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FURTHER WORK ON THE BROGAR LUNAR OBSERVATORY

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In a previous issue of this journal we showed[1] that the Megalithic site at Brogar almost certainly contains the remains of an important lunar observatory. We gave particulars of the probable foresights and backsights together with the resulting declinations, but there were uncertainties, and so, considering the importance of the site, we thought it desirable to revisit Orkney and attempt to fill the gaps. When we returned in 1973 the weather was clear and observing conditions apparently good but the wind was so high that accurate work was difficult and at times impossible. In 1974 we found bright sunshine, but anticyclonic weather made it impossible to see to all the foresights. Nevertheless, combining the results obtained on the two expeditions, we consider that we have advanced our knowledge of the site sufficiently to warrant a second report.

The Foresights

In 1971 and 1972 we had determined the profiles of the three foresights from the centre of the ring. At the same time we had made an accurate tacheometric survey of all the backsights then known to us. On the assumption that the foresights were two-dimensional silhouettes it was then possible to calculate the declinations obtained from any of the backsights. In 1974 we visited the foresights at Mid Hill and Kame of Corrigall. A close-up of the Mid Hill

FIG. 1. Close-up view of Mid Hill foresight (with signal for identification from Brogar).

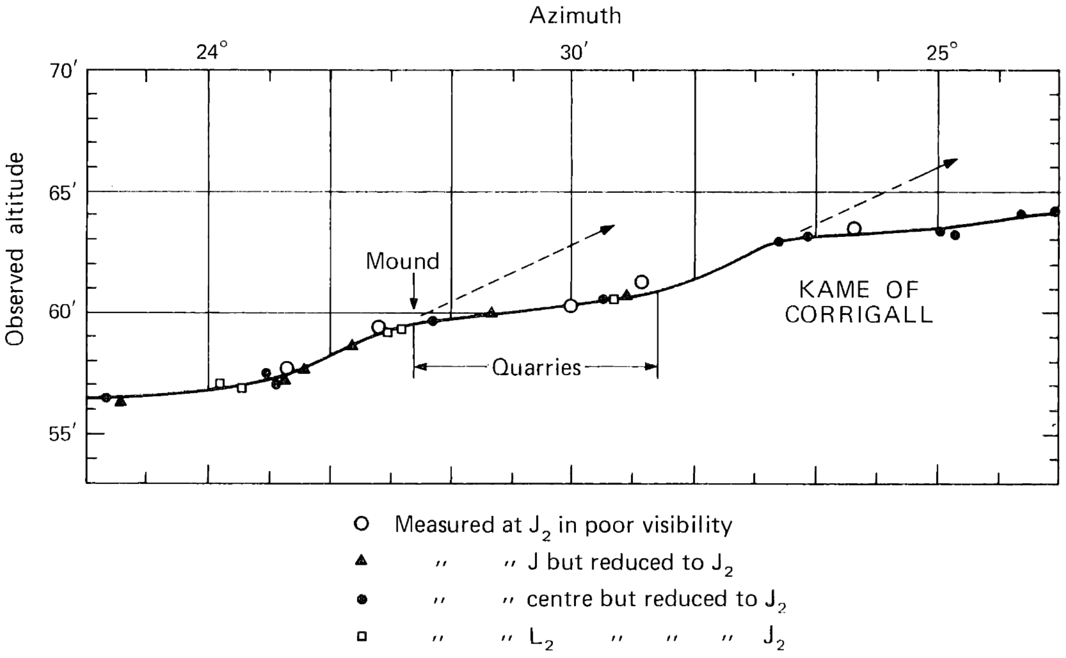

FIG. 2. Composite profile of Kame of Corrigall.

foresight is shown in Figure 1. It is evident that to treat Mid Hill as a two-dimensional silhouette would be quite accurate. Some members of our party considered that the peat had possibly advanced this notch to the north-east by three or four feet. This would have an effect on the declination of only some ten seconds of arc. The foresights at Kame of Corrigall (see Figure 2) certainly have some depth, but it did not seem likely that this would have a serious effect on calculated azimuths. We did not visit the foresight at Hoy, but examination of the modern 1:10,000 photogrammetric map of the island shows that this particularly rugged region cannot be taken as forming a two-dimensional foresight. The profile of the cliffs here has not yet been measured in detail from Brogar but there appears to be a small notch half way down the slope which runs down (parallel to the path of the setting Moon) to the edge of the cliffs. The co-ordinates of this notch viewed from the centre R are (227°04′·2, 65′·3) and not as shown on Figure 3 of the previous paper.

Accurate astronomical determinations of azimuth were made in 1974 at the Comet stone, at J, J_2, L_2 and T (see Figure 3). These were all completely mutually checked by using a remote referring object at a known distance.

When we visited the position of the foresights at Kame of Corrigall we found, over an area 50 yds × 50 yds, a number of holes from which slabs or stones had been quarried. The debris from each hole lay beside it and may have raised the ground profile by perhaps 2 ft in the part indicated in Figure 2, but this cannot appreciably affect the declinations. There is an artificial mound about 5 ft high in the position shown in Figure 2. The co-ordinates of this seen from the centre R of the ring are 25°21′·4, 61′·2 determined, when the visibility was too poor to use any other method, by placing a car head lamp

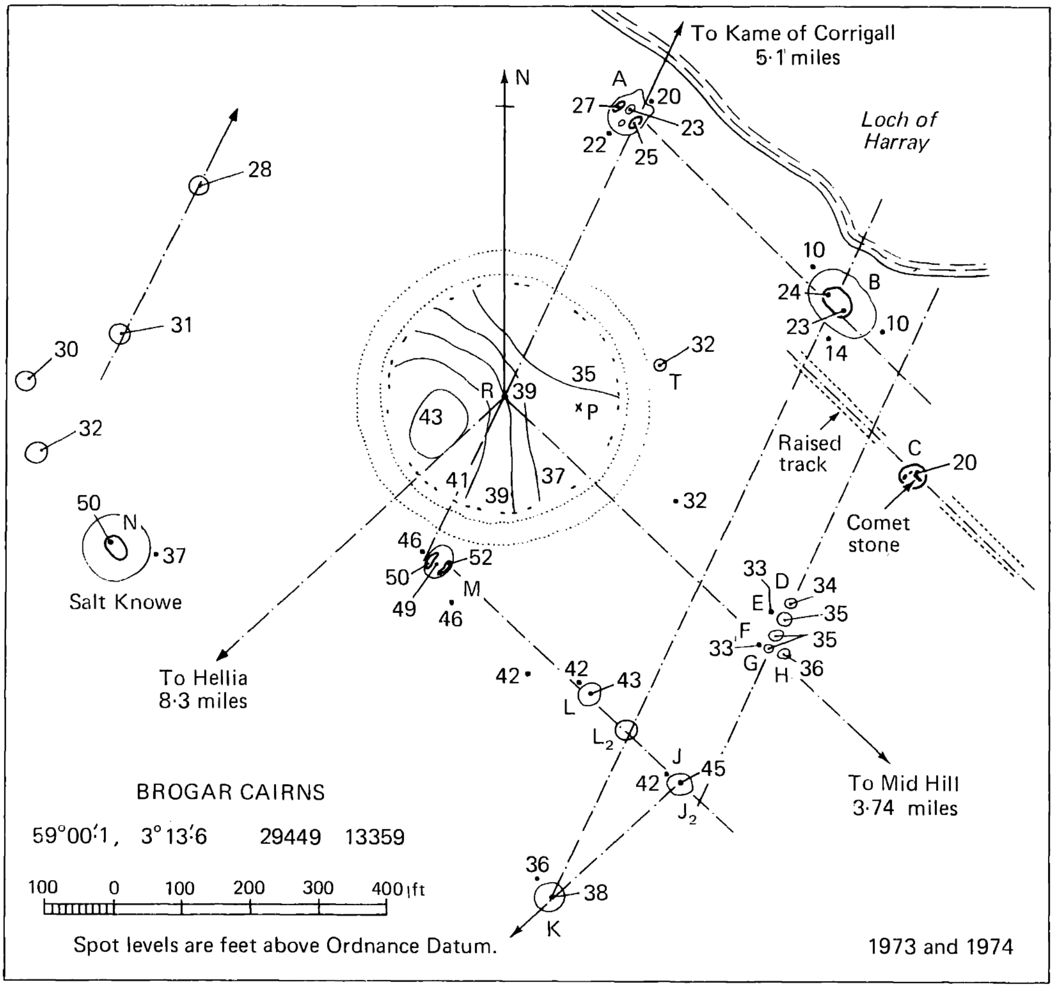

FIG. 3. The cairns surrounding the Ring of Brogar.

on the top of the mound after sunset. This mound is on the western edge of the quarried region and may have been raised when the quarries were dug, but the reason for its construction is not obvious. Since its declination from Brogar is about half a minute larger than that of the slope to its west, it is tempting to think that it has been an artificial foresight. Perhaps archaeologists can establish the age of the quarries and of this mound. There does not seem to be any road leading to the area of the pits but there are, not far away, the remains of a track along the hillside, perhaps for hauling peat.

Newly-surveyed Features at Brogar

We found an interesting feature near the Comet stone. There is a causeway or low ridge of slightly higher ground running towards the north-west. It appears faintly again, after the raised platform round the stone, to the south-east (see Figures 3 and 5). In 1849, Thomas showed a track (Figure 4) which follows this ridge so far, but dodges round the Comet stone and does not rejoin it on the other side. It seems likely that this was originally a Megalithic construction, but over the centuries it was perhaps used as a cart track across the low ground. A careful survey was made of the edges and centre line of this causeway, enabling its azimuth to be determined (see below).

We have now on our survey a cairn L_2 between L and J. Some indication of this is given on the large-scale Ordnance Survey and on Thomas's map. It is quite obvious that there has been a mound here, when the ridge is viewed, before the grass has grown, from slightly down the slope. There is no trace of a mark at J_2 but this position is easily found by standing on the ridge near J on the line of the small cairns G, F, E, D, and the Kame foresight. It is to be understood that the observer did not need to know a position any nearer than a foot or two.

Where Thomas marked a small cairn at T there is undoubtedly a high part on the ground consisting of earth and loose stones. We had not noticed this in the long grass before, but in 1974 we fixed this now unimpressive eminence on our plan. The employees of the Ministry were busy levelling out the surface at various places so that tourists could stroll round the site.

The field immediately to the north-west of the area enclosed by the Ministry is under cultivation. We noticed in this field three or four places where the ground was definitely above the surrounding level. These mounds may be natural or may have been deposited there recently. Nevertheless, we have marked their positions on our survey (Figure 3). It will be seen that the line joining two of the mounds points to Kame. The declination of the upper foresight there is about 28°53′·6 which is within a minute of $(\epsilon+i-s+\Delta)$,

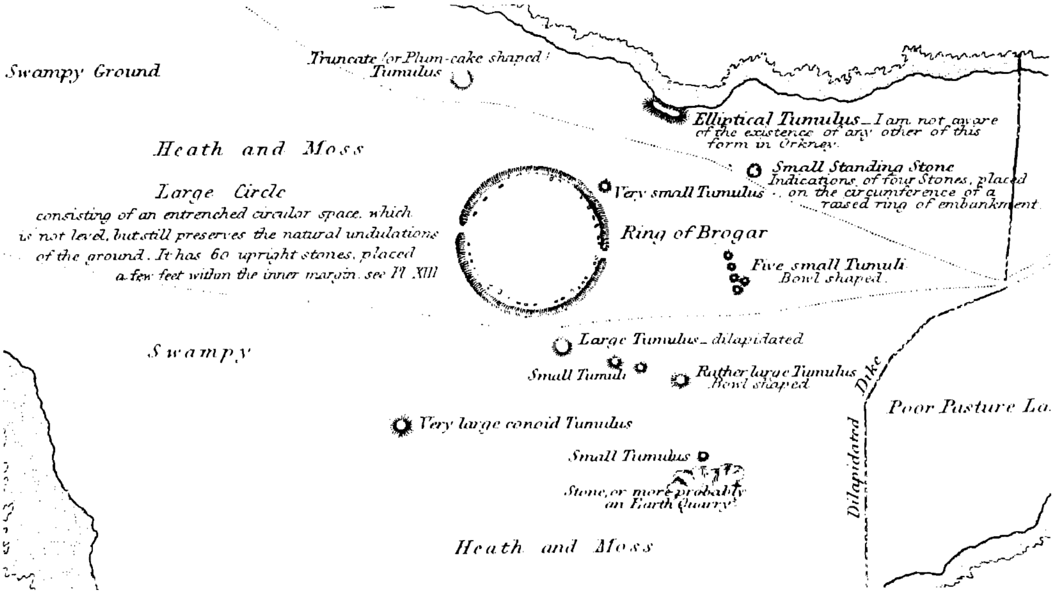

FIG. 4. Part of the survey made in 1849 by F. W. L. Thomas, taken from his "Account of some of the Celtic Antiquities of Orkney", *Archaeologia, or miscellaneous tracts relating to Antiquity*, xxxiv (1851), 88–136.

TABLE 1. Determination of the declinations from the Brogar backsights. As explained in the text, the residuals formed from $(\delta_0-\delta_n)$ should not be used for statistical analysis.

Foresight	Backsight	Azimuth	Altitude	Declination δ_0	Nominal values δ_n
Hellia	*J* over *K*	227°50′	65′·0	−18°44′·0	$-(\epsilon-i)$ = −18°43′·9
Hellia	*L*	227 36	64·6	−18 50·0	$-(\epsilon-i+s-\Delta)$ = −18 50·7
Hellia	*M*, ground level	227 13	65·0	−18 58·7	$-(\epsilon-i+s)$ = −18 59·4
Hellia	Salt Knowe, ground level	226 48	66	−19 07·4	$-(\epsilon-i+s+\Delta)$ = −19 08·1
Mid Hill	*A*, ground level over *B*	135 21	124	−18 59·0	$-(\epsilon-i+s)$ = −18 59·4
Mid Hill	*M*, ground level over *LJ*	133 27·8	120·1	−18 19·1	$-(\epsilon-i-s-\Delta)$ = −18 19·7
Mid Hill	*G*	134 08·0	126·4	−18 28·7	$-(\epsilon-i-s)$ = −18 28·4
Mid Hill	Thomas's cairn, *T*	134 43·0	124·5	−18 44·1	$-(\epsilon-i)$ = −18 43·9
Mid Hill	Comet stone	135 07·8	128·8	−18 49·5	$-(\epsilon-i+s-\Delta)$ = −18 50·7
Kame upper	Top of Salt Knowe	26 37·4	60·2	+28 54·5	$+(\epsilon+i-s+\Delta)$ = +28 54·5
Kame upper	Ridge over *RA*	25 46·0	61·4	+29 09·1	$+(\epsilon+i+s-\Delta)$ = +29 08·1
Kame lower	L_2 over *B*	24 27·5	58·4	+29 25·6	$+(\epsilon+i+s+\Delta)$ = +29 25·5
Kame upper	J_2 over *GFED*	24 40·0	61·5	+29 25·8	$+(\epsilon+i+s+\Delta)$ = +29 25·5
Kame lower	Salt Knowe, ground level	26 06·6	58·9	+29 01·2	$+(\epsilon+i)$ = +29 01·3
Kame upper	*T*	25 22·2	64·2	+29 18·2	$+(\epsilon+i+s)$ = +29 16·8

where ϵ is the obliquity of the ecliptic, i the inclination of the lunar orbit, s the mean semi-diameter of the Moon and Δ the perturbation. It is felt that it would be wrong to include this in any statistical analysis unless some more substantial evidence is found to show that these very low mounds are prehistoric remains.

The Site at Brogar

We believe that we can explain the position chosen for the observatory. The rugged cliffs at Hellia in Hoy form an attractive foresight because the slope at the top of the cliff is parallel to the path of the setting Moon; but the upper limb could not have been used as this would have forced the site south-eastwards down on to the lower ground. The ridge on which the cairns *M*, *L* and *J* stand formed a perfect platform along which the observer could move as he watched the setting Moon. Looking from this ridge in the other direction, there are the less impressive, but less ambiguous, foresights on Kame of Corrigall, and so this same ridge could also be used as the operating stance for viewing these foresights.

From the same general area, it was possible to watch the Moon rising at the minor standstill on the almost perfect foresight provided by the small notch on Mid Hill.

At the time when the Moon was expected to rise it was necessary to have some warning so that observers spaced along the line of movement could be prepared. For Mid Hill this meant that a man had to be stationed to the north-east. But here the site is limited by Loch Harray. To compensate it was necessary to raise the watcher's eye level. This fully explains the large mounds at *A* and *B* (Figure 3). These were as far to the north-east as possible and as high as necessary. In partial darkness it was desirable to have an indication of the direction in which the small notch lay. There could have been ranging poles on *A* and *B*.

For Kame, Salt Knowe served the same purpose, placed as it is well to the left (but not too far, or it would then have been on lower ground). As we shall see other considerations probably fixed its exact position. For the setting Moon no warning was necessary.

It is easy to criticize the foresights at Kame but it must be remembered that there is no other natural foresight available in this direction; and if the builders wanted to keep the backsights grouped in one compact unit, they were indeed lucky to find in the right place these two steeper slopes on the horizon. While they are unimpressive to look at they must have been perfectly satisfactory to use. We do not yet know the line along which the observer moved on successive days when looking toward Mid Hill. It could well have been along the line of small cairns *G*, *F*, *E*, *D*.

The Sightlines

In Table 1 we give particulars of all the sightlines which seem worthwhile recording. If anyone wishes to make a statistical examination of the declinations given by all three foresights viewed from all the backsights, then the necessary data can be calculated from Figure 3 and the azimuths in Table 1. This

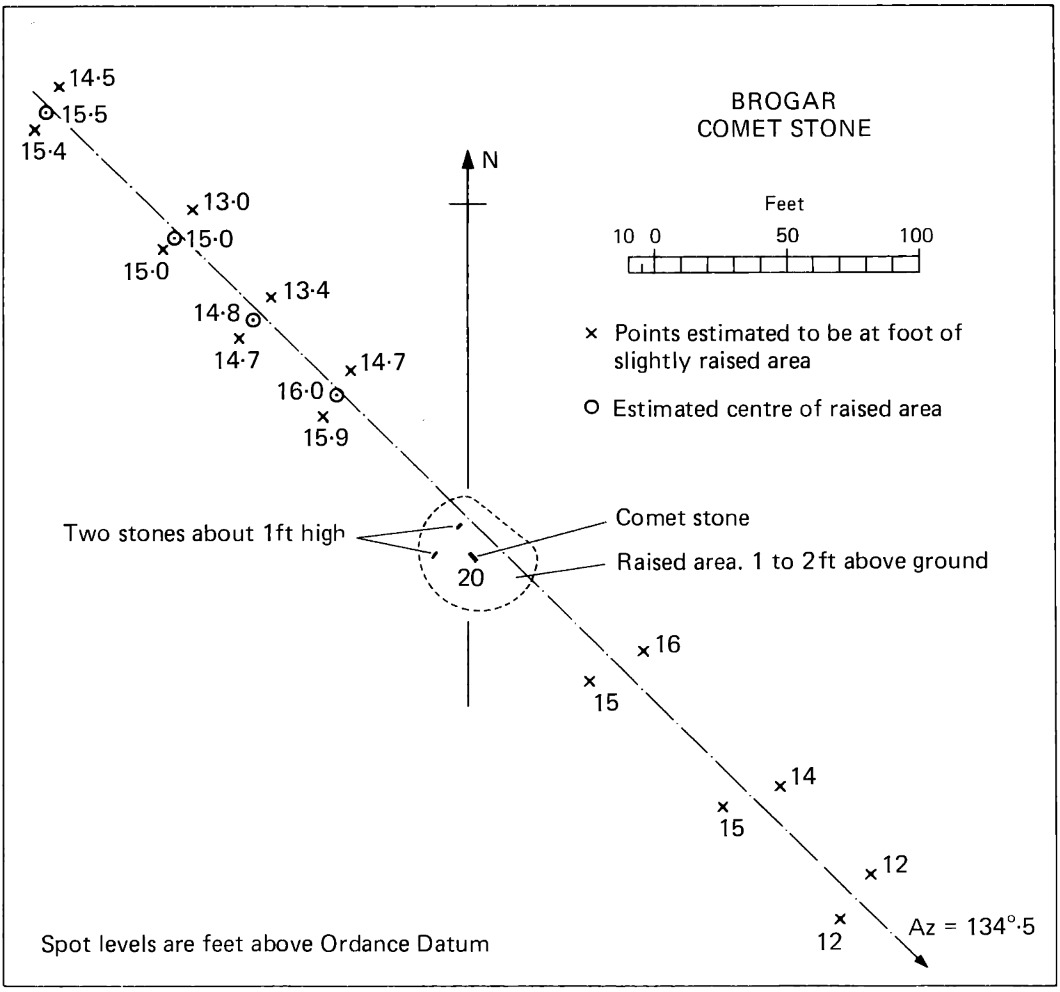

FIG. 5. The track at the Comet stone.

suggestion leads to the question of the desirability of using every possible foresight right round the horizon. We have no intention of attempting such an analysis and the reader must judge for himself as to the credibility of the lines we have tabulated. The half-dozen of these lines considered to carry most weight will be examined later in the paper.

The azimuths and altitudes given for Mid Hill and Kame are considered to be, apart from refraction uncertainties, reliable to better than half an arc minute, but the same cannot be said for Hellia because we do not know the exact part of the sloping cliff top which was used. We have tabulated the little notch near the middle of the long slope already mentioned. For comparison with the observed declinations, δ_0, we have given theoretical nominal values which are built up from the known values of i, s and Δ, but we have used $\epsilon = 23°52'{\cdot}6$. It is inadvisable to deduce too much from these numerical values without noting that in Figure 6 the four limiting values at A, B, C and D are all slightly lower than $\epsilon + i \pm \Delta$.

The mean directions of the two flat faces of the slab which is called the

Comet stone (Figures 3 and 5) are 133°30′ and 134°30′, and from here the Mid Hill notch is at 135°07′·8. The stone must have been well and truly set in a solid foundation to retain its orientation for over 3000 years. The mean direction of the centre line of the portion of the causeway (see above) which is visible is 134°30′ ± 30′, and it passes the Comet stone 9 ft to the north-east. If we view the Mid Hill notch from this point on the line of the causeway, the observed declination will be about 0′·6 lower than that tabulated. The argument against this procedure is that once we move on to the causeway we can take any point on it and so get a range of declinations.

The Theory of a Standstill

It is desirable to remind ourselves of what happens at a standstill and to consider the consequences in some detail. During a major standstill the ascending node of the Moon's orbit is near to the First Point of Aries, but the conditions are complicated by the perturbation induced by the Sun on the inclination of the orbit. This effect is greatest when the node is in conjunction with the Sun and again when it is in opposition.[2] Thus the monthly maximum of the Moon's declination has its highest values at dates separated by about 173 days (see Figure 6).

Any declination maximum happens when the longitude of the Moon is near to 90°. The highest will be that which occurs when the node is nearest to conjunction or opposition with the Sun; but the node is near the equinox and therefore the Sun's longitude is near to 0° or 180°. Thus we get the conditions for a maximum (see Figure 6, *A* and *B*):

(1) Moon's longitude is near 90°, and

(2) Sun's longitude is near to 0° or 180°.

As a result of (1) and (2) the Moon is at its first or third quarter when the maximum occurs. As a result of (2) the maximum declination occurs near either the vernal or the autumnal equinox.

We must now consider the hour of the day when the Moon was on a foresight. We calculate the hour angle of the foresight, add the Moon's longitude and subtract the Sun's longitude. The result converted into time units is approxi-

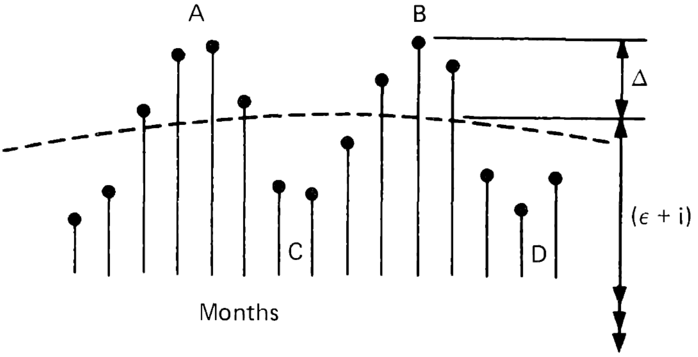

FIG. 6. The Moon's monthly declination maxima at a major standstill, showing the effect of the perturbation Δ, period = 173·3 days. The declination with no perturbation is shown by the dotted line which has its maximum $(\epsilon+i)$ when the node is at the First Point of Aries.

mately the required hour in the astronomical convention which places zero hour at midday. Now consider a foresight for the Moon *setting* with maximum positive declination. The hour angle is between 90° and 180°, and if we take the case when the Sun's longitude is 0° and apply the above rule we find that the time is between 12 hours and 18 hours. Since we are dealing with a date near the equinox, the Sun will be below the horizon from 6 hours to 18 hours, *i.e.* the Moon will set during the hours of darkness. If we consider a foresight for the *rising* Moon we find that we must adopt the case when the Sun's longitude was not 0° but 180°, *i.e.* the autumnal equinox, otherwise we find that the Moon rose in daylight.

It follows that we must have information (declination, parallax, *etc.*) for the two greatest maxima of the perturbation oscillation. One of these is for the Sun's longitude near to 0° and the other for 180°. We choose the one which suits in that it shows that the Moon was on the foresight in darkness.

The same arguments apply to the greatest south declination but here the longitude of the Moon is 270°.

The above deals with the cases $\pm (\epsilon \pm i \pm s \pm \Delta)$ in which Δ and i are of the same sign, but if we wish to consider a foresight that we think has been used when Δ and i are of opposite sign then we have to put the node in quadrature with the Sun,[3] and we find that the Sun's longitude is near to ±90°, and this is at the solstices.

The Greenwich Calculations

It was realized that without definite information regarding the Moon's declination and parallax throughout the first half of the second millenium it was not possible to get much further in an assessment of the suggested lines. Thanks to the good offices of the staff of The Nautical Almanac Office at the Royal Greenwich Observatory, we now have in full detail the information we needed. To calculate all the necessary values seemed a very long task, but Dr A. T. Sinclair found a somewhat simplified method which on examination gave values which agreed closely with those from the full theory. Nowhere in fact does the difference attain a value of 1 arc minute. Figure 6 shows how the monthly declination maxima behave near to a standstill. With no perturbation the maxima would have lain on a smooth curve coming to its greatest value when the node of the orbit was at the First Point of Aries. Greenwich provided us, from 2100 to 1300 B.C., with particulars of the Moon's position for times *A*, *B*, *C* and *D*, including longitude, declination and parallax of the Moon and longitude of the Sun. There is, as has been already explained, an important difference between *A* and *B*. One of these happens near the vernal equinox and one near the autumnal equinox. Similarly for *C* and *D*; one happens near Midsummer and one near Midwinter.

After consideration it was decided to present in this paper, in a manner which we shall now describe, such of the Greenwich results as we require. All the field measurements in Table 1 have been reduced to give the declination δ_0 of the foresights by using mean parallax (57'·0). Put the parallax $p = 57'{\cdot}0+q$. Had we used p instead of 57'·0 to deduce the declination, the result would have been $\delta = \delta_0+q\partial\delta/\partial p$. But $\partial\delta/\partial p$ is equal to $\partial\delta/\partial h$, where h is the altitude.

This can be evaluated by using the appropriate formula,[4] and for any particular case of $\pm (\epsilon \pm i)$ it is found to be sufficiently accurate for our present purpose to use a mean value from one end of Britain to the other, 0·95 at Major Standstills and 0·86 at Minor. Note that when we know p we also know s, the semi-diameter; in fact $s = 0{\cdot}2725p$.

Let D be the appropriate value of the declination given by Greenwich. We want to compare δ (that is, $\delta_0 + q\partial\delta/\partial h$) with $D \pm s$ or, what is the same thing, to compare δ_0 with

$$D_0 = D - q\partial\delta/\partial h \pm s.$$

Accordingly we evaluate D_0 for all the required cases and present it in such a form that we can see at a glance if the value of δ_0 found at any foresight is sufficiently close to D_0 at some or other standstill or range of standstills to make it possible that the backsight and foresight were arranged at that date.

To have all the Greenwich values of D ready to be used on any possible foresight we need to present many sets of derived values of D_0; but for Brogar we shall need only five and these are shown in Figure 7. The apparent scatter of the points is produced partly by the varying time interval between the time of the actual declination maximum and the time when the node was at the equinox, *i.e.* at the time on top of the dotted line in Figure 6. It will be seen that there is a long period sinusoidal oscillation in all the curves in Figure 7. This is produced by the peculiar manner in which lunar parallax affects the results. By extending for several thousand years the method of argument given in *Megalithic lunar observatories*[5] we found that the oscillation has a period of about 65,456 days and this agrees in broad outline with the values provided by Greenwich. The actual amplitude is, however, rather smaller than that shown in *Megalithic lunar observatories*. Note that the values of D_0 in Figure 7 are all falling gradually with a slope of 38″ per century, *i.e.* the rate of decrease of the obliquity.

A More Realistic Examination of the Brogar Backsights

Some of the lines tabulated in Table 1 may be subject to criticism. We now propose to select for examination the four or five which seem to be the most convincing. Line JK points unequivocably to Hellia and if it gives $-(\epsilon - i)$ then L to Hellia gives $-(\epsilon - i + s + \Delta)$. This rules these out as backsights for Kame, which is shown by the line KL_2B. Hence we adopt L_2 as a backsight for Kame and since L_2 shows $(\epsilon + i + s + \Delta)$ with the lower foresight at Kame and J_2 shows the same value with the upper we shall accept these two. We must accept the Comet stone for Mid Hill and we might also take the line MLL_2J to Mid Hill.

In our second paper on Stonehenge[6] we showed how one of the rays grazed the ground at a ridge and in the evening suffered a bend of about 2 arc minutes. All the rays at Brogar (and in fact anywhere) graze a ridge at the foresight, and so we ought to increase the normal astronomical refraction by an amount which at present can only be estimated but may be important. The greater the length of the ray passing close to the ground, the greater will be the effect. In the absence of information we propose to adjust all the values in Table 1 by 1 arc minute.

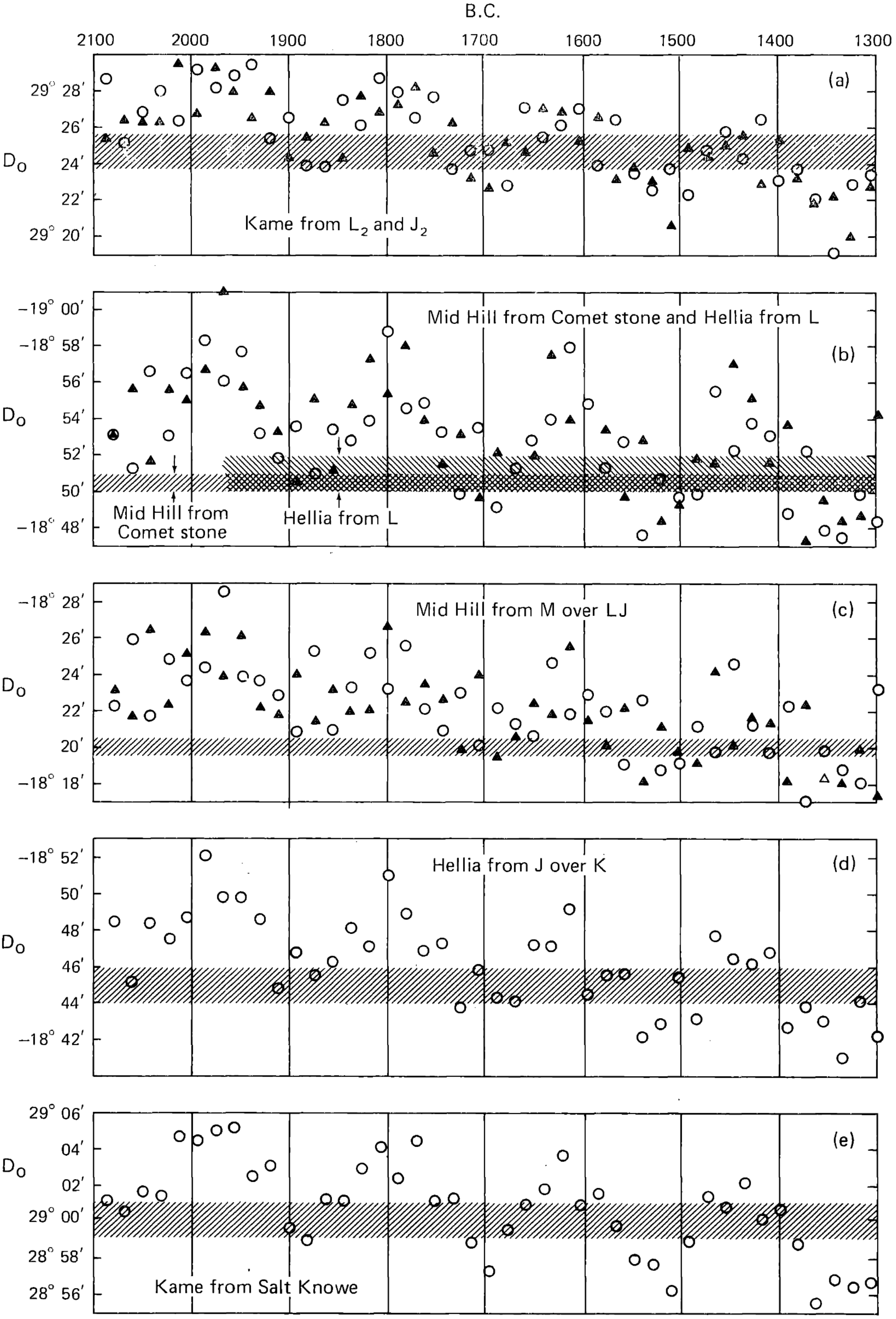
B.C.
2100
2000
1900
1800
1700
1600
1500
1400
1300
(a)
Kame from L2 and J2
29° 28′
26′
24′
22′
29° 20′
D0
(b)
Mid Hill from Comet stone and Hellia from L
−19° 00′
−18° 58′
56′
54′
52′
50′
−18° 48′
Mid Hill from Comet stone
Hellia from L
(c)
Mid Hill from M over LJ
−18° 28′
26′
24′
22′
20′
−18° 18′
(d)
Hellia from J over K
−18° 52′
50′
48′
46′
44′
−18° 42′
(e)
Kame from Salt Knowe
29° 06′
04′
02′
29° 00′
28° 58′
28° 56′

FIG. 7(a). Kame from L_2 and J_2 compared with
○ $(\epsilon+i+s+\Delta)$ autumn 8 p.m. Longitude of Moon approx. 90°, Longitude of Sun approx. 180°
▲ $(\epsilon+i+s+\Delta)$ spring 8 a.m. LM approx. 90°, LS approx. 0°

FIG. 7(b). Mid Hill from Comet stone compared with
○ $-(\epsilon-i+s-\Delta)$ autumn 3 p.m. LM approx. −90°, LS approx. 180°
▲ $-(\epsilon-i+s-\Delta)$ spring 3 a.m. LM approx. −90°, LS approx. 0°
and Hellia from L compared with $-(\epsilon-i+s-\Delta)$ autumn 9 p.m. and spring 9 a.m.

FIG. 7(c). Mid Hill from M ground level over L and J compared with
○ $-(\epsilon-i-s-\Delta)$ spring 3 a.m. LM approx. −90°, LS approx. 0°
▲ $-(\epsilon-i-s-\Delta)$ autumn 3 p.m. LM approx. −90°, LS approx. 180°

FIG. 7(d). Hellia from J over K compared with
○ mean of { $-(\epsilon-i-\Delta)$ autumn 9 p.m. LM approx. −90°, LS approx. 180°
$-(\epsilon-i+\Delta)$ summer 3 a.m. LM approx. −90°, LS approx. 90° (Full Moon)

FIG. 7(e). Kame, lower, from Salt Knowe ground level, compared with
○ mean of { $(\epsilon+i-\Delta)$, winter 2 p.m. LM approx. 90°, LS approx. 270° (Full Moon)
$(\epsilon+i+\Delta)$, spring 8 a.m. LM approx. 90°, LS approx. 0°

Note. A narrower band has been used for Mid Hill because Mid Hill lines are probably less liable to be affected by the graze.

Details for the Important Lines

We show in Figure 7 the relevant values of

$$D_0 = D - q\partial\delta/\partial h \pm 0{\cdot}2725p$$

for all standstills from 2088 to 1307 B.C. calculated from the values of D and p provided by Greenwich. It will be evident from what has already been said that no two sets of values in the figures are the same, and so we give in the underlay to each figure the values of the Moon's and Sun's longitude corresponding to the particular case. For convenience we have also given the appropriate values of $\pm(\epsilon \pm i \pm s \pm \Delta)$ but it will be understood that these are nominal only since actual values of s and Δ are slightly different for every point.

We have also given the approximate hour of the phenomenon. This can be calculated exactly for any particular standstill but it is found that the Sun's longitude, and so the time, may be different by as much as 10° from the stated value. This variation is caused by the fact that the declination maximum, which occurs only once a month, may take place up to a fortnight on either side of the date when the Sun passes the node.

The declinations δ_0 in Table 1 have been calculated by using ordinary astronomical refraction, but to allow for the effect of the graze this must be increased by an amount which is, at the time of writing, rather uncertain. To draw attention to the uncertainty we have in Figure 7 used a band instead of a line to show the "observed declination", that is, δ_0 corrected as above.

Kame of Corrigall from L_2 and J_2 (Figure 7a)

There were at each standstill two possible observing opportunities for the maximum. One of these occurred on an evening in the autumn after sunset and the other in the spring after sunrise. It is possible to see the Moon rise or set on a reasonably high horizon in daylight, but it is not certain that a satisfactory observation could have been made with the Moon only about 90° from the Sun. We have, however, shown the declination for autumn and spring.

Mid Hill from Comet Stone (Figure 7b)
Since the altitude is over 2° we have again given the two possible times but the 3 p.m. rising is perhaps a little doubtful.

Mid Hill from M (Figure 7c)
This differs from the last in using the upper limb instead of the lower.

Hellia from L
Here we can use Figure 7b.

The above four lines were used near the equinoxes when the Sun rises about 6 a.m. and sets about 6 p.m. The line *J* over *K* to Hellia is not so simple.

Hellia from J over K (Figure 7d)
This line shows a declination close to $-(\epsilon - i)$. If we admit, as the evidence suggests, that this was the intended use then we must consider how the line was set out or how it was used. In the autumn two observers, one using the upper limb and one the lower, could establish a stake for the centre at $-(\epsilon - i - \Delta)$ and near Midsummer for $-(\epsilon - i + \Delta)$. Midway between the two would be the required position for $-(\epsilon - i)$.

The same method must have been used to establish the Salt Knowe to Kame line for $(\epsilon + i)$, Figure 7e, and perhaps also for the line to Mid Hill from Thomas's cairn.

Lines for $\pm(\epsilon \pm i)$ *in general*
The reason for having one or other of these declinations marked is discussed in *Megalithic lunar observatories*;[7] these were used at several of the important observatories, for example, at Temple Wood, Dirlot, Fowlis Wester and Lundin Links. So we need not be surprised to find at Brogar two lines for $-(\epsilon - i)$ and one for $+(\epsilon + i)$, as detailed above.

We have assumed in the above that only the extreme declination maxima were observed. It is, however, unlikely that the observers would have had more than a general idea of the date of the expected maximum, and so they would have begun work long before and tried to observe every monthly maximum before and after the extreme. This would also have had the advantage of training the assistants in the technique of observing.

A method of extrapolating to each *monthly* maximum was essential and had been developed.[8] Every month's work would have left an extrapolated stake on the ground and so if bad weather interfered at the extreme maximum there would not have been much difficulty in estimating the ground position. The solution of the case of a missing monthly maximum involved only small movements corresponding to 2 or 3 arc minutes.

No detailed study has yet been made of the conditions (daylight or dark) which obtained at the time of the monthly maxima on each side of the absolute maximum, but it is not thought that these would have presented any serious difficulties to the observers.

Date of the Cairns

Let us assume that we have underestimated the effect of the graze on refraction. Then in Figures 7a and 7e the band covering the corrected observed declination δ_0 ought to be lowered and in Figures 7b, 7c and 7d it should be raised *on the figures*. Unless this additional correction is large, say 2′, any conclusions are not seriously affected.

An examination of Figure 7 shows that no definite date is indicated. On the assumption that the backsights were erected following observations made over a short period of say 30 years, then we see that the date might have been 1700, 1500 or 1400 B.C. If, however, we believe that the backsights were placed to show a mean position obtained as a result of observations spread over a time interval nearly equal to a parallax period of 178 years, then the earlier dates are excluded and we think of 1600 to 1400 B.C.

The difficulty in giving a date arises from three considerations: (a) the wide range of apparent declination D_0 produced by parallax, (b) the very slow rate of fall of the obliquity, and (c) the uncertainty of the effect of the graze on refraction. The method of presenting the results which we have used makes it easy to adjust the bands should further information on the effect of the graze become available.

We have treated Brogar in isolation, but obviously the knowledge we now have regarding actual lunar declination, *etc.*, ought to be applied to other sites we have measured in Britain and France, to see if a coherent pattern can be discerned.

Archaeologists so far have neither dated the site nor given an estimate of the period of time throughout which it was occupied. To judge by Stonehenge this period may have been many centuries. The high ground inside the ring may have been used for general observation of the major and minor standstills at an early date without any attempt to observe the perturbation in detail. Later, as more refined methods appeared necessary, the cairns and the Comet stone may have been erected. Nothing we have so far seen at the site contradicts this surmise. We must continue to hope that other methods will eventually provide accurate dating of the ring and of the cairns. This might allow us to come to more definite conclusions about the erectors' method of working.

The Residuals in Table 1

It will be noticed how closely the observed values of the declinations (δ_0) in Table 1 agree with the 'nominal values' δ_n built up from ϵ and mean values of i, s and Δ. The effective value of Δ is in general slightly different from the assumed mean (8′·7), and so it is inadvisable to attempt any statistical examination of residuals.

When we look at the scatter of the actual known values of the 'apparent' declination D_0 in Figure 7 we realize that residuals in Table 1 are much smaller than we would expect. There are four possible explanations of this unexpected agreement:

(1) pure chance;
(2) our choice of backsight was unduly influenced by prior knowledge of the expected declination;
(3) the erectors worked for 100 to 200 years before finally placing the backsights; or
(4) their knowledge was much greater than we are yet prepared to admit.

The second alternative may explain some of the results but cannot explain them all. If we accept (3) or (4) then concomitantly we admit the effect of interchange of information with other observatories.

Solstitial Rising of Sun

It may be mentioned that the two small upright slabs beside the Comet stone lie with their axes along their own line at an azimuth of about 41°, which, with the measured altitude of the hill horizon, gives the declination of the solstitial rising Sun. Unless some foresight can be found on the horizon, which is over 5 miles distant, no use can be made of this line.

Conclusion

We consider that the results obtained go far to substantiate our claim that the Brogar site shows that the erectors had eventually developed an accurate method of observing the movements of the Moon at the standstills. The importance of the site is such that much further work should be done to extend our measurements, and we hope that archaeologists will investigate in detail this and other sites in the immediate neighbourhood.

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2. A. Thom, *Megalithic lunar observatories* (Oxford, 1971), 18.
3. *Ibid.*
4. Thom, *Megalithic lunar observatories*, 2.6.
5. Thom, *Megalithic lunar observatories*, Figure 7.2.
6. A. Thom, A. S. Thom and A. S. Thom, "Stonehenge as a Possible Lunar Observatory", *Journal for the history of astronomy*, vi (1975), 19–30.
7. Thom, *Megalithic lunar observatories*, p. 86.
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