - (\epsilon \pm i)$; the expected values of β, namely Q, are shown by arrows as in the key. Of the pairs of numbers beside each arrow, the upper shows Q for $c_s = 0$; the lower shows Q for $c_s = 0'{\cdot}6$ (equinoctial or solstitial values) or for $c_s = 0'{\cdot}3$ (mean of equinoctial and solstitial values) for $(\epsilon \pm i)$ cases.

at this interval. Accordingly we assumed that the values shown for Callanish V looking south in our book *Megalithic lunar observatories*[5] are correct. G. R. Curtis has sent us, in a private communication, his recent survey of the site at Callanish V and from this it appears that the two top stones in the row point to Mhor Monach. We are thus able to use the details for this hill, but there does not seem to be any definite backsight to be used for looking north as suggested in *Megalithic remains in Britain and Brittany*.[6]

Histogram of β and Evaluation of ϵ

In order to plot the final histogram shown in Figure 2 we must find β, which is defined as

$$\beta = \delta_0 - (\epsilon \pm i). \qquad (1)$$

Thus β is the angle by which the observed declination δ_0 is above the top of the chain-dotted curve in Figure 1. δ_0 is the declination obtained from the measured azimuth and altitude and i is the mean inclination of the Moon's orbit to the ecliptic. Mean i remains constant over the centuries; we propose to use the mean obliquity of the ecliptic ϵ as found from the observations themselves.

Let Q be the 'expected' value of β from Figure 1. Since *ideally*

$$Q = \beta = \delta_0 - (\epsilon \pm i)$$

we can write for the value of ϵ obtained from a single observation line,

$$\epsilon = \delta_0 \pm i - Q. \qquad (2)$$

Taking Q from Figure 2 we thus find a value for ϵ from every observation. Let the mean value of ϵ from the positive declinations be ϵ_N and that from the negative declinations be ϵ_S. The value of the graze, or if we have already used a graze, the correction to this, is then given by $\frac{1}{2}(\epsilon_S - \epsilon_N)$. If this correction is more than a small fraction of a minute then we adjust the mean graze and do the whole calculation again. ('Graze' is the extra bend experienced by a ray when it passes over a ridge, especially in the hours of darkness. We assume that the graze effect occurs from one hour before sunset to one hour after sunrise, but this may not be exact.)

An increase in altitude numerically raises north declinations but lowers south declinations. Since the value of ϵ depends on the numerical value of the declination it is evident that the mean ϵ will not be affected by errors in altitude provided these are always of the same sign. The difference between the two values of ϵ is twice the error in the altitudes. Since graze leads to an error in altitude, this allows the mean graze to be determined. The graze will include any error that is introduced due to the fact that we have not allowed for the sagitta of the sector of the Moon's limb which had to show above the horizon before it could be recorded by the observers. The sagitta effect and the graze are of opposite sign but it is not possible to separate them unless we make actual experiments in the field. For our present purposes, however, this is not necessary. We take the mean value of ϵ, which is $23°53'\cdot1$, but we should bear in mind that the observatories were probably not all erected at the same time and so the actual value of ϵ may vary and this introduces another possibility of error.

With the values found by using the adjusted graze we now repeated the whole calculation for each of the observed declinations. β was then obtained for each line from Equation (1). Part of the procedure is shown in Table 2 of our 1978 article.[7]

The theoretical values of Q are shown by the broad arrows in Figure 2. The values for the Moon's centre are taken from Figure 1; those for the upper and lower limbs are obtained by application of the semi-diameter ($s = 15'\cdot4$ at the equinoxes and $15'\cdot6$ at the solstices). Note that in Figure 2 the values of Q occur in groups of three, that is, one for the Moon's centre and one for each limb.

Observed Values of β near Zero

It will be seen in Figure 2 that there are observed values of β also near zero, s and $-s$. These correspond to the values of declination at the mid-point between the top and bottom of the wobble shown in Figure 1. In Table 1 there are fourteen examples of this kind of site and since in each case the erectors must have used a mean position between the solstitial and equinoctial positions we might expect this method to yield more accurate positions than the others. In fact the 'root mean square' of the discrepancy for the fourteen examples is $1'\cdot19$. As we shall see later, this is the lowest we have found. We know of no method whereby Megalithic Man could have determined the backsight locations consistent with these values other than by placing stakes in the ground midway between the positions found at the standstill adjacent to the equinox and at that at the solstice. Hence for these values we used for Q at the major standstill, positive declination, $Q = \frac{1}{2}(8\cdot6-10\cdot0) = -0\cdot7$ (see Figures 1 and 2). (The expected Q values must be used of course with the appropriate sign.) Also, in calculating δ_0 and β for these cases we used the mean value for the refraction, *i.e.*, the mean of the solstitial and equinoctial values.

Clustering of β Values Round Expected Q Values; Low Probability Level

The first thing to notice about the histograms in Figure 2 is the manner in which the β values cluster round the *expected* values, that is, the Q values. In order to show how really closely these follow the Q values let us make a crude estimate of the probability level. In our book *Megalithic sites in Britain* we have described in detail Broadbent's method of dealing with uniformly spaced 'nodes'. Note first that in Figure 2 the Q values (the 'nodes') are *roughly* uniformly spaced. (Any inequality of spacing should have but little effect on the following estimate.) *Using Broadbent's notation,* the spacing 2δ is equal to about 8 arc minutes. Using R for the residual error in each case, the 'lumped variance' is $S^2 = 1/n \cdot (\Sigma R^2)$ where n is the number of observations (42) and $R = \beta - Q$. The square root, or what we call here the 'root mean square' (r.m.s.), is 1·51 at most and it goes as low as 1·3 (see Table 2). So we find S^2/δ^2 to be about 0·14. Using Fig. 2.1 of *Megalithic sites in Britain* we find the probability level to be so small that it is off the figure and is perhaps about 0·01 per cent or 1/10,000. This very low value shows how far the β values are from being randomly distributed on the histogram. Looking at the way in which the values are grouped, the result is not surprising.

Rising v. Setting Lines

There is another point that strengthens the case that we are dealing with intended observing positions. It is obviously much easier to observe the setting Moon than the rising. The setting Moon can be followed along the horizon until it vanishes, whereas the rising Moon appears suddenly. To overcome this at Brogar, Megalithic Man erected special mounds (Salt Knowe and mound A[8]), so that a watcher could be placed to give a warning to the observers below that the Moon was about to emerge. Similarly the special row of boulders on the hill behind Mid Clyth served the same purpose. Nevertheless the setting Moon was preferred. Witness that we find in the list used here that there are twenty-eight setting and only fourteen rising examples. If we discount the remote possibility that these figures are the result of chance (about one in forty-five) then we must accept the lunar hypothesis.

Another Indication

We have described already how Megalithic Man probably preferred to observe the extreme values at M, M_1, N and N_1 (Figure 1). This is reflected in the manner in which we get clumps on the histogram at the extreme declinations. We have surrounded these positions in Figure 2 by rectangles of arbitrary width 6′, placed in each case at the correct Q position.

Lunar Declinations at Solstice

We might mention here that there are only three alignments which show *directly* the lunar declinations at the solstices. These are Callanish V, Stenness and Crois Mhic Aoida (McKie's Cross), none of which is a particularly impressive site. The upper limb values of Q for these are shown in Figure 2 by *dotted* broad arrows at $Q = s+\Delta = 15{\cdot}6+10 = 25{\cdot}6$. As we cannot simply ignore these, all three are retained.

We have made no attempt to show the other combinations of Δ and s for the solstitial cases. They would complicate Figure 2 unnecessarily, and even if we attributed the β values in their vicinity to them the probability level would still be low.

It has to be remembered that at the summer solstice in Scotland there is no real darkness and that at the winter solstice the observing conditions must often have been very uncomfortable.

Evaluation of the Residual $R = \beta - Q$; the c Correction

We wish to evaluate $(\beta - Q)$ but before we can do this it is in some cases necessary to apply certain corrections to Q. The period of the wobble in Figure 1 is about 173 days and so at any particular standstill the highest declination shown by the large dots (Figure 1) may occur any time between zero and eighty-six days before or after the top of the chain-dotted curve. As the wobble follows the chain-dotted curve any maximum observation, for example, will in general be lower than the ideal $(\epsilon+i+\Delta)$ (Figure 1). Unless we know the date we cannot tell how far the observation was from the top of the chain-dotted curve, and so we cannot calculate the amount by which the declination was low. We can only apply a mean correction (a mean over the eighty-six days) and we showed in *Megalithic remains in Britain and Brittany*[9] that the appropriate *mean* deduction from Q is about $c_1 = 0'{\cdot}3$. Similarly, looking at the large dots in Figure 1 we see that the highest may be as much as half a lunation before or after the top of the wobble. The mean correction c_2 for this happens also to be

TABLE 2. Collected results of calculations under various assumptions regarding conditions and the graze.

Case	Condition assumed	c_s	ε from N declination	ε from S declination	ε mean	Graze found	r = r.m.s. R
1	Mean of day and dark	0'	23°53'.0	23°53'.2	23°53'.1	-0'.5	1'.34
2	Mean of day and dark	appropriate c_s	←	see Table 1	→		1'.53
3	Dark	0'	23°52'.6	23°53'.3	23°53'.0	-0'.2	
4	Dark	0'					1'.41
5	Dark	appropriate c_s	23°53'.09	23°53'.14	23°53'.1	-0'.2	1'.55

about $c_2 = 0'{\cdot}3$, but when we are taking the mean of the top and bottom of the wobble, c_2 cancels itself leaving the total correction, which we shall call c_s, with a value equal to c_1. Thus we write

$$\text{total corrections} = c_s = c_1 + c_2$$

where c_2 may be zero in cases when we are taking the mean between the top and bottom of the wobble. For the maximum positive declination at the major standstill, for example, we must subtract c_s from the Q values already mentioned, before we can compare the results with the observed β values. This is because if the observers erected each backsight as a result of an observation made at a single standstill, we could expect the resulting declination to be, *on the average*, low by c_s. However, if the determinations of the positions of the backsights were spread over a number of standstills then correction c_s is not appropriate because the erectors would probably have used, for example, at M the maximum of the values obtained from the various standstills. One of the objects of the present paper is to find out if this method of observing was used and so we shall try both with and without the above c correction.

In Table 2 we summarize the results of repeating several times the whole calculation shown in Table I using in each instance the graze found and the appropriate value of refraction. If we look at Table 2 of our 1978 paper,[10] we see that there are always two dates in the year when the observation might have been made, namely in March or September (or June or December). Usually, for instance, either in March or September the Moon was on the foresight in darkness, and six months later was again on the foresight in daylight. We shall first of all assume that both of these could be observed and so we call this case "day and dark". In Table 2, case 1, we make the assumption that c_s is zero and the graze $-0'{\cdot}6$. We then find eventually that the half difference between ϵ from the south declination and that from the north is $+0'{\cdot}1$, so the graze assumed as $-0'{\cdot}6$ becomes $-0'{\cdot}5$. We assume here that $\partial\delta/\partial h$ is approximately unity. At the same time we find r, the root mean square of R, equal to $1'{\cdot}34$. (The calculation will be found in the first seven columns of Table 1.) Now consider case 2. Here we do not make the assumption that c_s is zero but use the value appropriate to a single observation, which would have resulted had each backsight been placed following a single observation, as opposed to the maximum of several observations. The calculation will be found in columns 8 and 9 of Table 1, yielding the final value of r of $1'{\cdot}53$.

In the next three cases, 3, 4 and 5 (see Table 2), we entirely neglect possible observations when the Moon was on the foresight in daylight and use only the dark condition. In case 3 we find that the graze was $-0'{\cdot}2$. We use this in case 4 and find $r = 1'{\cdot}41$. Case 5 shows the same calculation but with the value of c_s appropriate to a single observation. Again we find the graze $-0'{\cdot}2$ but r has risen to $1'{\cdot}55$. We thus see that in both comparisons the value of the r.m.s. residual is lowest when c_s is assumed zero.

In both comparisons made above we get a lower (albeit by a small amount) deviation with correction $c_s = 0$. If this means anything it shows that each backsight was not erected following observations made at one standstill, but that the work at each was spread over a number of standstills, perhaps as many as ten. The evidence is obviously *very* slight, so fortunately there is another method of showing the same thing and this we shall now describe.

Adjustments to β over 179 Years

We have shown in our books[11] the peculiar manner in which the parallax at the standstill is subject to a sinusoidal oscillation of period 179 years and amplitude about 3′. This is borne out by calculations made by A. T. Sinclair of the Royal Greenwich Observatory. We give an example in Figure 3 chosen from sixteen possibilities. Five other examples can be found in our earlier books. Before being plotted, Sinclair's results were adjusted so that they were ready for comparison with the Moon's declinations. If we assume that the values are evenly scattered along a sinusoidal curve with amplitude b then the r.m.s. value is about

$$\left\{\frac{1}{2\pi}\int_{o}^{2\pi}(b\sin\theta)^2 d\theta\right\}^{\frac{1}{2}}.$$

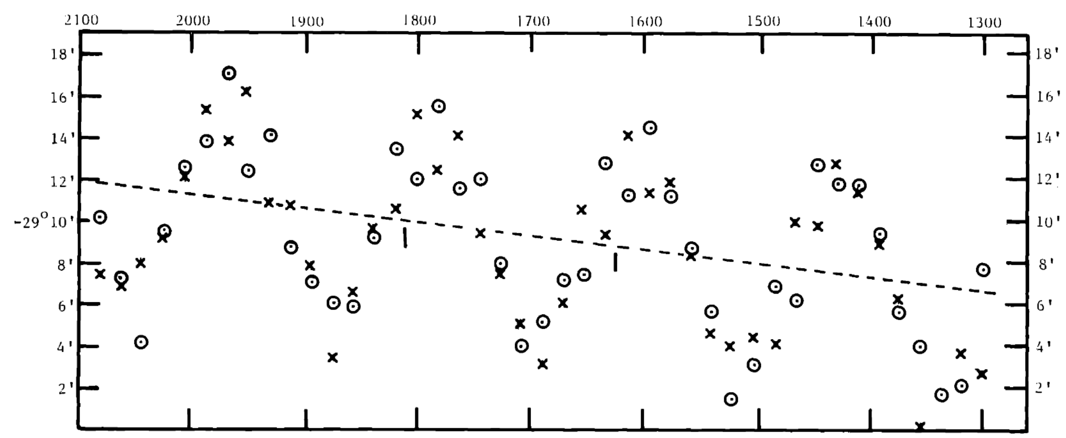

FIG. 3. Calculated lunar declinations at standstills over the period 2100–1300 B.C. Values deduced from Greenwich calculations of declination and parallax so as to be ready for direct comparison with observed declination obtained by using parallax of $57'{\cdot}0$ (see *Megalithic remains in Britain and Brittany*, para. 2.6). Crosses indicate spring and circled dots autumn. The dotted line shows how $-(\epsilon+i-\Delta+s)$ decreases numerically at about 39″ per century. The figure is for use at Wormadale Hill.

This has a value of $b/\sqrt{2}$, and so if $b = 3'$ it becomes $2'\cdot12$. If however we add up the squares of the deviations of twenty points in Figure 3 between 1800 and 1630 B.C. we obtain a r.m.s. of about $3'\cdot4$. We assume that the dates of the various observatories were spread over a number of years and so if the values of R we have found from our field measurements in Table 1 depended on stones each of which had been set up individually as a result of observations made at one standstill then we might expect them to be distributed roughly as in Figure 3, and so have a r.m.s. value of the order of $3'$ as above. But the r.m.s. value which we actually find is sometimes as low as $1'\cdot3$ or $1'\cdot4$ and this must be already raised by various factors which affect the results, for example unknown refraction and graze; errors due to faulty surveying; errors due to faulty erection; geological movement; erosion and the growth of vegetation on the foresight; and so on. The only explanation of the discrepancy is that the observations made by Megalithic Man before he erected a backsight were spread over a period of the same order as the parallax period which we have seen is about 179 years.

Geographical Division of the Sites

We tried the effect of dividing the data geographically into two lots. The NW lot contained, arbitrarily, Shetland, Orkney, Caithness and the Hebrides, seventeen sites in all. The SE lot contained all the remainder. The mean values for the obliquity of the ecliptic found for the NW group was a fraction of a minute smaller than that found for the SE group. The differences, while not significant statistically, might indicate that the NW sites were built about a century after the SE sites.

Discussion on Dating

If we assume that at any one observatory the observations were spread over three or four standstills, then what cannot have happened is that at one observatory the three or four were centred on (say) 1800 B.C. and at the next on 1700. If we look at Figure 3 we see that this would have produced a difference of perhaps as much as 7 arc minutes, an amount which on our results is completely unallowable. If on the other hand the measurements were spread over the parallax period (see Figure 3) there is no reason why the mean ϵ should not be used to calculate the date directly. As we have seen, the mean ϵ is about $23°53'\cdot1$ and this corresponds to a date of 1590 B.C., but we have seen that the time of the erection was spread over at least 150 years and so this can only be a mean.

Graze Effect; Future Work

It will be obvious that it is important to know the graze effect. Meteorologists tell us that the graze is effective from one hour before sunset to one hour after sunrise (communication from the late Dr Alexander Strang Thom). We had to assume that the effect was the same for all lines, but this cannot be correct—a wide-topped ridge will contribute more than a sharp-topped ridge.

If we are to advance the subject it is necessary to measure the graze at a number of sites. We have done this from home by measuring the altitude of the Sun setting over hills some twelve miles distant and comparing with the altitude found by calculation from the time and corrected by the estimated refraction, but this investigation is not complete. Moreover the graze for the setting Moon may be different from that for the Sun. Much more research is needed.

Conclusions

Using the forty-two lunar lines, we have shown that the backsights were not erected as a result of measurements made at a single standstill. It seems likely that the work leading to the erection of a backsight was spread over about 150 years. Does this explain why many of the lunar backsights consist of huge stones erected to last for generations?

The mean obliquity of the ecliptic appears to be about 23°53′·1 which would indicate a date of 1590 B.C. ±100. The three good solar solstitial sites discussed in Chapter 4 of *Megalithic lunar observatories* give 1750 B.C. ±100.

It now appears certain that by the beginning of the second millenium B.C. Megalithic Man observed not only the larger lunar movements but also the 9 arc minute perturbation of the Moon's orbit. Continuous observing would be taking place and eclipses could have been forecast. We are convinced that apart from any practical use, they were scientifically interested in the relative movements of Sun, Moon and Earth.

We place strong emphasis on the smallness of the residuals in Table 1. Other investigators have been glad to get an agreement of about one degree in declination, but we find the residuals are so small that their root mean square does not approach 2 arc minutes; in Table 1 it is about 1·4 arc minutes, the biggest residual being 3·0 arc minutes.

Attempts to analyze the results statistically indicate the extremely low probability of the forty-two lunar lines having occurred by chance.

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5. Fig. 6.14.
6. Pp. 172–3.
7. *Op. cit.* (ref. 1), 175.
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9. Paragraph 2.2.
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11. *Megalithic lunar observatories*, paragraph 7.5, and *Megalithic remains in Britain and Brittany*, paragraph 2.6.