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A RECONSIDERATION OF THE LUNAR SITES IN BRITAIN

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The Orkney Site

In 1971 the senior author, accompanied by his daughter Mrs Austin, went to Orkney to measure up the two circles known to be there. When we set up our theodolite in the middle of the Ring of Brogar and looked around for a suitable 'referring object', we seized immediately on the cliffs at Hellia on Hoy. On subsequent calculation we noticed that the Moon as seen from Brogar at the minor standstill must have appeared to slide down the slope at the top of the cliff.

Following this we obtained the 1/2500 surveys of the island and saw that near the circle there were rows of cairns. A little investigation shows that the lines of these rows indicated approximately the rising or setting of the Moon at the standstills. We also obtained a copy of a survey made by Thomas early last century and noticed that the same cairns appeared on that, except that one of them had been destroyed and flattened out recently. Foresights indicated by the lines turned out to be definite and to show a remarkable accuracy. To check this we went back on four other occasions with heavier equipment and measured everything accurately. In Orkney this is not particularly easy because the high winds which often blow there sometimes make it difficult to use a theodolite effectively.

The foresight at Mid Hill is particularly impressive. It consists of a small step about 2 arc minutes deep in an otherwise long flat sloping horizon.[1] It is indicated unequivocably by the orientation of the Comet stone and by the direction of the remains of the prehistoric ridge that runs past this stone. It is also indicated by the line of the four cairns on top of the main ridge and by the line joining the large cairns on the loch shore. In Figure 1 we show our latest survey of the cliffs of Hoy. It shows two notches and as both of these give the same declination we have used these. The cliffs at Hoy are indicated by a line joining two cairns. The whole observatory and its use has been described in this journal and there is no need to repeat it here, but it ought to be mentioned that on our last two visits we measured another notch to the NNW that is indicated by two lines amongst the cairns. This notch is rather unsatisfactory because it has a low altitude, only 14′ or 15′, and this makes the refraction somewhat uncertain.

If we accept that Brogar is a lunar observatory then we are entitled to look for the missing foresights. There is no possible natural foresight visible to the north-west for $(\epsilon - i)$ and the ground is totally unsuitable for the erection of an artificial foresight. Accordingly we might possibly be entitled to use the nearby Stenness ring that has an artificial foresight consisting of a cairn built on a ridge amongst the quarry tips that are now there near Bookan. While this gives a perfect value for the declination from the centre of the ring, we do not include it in this paper because it is excluded by the terms of reference that we have adopted (see below).

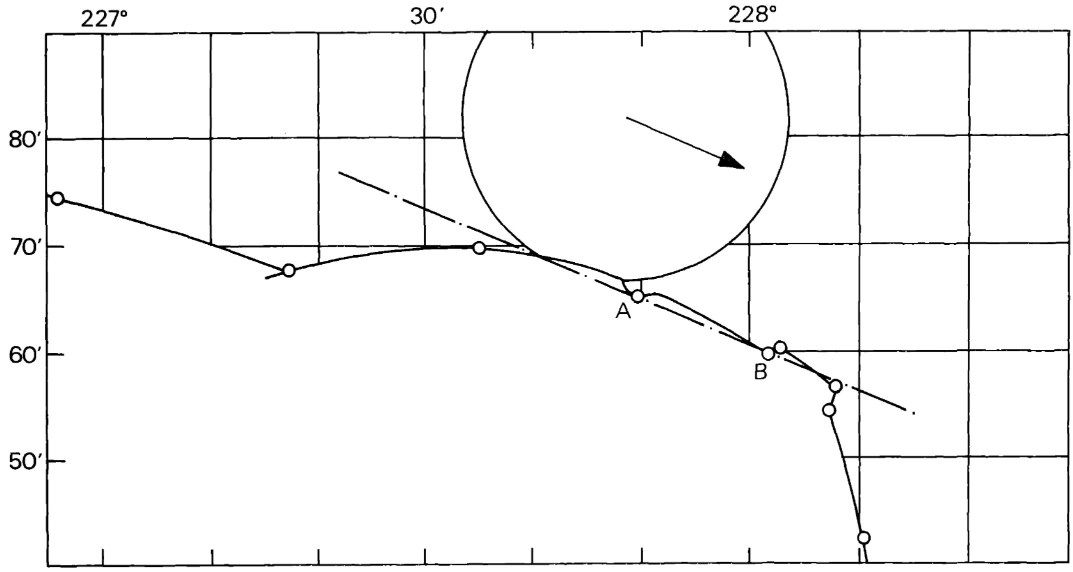

FIG. 1. Brogar: Moon setting on the cliffs at Hellia as seen from *J* over *K*.

In our recent studies of the Brogar site we have taken considerable pains, not only with the surveying, but also in the subsequent reduction of our observations. We have calculated the time of year when the foresight was used and the time of day when the Moon was on the foresight. This has enabled us to estimate the probable value of temperature and so to improve on our estimation of refraction. The results agree so well with the lunar theory as to make it desirable to reassess in a similar manner all the lunar lines that we have collected over the years. This we have done and it is proposed to give the results here; but first we must consider what can be accepted as a foresight.

Possible Types of Foresight

Guided by what we find, we see that probably the most effective type of notch is that where the upper limb shone through the bottom of a notch (see *Megalithic lunar observatories*,[2] Figure 4.2). In Brogar at Hellia, for example, the lower limb was used in the same way. At Temple Wood we see a slight variation where the limb ran down the side of the notch. There are also what must have been unsatisfactory cases where the path of the setting orb was steeper than the side of the notch, and one or two cases like that at Dunskeig where the limb emerged from the angle produced by the fall of a hill on a relatively level horizon; finally, there are various places where the limb of the Moon ran up or down a short length of the horizon that was parallel to its track.

A Reconsideration of All Lunar Sites

Since the writing of *Megalithic lunar observatories* we have extended our knowledge considerably. We have measured accurately some other lunar observatories; equally important, we have learned how to reduce the observations in a more satisfactory manner. Accordingly we wish to give here particulars of all reliable sites that we have surveyed.

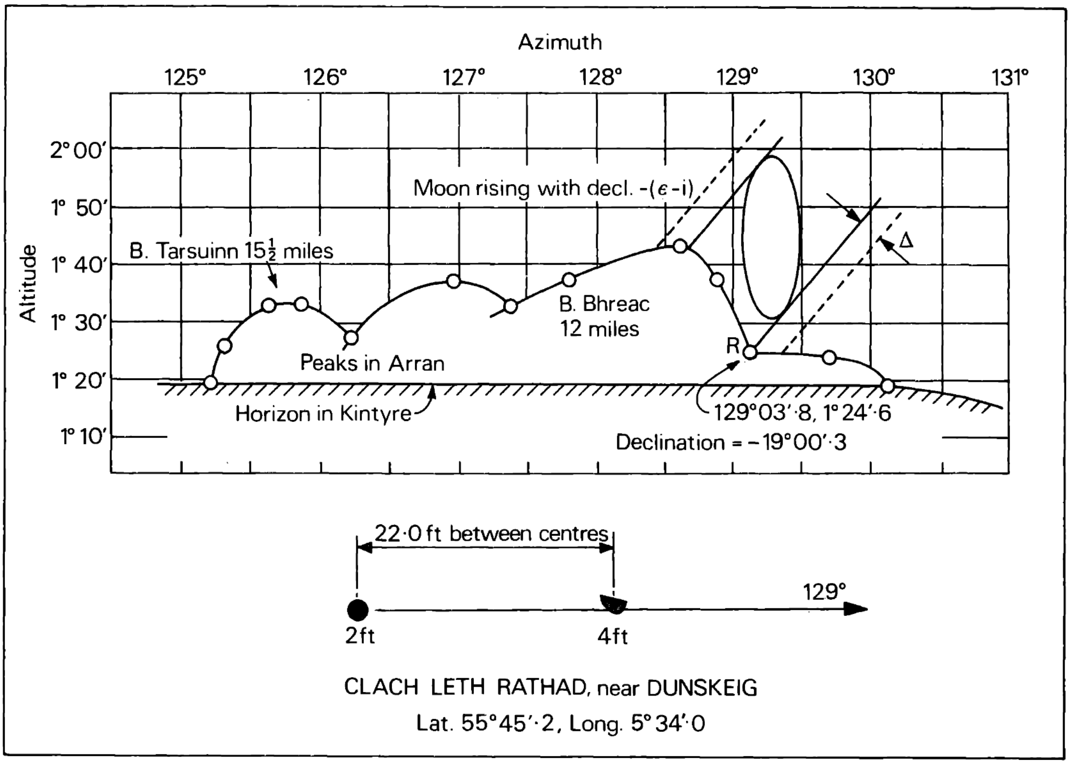

FIG. 2. Peaks in Arran seen from Dunskeig stones in Kintyre.

We have excluded sites where the horizon profile used had been calculated from map contours, such as Callanish I and V. The remaining sites have been subdivided as follows:

Type A: Sites where, at the stones, there is a definite indication of the direction of the foresight;

Type B: Sites where the indication is less definite.

By a definite indication we mean two or more stones, or two or more cairns, lined up on the foresight. In this category we include single slabs where these are wide enough to permit the direction to be determined within a degree or two. To Type B we assigned, for example, the Brogar lines to Hellia from *M* and *L* because, while the direction to Hellia is indicated by *JK*, there is no indication on the ground that the same foresight is to be used at *M* and *L*.

We exclude sites which have several possible foresights inside of the band of sky covered by the Moon at the standstill. In Figure 2, for example, no other foresight exists on the horizon in the band between the dotted lines.

From Figure 3 it can be shown dynamically that the maxima at *A* and *B* occurred in March (or September) and that the minima at *C* and *D* occurred in June (or December). It is possible to generalize this as follows. In the expression for the declination, namely (with the usual symbols) $\pm(\epsilon \pm i \pm \Delta \pm s)$, if i and Δ are of the same sign then the maximum occurred in March or September, whereas if i and Δ are of opposite sign then the dates were either in June or December.

We take from *Megalithic lunar observatories* the azimuth and altitude of all the lines which are of Type A or B and we add all the sites which we have measured recently. A most important site is that near Dunskeig in Kintyre called Clach Leth Rathad which means "the stones middle (in time)". This site has not been described before and accordingly we give particulars here. It will be seen in Figure 2 that the site itself consists of two menhirs 2ft and 4ft high. The near horizon is a relatively flat ridge some miles away. Along the line of the stones one sees that they indicate accurately those peaks of Arran which show over the ridge. This makes it a most impressive site and we hastened to measure up exactly the profile of the peaks (see Figure 2). It appears that it is a site for the Moon at its greatest negative declination at the minor standstill. As a standstill approached the Moon would rise, at its greatest negative declination, further and further to the left until at the standstill it would emerge as shown from the notch at *R*. The altitude of the foresight is sufficiently high (about $1\frac{1}{2}°$) to allow the refraction to be estimated with reasonable accuracy. It will be seen that the azimuth of the line of stones is about 128° and so is almost the same as that of the notch.

Another important site is that at Ballinaby on the west coast of Islay.[3] At that site there is a curiously thin slab, one of the tallest in Scotland. The flat sides are accurately orientated on the foresight. This is another illustration that very large slabs are generally associated with lunar backsights. An example will be found at Knockstaple (*Megalithic lunar observatories*, par. 6.7), where the large slab is undoubtedly of lunar significance. The only possible notch is that at *B* (*ibid.*, Figure 6.6). Another site worthy of mention is that which lies near the two stones known as The Dogs at Borgue in Caithness. This single 13×6ft slab is orientated on the setting point of the Moon at the major standstill, but the only visible foresight is a very shallow V in the hills.[4] The ground on the hills was examined here superficially but no sign of an artificial foresight has so far been found. The great width of the stone, however, allows us to be certain of its orientation and certain that it is a lunar backsight. There are other large stones, obviously lunar, for instance that at Campbeltown, that at Beacharr, and also a slab in the south-west corner of Jura, but none of these satisfies our terms of reference. We have reluctantly excluded Stonehenge because of the lack of

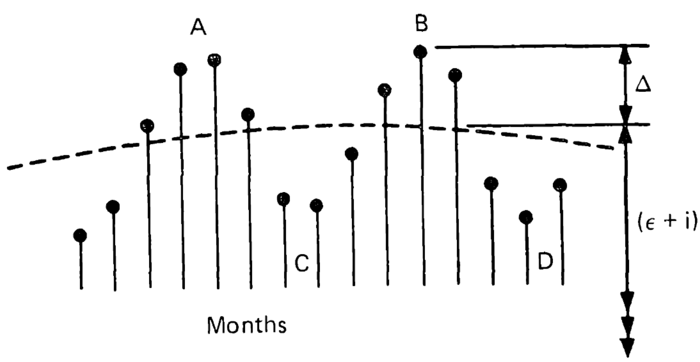

FIG. 3. The Moon's monthly declination maxima at a major standstill, showing the effect of the perturbation Δ, period = 173·3 days. The declination with no perturbation is shown by the dotted line which has its maximum $(\epsilon+i)$ when the node is at the First Point of Aries.

definiteness about the position of the backsights and foresights, and we have excluded Bellanoch Hill[5] because the band of sky covered by the setting Moon with declination $-(\epsilon+i\pm\Delta)$ covers four possible notches, of which apparently two were used.

Method of Calculation

As already mentioned, when Δ and i have the same sign then the standstill occurs at March or September; when they are of opposite sign it occurs in June or December. It is possible to extract from Danby's *Celestial mechanics*[6] the necessary information regarding the mean values of parallax, semi-diameter and perturbation at both standstills. Details will be found in our forthcoming *Megalithic remains in Britain and Brittany* but the necessary values are summarized in Table 1. We can find the time of day when the Moon was on the foresight as follows. First calculate in degrees the hour angle of the foresight, measuring it from the south meridian. To this add the longitude of the Moon which is 90° for the north declination and −90° for the south. From the sum subtract the longitude of the Sun which is 0° in March, 90° in June, 180° in September and 270° in December. The figure we obtain must be divided by 15 and increased by 12 hours to give the hour of the day from midnight. We now know the time of year and the time of day and so we can estimate the temperature. If the altitude is not too low this enables us to find the refraction to be used. We have shown elsewhere[7] that when a ray grazes the ground at night it is deflected to a greater extent than expected. This we shall call the 'graze effect'. It follows that we must increase the refraction at all foresights because at at least one point the ray passes close to the ground. Meteorologists tell us that with clear or partly clear skies over land this effect lasts from about one hour before sunset until about one hour after sunrise. The actual values may differ from site to site and from one occasion to another at a given site, but in typical viewing conditions (with clear or partly clear skies) it is probably little affected by time of year. In the absence of better information we have simply assumed that the graze effect is always the same at all points and at all times when it is operative.

Deducting standard refraction and, when appropriate, the additional graze effect from the observed altitude, and then adding the parallax found from Table 1, gives the necessary geocentric altitude. With this altitude, the latitude and the azimuth, we solve the spherical triangle to find the observed declination.

This is the broad outline of the procedure but when we come to apply it we find difficulties. For example, we do not know whether the backsight was chosen in March or September. We have accordingly generally worked both and taken the mean, but in some rising cases it seemed better to ignore the daylight risings.

The Case of $\epsilon\pm i$

It will be noticed that there are examples where no Δ appears in the nominal

TABLE 1. Values of the perturbation Δ, the parallax p and the semidiameter s at the standstills.

	Δ	p	s	$s-\Delta$	$s+\Delta$
Δ and i of the same sign	7′·1	57′·2	15′·6	8′·5	22′·7
Δ and i of opposite sign	9′·0	57′·7	15′·7	6′·7	24′·7

value. This means (Figure 3) that the value of the declination lies between the top and the bottom of the wobble. There does not seem to be any method whereby Megalithic Man could obtain this value by direct observation apart from simply taking the mean position on the ground for observations of the solstitial and equinoctial values. So in these cases we worked out the values separately and took the mean declination. If we think of how Megalithic Man must have worked we see that this is a reasonable decision. He presumably marked on the ground every position for every maximum, starting perhaps a year before the standstill. He would then have been able to consider at one time all the information he had collected. It will be noticed that this method overcomes the difficulty of a spell of bad weather occurring at one of the maxima; it would be relatively easy to fill in the gap.

The Case of $\epsilon \pm i \pm (s-\Delta)$

It so happens that Δ and $s-\Delta$ are roughly the same. This means that we cannot decide from the ground information which value Megalithic Man used; perhaps he used both. Accordingly here again we have worked out both cases and taken the mean; that is, we have made the requisite calculations for $s-\Delta$ and for Δ (see example in Table 2). There is occasionally a difference of a minute or so between the two calculated declinations because of different parallax value and also because of differing temperature effects on refraction.

TABLE 2.

	Ballinaby upper foresight		Temple Wood S_1 to A			
Height (ft)	150±		50±			
Latitude ϕ	55°49′·0		56°07′·3			
Azimuth	327°28′		316°59′			
Altitude	0°44′·2		4°37′·7			
Nominal declination	$\epsilon+i+\Delta+s$		$\epsilon+i+\Delta-s$		$\epsilon+i-\Delta$	
Month	Mar.	Sept.	Mar.	Sept.	June	Dec.
Hour angle	143°	143°	130°	130°	130°	130°
Longitude of Moon	90°	90°	90°	90°	90°	90°
Longitude of Sun	0°	180°	0°	180°	90°	270°
Hour	3·5	15·5	2·7	14·7	20·7	8·7
Temperature (F°)	39	54	39	54	51	39
Refraction r	−27′·4	−26′·3	−10′·9	−10′·5	−10′·6	−10′·9
Graze g	−2′·0	0′·0	−2′·0	0′·0	−2′·0	−2′·0
Parallax p	57′·2	57′·2	57′·2	57′·2	57′·7	57′·7
Geocentric altitude h_g	1°12′·0	1°15′·1	5°22′·0	5°24′·4	5°22′·8	5°22′·5
Declination	29°24′·0	29°26′·9	28°54′·6	28°56′·8	28°55′·3	28°55′·0
Mean declination δ_0	29°25′·4		28°55′·4			
Δ	7′·1	7′·1	7′·1	7′·1	9′·0	9′·0
s	15′·6	15′·6	15′·6	15′·6	—	—
i	5°08′·7		5°08′·7			
ϵ	23°52′·6	23°55′·5	23°54′·4	23°56′·6	23°56′·6	23°55′·3
Mean ϵ	23°54′·0		23°54′·7			

Height is height in feet above sea level.
'Hour' is number of hours elapsed since midnight.
Temperature is mean Kirkwall value.
Refraction r is from tables and diagram in *Nautical almanac* with barometer and temperature; barometer is mean value for height.
Graze g is taken as $-2'$ from 1 hour before sunset to 1 hour after sunrise, and zero during the remainder of the day.
p, Δ and s are appropriate values from Table 1.
Geocentric altitude $h_g = p+r+g+$altitude.
Declination $\delta_0 = \arcsin(\sin\phi \sin h_g + \cos\phi \cos h_g \cos \text{Azimuth})$.

Details of the Workings

We cannot give details of all the working of all values and accordingly in Table 2 we have worked out two examples fully; but all the results are gathered in Table 3. In this Table we also give the latitude, the azimuth and the measured altitude so that anyone can reconsider the evidence.

We now take the difference between the declination found δ_0 (the "observed" declination) and the appropriate value of $\pm(\epsilon \pm i)$. This we have called β. We expect the value of β to be one of the four values 0, Δ or $(s-\Delta)$, s and $s+\Delta$. The actual values of β are given in Table 3 and the various combinations of Δ and s are shown above the histogram (Figure 4) where at *A*, *B*, *C* and *D* we also indicate the assumed "nodes". It will be seen that the nodes are almost uniformly spaced at 7·87 arc minutes apart. Clumps do in fact appear on the histogram near these nodes in a highly significant manner. We do not know how to estimate the probability level accurately but we have adopted the following simple-minded method. We assume that the nodes we have just mentioned are part of an infinite series of equally spaced values, and then use Broadbent's method of obtaining the probability level. In other words we find the error γ_1

TABLE 3. Lunar lines with indicated foresights.

Site	Foresight	Type	Latitude	Azimuth	Altitude	δ_0	β	γ_1
Brogar *JK*	Hellia	A	59°00′·1	227°50′	65′·2	−18°44′·0	0′·9	0′·9
,, *M*	,,	B	,,	227 13	65	−18 59·2	14·3	1·2
,, *L*	,,	B	,,	227 36	64·6	−18 50·5	5·6	2·2
,, Comet stone	Mid Hill	A	,,	135 07·8	128·8	−18 50·2	5·3	2·5
,, *MLJ*	,, ,,	A	,,	133 27·8	120·1	−18 20·0	24·9	1·3
,, J_2GD	Kame lower	A	,,	24 27·5	58·4	+29 24·5	22·2	1·4
,, L_2B	,, upper	A	,,	24 40·0	61·5	+29 24·7	22·4	1·2
,, *HFT*	Ravie Hill	A	,,	336 47	14	+28 52·5	9·8	2·0
,, Comet stone	,, ,,	A	,,	336 23	15	+28 48·0	14·3	1·2
Temple Wood S_1	A_1 (ref. 2)	A	56 07·3	316 59	277·7	+28 55·4	6·9	0·9
,, ,, S_4S_5	A_1 (ref. 2)	A	,,	317 52·5	277·6	+29 18·6	16·3	0·8
,, ,, *Q*	A_1 (ref. 2)	A	,,	317 12·6	277·7	+29 01·5	0·8	0·8
Ballymeanach	A_1 (ref. 2)	A	56 06·0	321 30	176	+29 12·8	10·5	2·7
,,	A_2 (ref. 2)	A	,,	322 13	174	+29 28·0	25·7	2·1
Ballinaby	Lower (ref. 3)	A	55 49·0	328 49·2	11·2	+29 16·4	14·1	1·4
,,	Upper (ref. 3)	A	,,	327 28	44·2	+29 25·4	23·1	0·5
Kintraw	A_1 (ref. 2)	B	56 11·3	233 23	41·5	−18 20·8	24·1	0·5
Dunskeig	*R*	A	55 45·2	129 03·8	84·6	−19 00·3	15·4	0·1
Escart	See ref. 2	A	55 50·8	207 17	49	−28 39·9	22·4	1·2
Stillaig	See ref. 2	A	55 52·5	326 00	45	+28 53·2	9·1	1·3
Knockstaple	*B*	A	55 21·1	326 09	20	+28 53·5	8·8	1·0
Knockrome	See ref. 2	B	55 52·5	204 07	52	−29 27·8	25·5	1·9
Lundin	See ref. 2	B	56 12·8	126 49	8	−19 00·8	15·9	0·4
Haggstone Moor	A_1	A	55 00·2	304 25	−4	+19 08·9	24·0	0·4
Fowlis Wester	See ref. 2	A	56 24·3	30 46	32·5	+29 20·5	18·2	2·7

Type A: Site with good indication of foresight.
Type B: Site with poor indication of foresight.
Azimuth: Observed azimuth of foresight.
Altitude: Observed altitude of foresight.
δ_0: Declination deduced by use of refraction from *Nautical almanac*, parallax from Table 1, and 2′ graze effect.
β: The numerical difference between δ_0 and $\pm(\epsilon \pm i)$, where $\epsilon = 23°53'{\cdot}6$ and $i = 5°08'{\cdot}7$.
γ_1: The numerical difference between β and the nearest "node", where the nodes are $A = 0$, $B = 7'{\cdot}8$, $C = 15'{\cdot}5$, and $D = 23'{\cdot}6$.
The mean interval, $2\delta_1$, is 7′·87. For the 25 sites we find that $\Sigma\gamma_1^2 = 55{\cdot}48$, the lumped variance s_1^2 is $55{\cdot}48/n = 2{\cdot}22$, and $s_1^2/\delta_1^2 = 0{\cdot}143$. Hence, from Figure 2.1 of *Megalithic sites in Britain*, the probability level is 0·1 per cent.

or the discrepancy of each value from the nearest "node"; sum the squares of these, divide by the number of observations and so obtain what Broadbent calls the 'lumped variance'. We then divide by δ_1^2 where $2\delta_1$ is $7'{\cdot}87$, the mean distance between the nodes. We now use Figure 2·1 in *Megalithic sites in Britain*[8] (extrapolating where necessary) to determine the probability level. We find this to be about 0·1 per cent, which indicates that there is only about one chance in a thousand that the agreement we have obtained could have come about by accident.

Repeating the calculation but using only the twenty lines of Type A we find a probability level of about 0·2 per cent. Criticism may be directed against the use of the upper foresight at Ballinaby; if we remove this we are left with nineteen sites and a probability level of 0·3 per cent. It might possibly be claimed that the Ravie Hill foresights at Brogar and both the Ballymeanach lines are poor; the effect of removing these is to leave an s_1^2/δ_1^2 of only 0·11, but since the number of lines left is now only fifteen it is difficult to get a reliable value for the probability level. It is still low, perhaps 1 or 2 per cent.

The Mean Value of ϵ

In Table 4 we give the values of ϵ for each site, calculated by applying the appropriate values of Δ and s to the measured declination. These are divided into those coming from positive declinations and those coming from negative declinations; the mean value from the former is $23°54'{\cdot}1$, and from the latter $23°53'{\cdot}1$, while the overall mean is about $23°53'{\cdot}6$. In Table 4 we have given values for a graze effect of both 2′ and 3′. While $\epsilon = 23°53'{\cdot}6$ corresponds to a date of 1680 B.C., we again draw attention to the fact that this method of dating is subject to an uncertainty of perhaps ±150 years.[9]

It will be seen that when we use a higher value for the graze effect it reduces the values of ϵ obtained from the north declinations and increases those from the south. That the north and south means are nearly identical is some justifi-

TABLE 4. Collected values of obliquity (ϵ) from north declinations and from south declinations with graze = $-2'$ and $-3'$.

Obliquity from north declinations	graze $-2'$	graze $-3'$	Obliquity from south declinations	graze $-2'$	graze $-3'$
Kame lower	23°53′·1	23°52′·6	Brogar *JK* to Hellia	23°52′·7	23°53′·1
Kame upper	53·3	52·8			
Ravie Hill from *G*	52·6	52·2	Brogar *M* to Hellia	52·3	52·4
Ravie Hill from *C*	55·0	54·7			
Temple Wood S_5 to *A*	54·2	53·4	Brogar *L* to Hellia	50·5	50·9
Temple Wood S_1 to *A*	55·4	55·0			
Temple Wood *Q* to *A*	52·8	52·1	*C* to Mid Hill	50·3	50·9
Ballinaby, Lower	52·0	51·4	*M* to Mid Hill	51·4	51·9
Ballinaby, Upper	54·1	53·5	Escart	55·9	56·4
Ballymeanach A_1	57·0	56·6	Kintraw	52·2	52·6
Ballymeanach A_2	56·5	56·0	Dunskeig	53·3	53·8
Knockstaple	53·5	52·6	Temple Wood	55·5	56·3
Hagstone Moor	52·8	52·1	Knockrome	56·4	56·8
Stillaig	53·3	52·8	Lundin	53·8	54·4
Fowlis Wester	56·2	55·2			
Mean	23°54′·13	23°53′·53		23°53′·12	23°53′·59

Mean obliquity with graze of $-2' = 23°53'{\cdot}62$;
Mean obliquity with graze of $-3' = 23°53'{\cdot}56$.

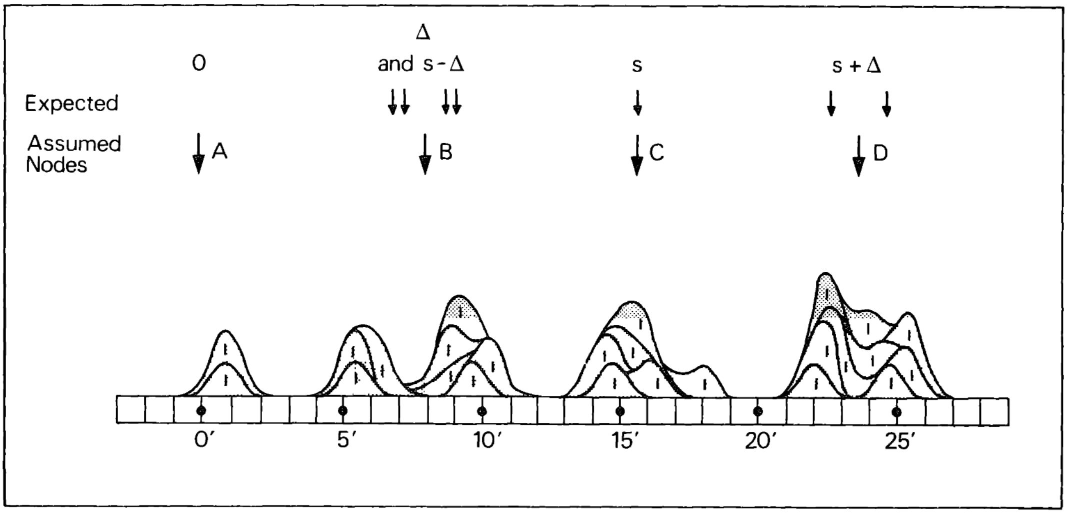

FIG. 4. Histogram of differences β between the observed declinations and values of $\pm(\epsilon \pm i)$. The "expected" values are one or other of the values of Δ, s, $s-\Delta$ and $s+\Delta$ that are given in Table 1. The "assumed nodes" are the means of the groups of expected values.

cation for the value of the graze we use, namely 2′ to 3′. In a paper[10] in 1969 we showed by a statistical analysis that we were perhaps using too low values both for terrestrial and for astronomical refractions. We now see that that was because we were making no allowance for the graze effect.

We also tried the effect of using γ_2 as the error of each value, where γ_2 is the difference of the observed β from the combination of the appropriate values of Δ and s. In other words γ_2 is the distance of a point on the histogram in Figure 4 from the *appropriate* little arrow in the row at the top marked "expected" values, whereas γ_1 is the distance from the lower arrow *A, B, C* or *D* marked "assumed" node. We found that this raises the value of s_1^2/δ_1^2 somewhat and so raises the probability level to about 1 per cent. But the overall picture remains the same, namely, that there is a very low probability that the results we have obtained could come about by accident.

We wish to state here that at no stage have we made any attempt to pull the values this way or that way to produce a better fit. In choosing material we have stuck to the terms of reference stated earlier and we have ignored only values which are outside the range of the declinations at the standstill. We give all the original measured azimuths and altitudes so it is possible for anyone to re-do the whole calculation provided he has sufficient knowledge of the subject. He may find trifling differences produced by the method which he has used for refraction, graze, etc., but we are sure that our work will stand up to any honest criticism.

Low Values of Residuals

We have discussed elsewhere the difficulties that the erectors must have found in establishing the positions of backsights and we stated that we did not know how these had been overcome. The present investigation does nothing to resolve this dilemma. We can only state again that we are puzzled by the accuracy which these people obtained.

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