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A MEGALITHIC LUNAR OBSERVATORY IN ORKNEY: THE RING OF BROGAR AND ITS CAIRNS

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The Ring

The Orkney Islands are rich in archaeological sites of many kinds and periods, but perhaps the most impressive is the Ring of Brogar (see Figure 2). It stands in a commanding position on the peninsula that separates Loch of Harray from Loch of Stenness on the Mainland of Orkney, so that the stones forming the circle can be seen from far and near. The stones consist of flat slabs up to 15 ft high placed along the circumference of a true circle. As the average thickness of the slabs is not much over nine inches it is possible to

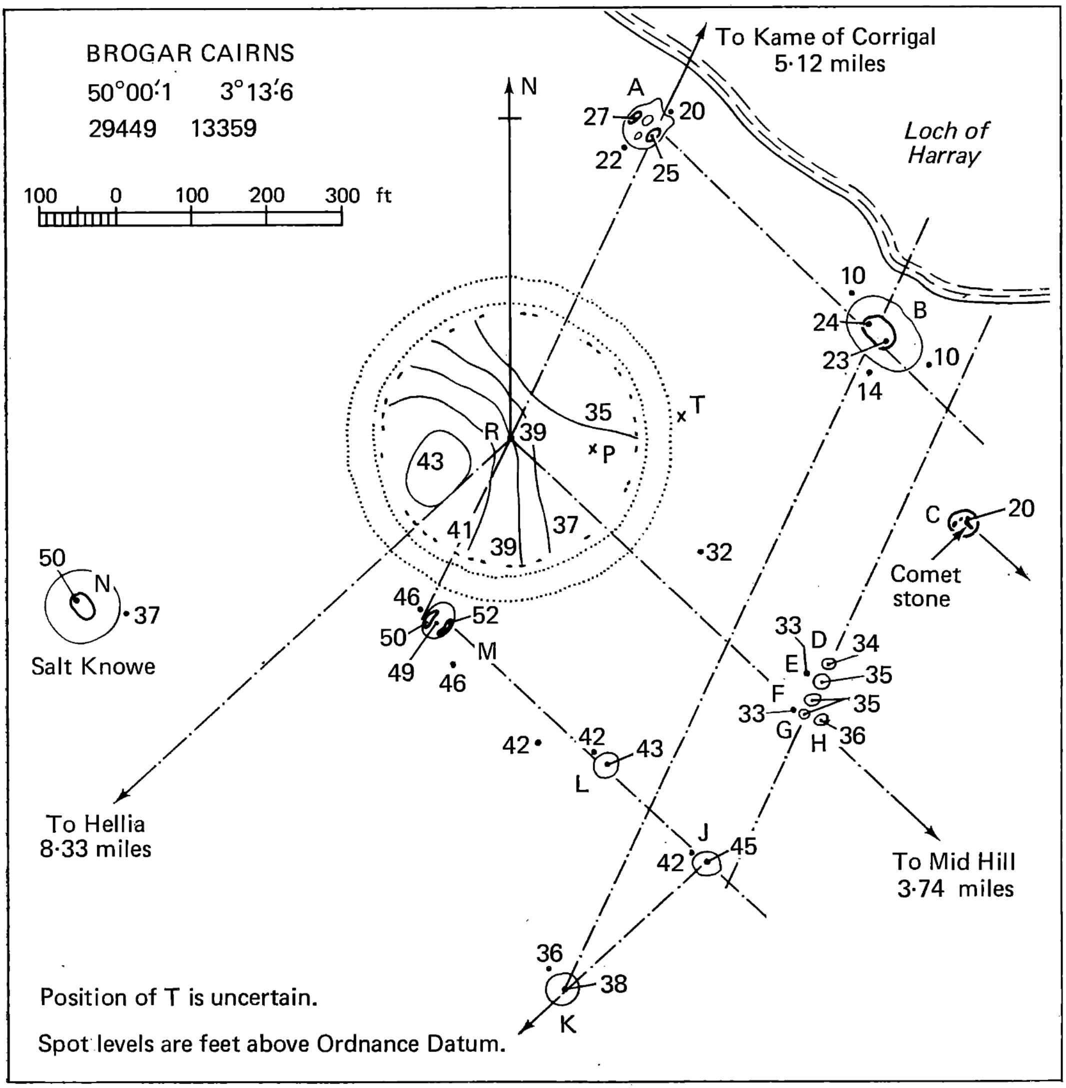


FIG. 1. The cairns surrounding the Ring of Brogar.

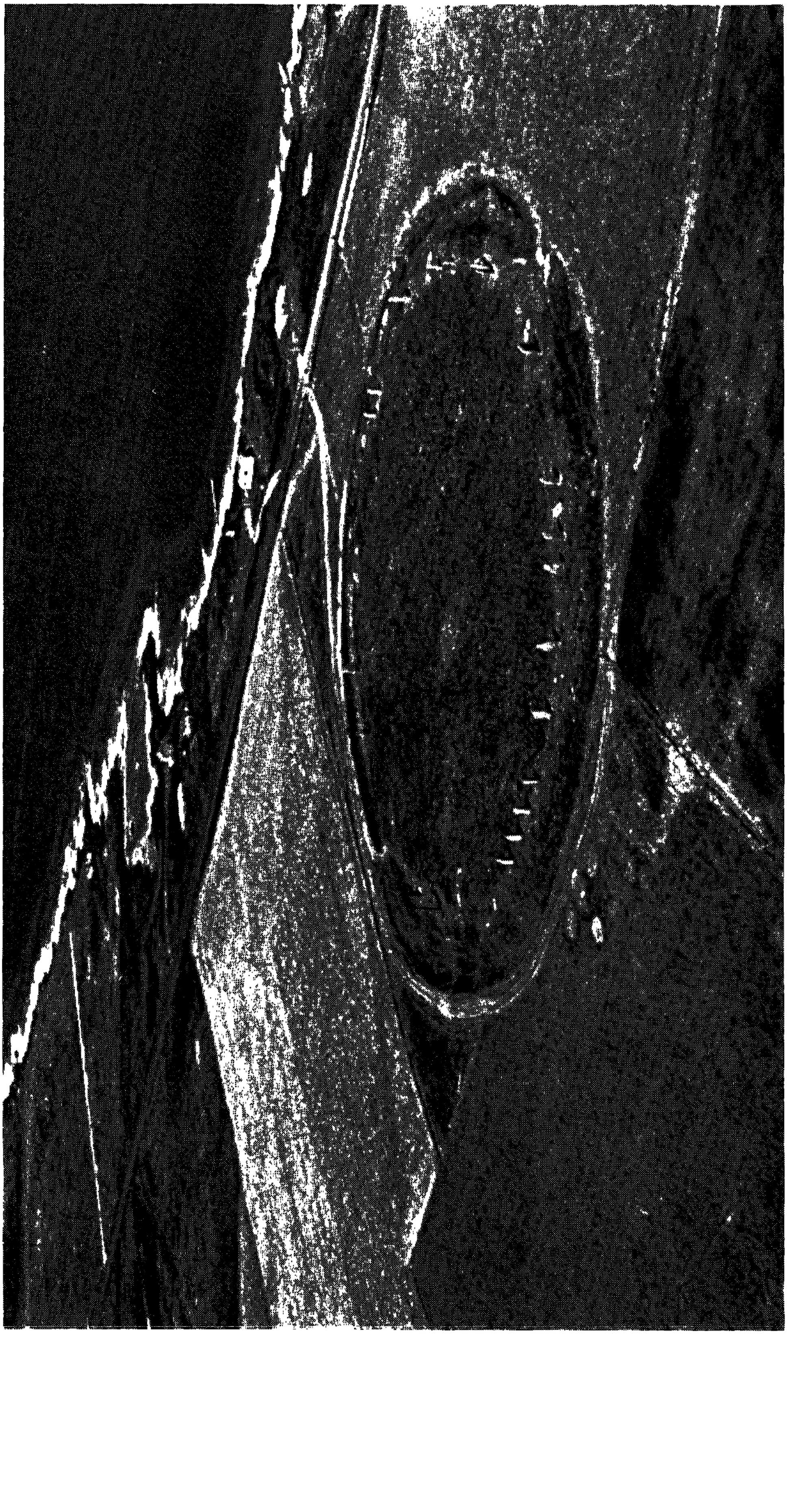


FIG. 2. The Ring of Brogar (Crown Copyright reserved).

TABLE 1. Determination of the declinations from the Brogar backsights.

Foresight	Backsight	Height O.D., feet	Azimuth	Altitude	Declination δ_0	"Expected" Declination δ_e			Residual $r = \lvert\delta_0\rvert - \lvert\delta_e\rvert$
Hellia, small notch	*J* over *K*	42	227° 47′·2	65′·0	−18° 45′·1	$-(\epsilon-i)$	=	−18° 44′·2	+0′·9
	L	42	227 32·8	65·0	−18 51·0	$-(\epsilon-i+s-\Delta)$	=	−18 51·0	+0·0
	M	46	227 09·7	64·8	−19 00·2	$-(\epsilon-i+s)$	=	−18 59·7	+0·5
Kame of Corrigall	*N*, Salt Knowe, top	55	26 37·4±1	60·1	+28 54·2	$+(\epsilon+i-s+\Delta)$	=	+28 54·8	−0·6
	Ridge, over *RA*	46	25 46·0	61·4	+29 09·0	$+(\epsilon+i+s-\Delta)$	=	+29 08·4	+0·6
	Ridge, over *GFED*	42	24 41·5	61·8	+29 25·8	$+(\epsilon+i+s+\Delta)$	=	+29 25·8	+0·0
Mid Hill	Cairn *A*, ground level	21	135 20·9	124·1	−18 59·0	$-(\epsilon-i+s)$	=	−18 59·7	−0·7
	Cairn *B*, top	28	135 24·8	125·5	−18 59·2	$-(\epsilon-i+s)$	=	−18 59·7	−0·5
	Comet stone	20	135 07·2	128·5	−18 49·5	$-(\epsilon-i+s-\Delta)$	=	−18 51·0	−1·5
	Thomas's cairn, position uncertain	30±	134 39±	124·5	−18 43±	$-(\epsilon-i)$	=	−18 44·2	—
	Cairn *M*, top	57	133 25·5	119·4	−18 19·0	$-(\epsilon-i-s-\Delta)$	=	−18 20·0	−1·0
	Cairn *M*, ground level over *LJ*	46	133 27·8	120·1	−18 19·1	$-(\epsilon-i-s-\Delta)$	=	−18 20·0	−0·9
Hellia, slope, top of cliff	Centre of ring, *R*	39	227 19·0	60·0	−18 59·5	$-(\epsilon-i-s)$	=	−18 59·7	−0·2

The values used to calculate the expected declinations are

Obliquity of ecliptic	$= \epsilon$	= 23°52′·9
Inclination of lunar orbit	$= i$	= 5°08′·7
Moon's mean semidiameter	$= s$	= 15′·5
Mean perturbation of i	$= \Delta$	= 8′·7

The value of ϵ was chosen to give small residuals for most of the lines. In forming the residuals, all declinations are taken positive so that each residual is a correction (given by that line) to the assumed ϵ.

obtain statistically an accurate diameter, and this turns out to be within an inch or two of 125 Megalithic yards, *i.e.*, 50 Megalithic rods (1 rod = $2\frac{1}{2}$ my).[1] The ring is surrounded by a trapezoidal ditch with an average width at the top of 5 rods. Between the stones and the edge of the ditch there is a berm with a mean width of $1\frac{1}{2}$ rods.

The ground on which the ring stands is by no means level; it rises considerably towards the west. A more level site could have been found, and so some other conditions presumably controlled the positioning of the ring. As we shall see, the conditions were stringent and difficult to meet. In fact the circle and the small cairns close to it form a lunar observatory from which the Moon was observed on three foresights.[2] In general, given two natural foresights, it is possible to find a position for a backsight from which the foresights can be used to show the setting or rising points of two celestial bodies. Consider observing the Sun setting behind a hill. We can see the phenomenon from anywhere along a line passing through our position and the foresight (the hill). Suppose there is another hill and another body; then there will be another such line across the country. *Provided the terrain permits,* a backsight can be placed where the lines cross and this will serve for both foresights. But it will be only by chance that this backsight can serve for a third foresight. Apparently the Ring of Brogar is in such a position that the required backsights for *three* foresights could be placed in its immediate neighbourhood.

The Cairns

We made a tacheometric survey of the cairns surrounding the ring (Figure 1) to a scale of 1 : 1250. It agrees closely with the 1 : 2500 Ordnance Survey but we have added spot levels at various places and contoured the inside of the ring. In 1849 Thomas[3] surveyed the whole area and he shows a small cairn at or near *T*. This is neither on the Ordnance Survey nor on our survey, but perhaps a careful examination of the ground might show some trace. Thomas speaks of cairn *A* (of which he shows an elevation) as being like a plumcake and says it ". . . rises nearly perpendicular for five feet when it becomes almost flat on the top . . . surmounted by a very depressed cone", but unfortunately, within living memory, the soil in the middle was dug out to act as binding for the new road. Obviously cairn *M* has suffered a similar fate. We were told locally that about the same time the top of *B* had been removed, but if this is correct the top has been left flat. Thomas also speaks of the large cairn called Salt Knowe being 50 ft in height and 29 ft in diameter. This makes sense only if we read it as 50 ft above sea level and 29 ft diameter at the top. The other cairns are now like very flat inverted saucers with heights from 1 to 2 ft, but Thomas speaks of them as being bowl shaped.

From Figure 1 it can be seen that, with the exception of the Salt Knowe, the cairns form lines at azimuths of about 26°, 135° and 227°. The standing stone called the Comet Stone is a flat-sided slab and so allows its orientation to be determined as 135° ± 2°, which agrees with the azimuth of the lines *MLJ* and *AB*. Accordingly the horizon at these three azimuths was examined and accurately measured from eye level at the centre of the circle where several astronomical time/azimuth sets had been observed to the Sun.[4] The profiles are shown in Figure 3. At Kame of Corrigall (Figure 3a) the horizon rises smoothly to the top, but at one place there is a short steeper part which, as the figure shows, has the same slope as the apparent path of the Moon when it rose with its maximum declination at the major standstill.[5] At Mid Hill (Figure 3b) the horizon likewise rises smoothly but the notch here is shorter and sharper so that it defines an accurate declination of the Moon at the minor standstill. The other notch (Figure 3c) is that above the very prominent cliffs at Hellia in the island of Hoy.

With a knowledge of the azimuth and altitude of these marks from the centre of the ring, it is easy to estimate the values as seen from any nearby point *X* provided the three coordinates of *X* are known relative to the centre (*R*). The declinations as seen from *X* can then be calculated. There is, it is true, a slight uncertainty introduced, in that we need to use the distance from the centre to the foresight, and when we move to *X* the shape of the foresight may change slightly in so far as it is not a two dimensional profile. The effect of this is not always negligible and it would be more satisfactory if the profiles were measured astronomically from each position. Columns 4 and 5 in Table 1 give the particulars of the azimuth and altitude calculated from the horizontal coordinates as taken from Figure 1 and the heights shown in column 3. For the summits of *A*, *B*, *M* and *N*, the heights can only be estimates because (as explained above) the tops of these cairns were certainly higher than they are today. The declinations (δ_0) deduced in Table 1 are believed to be within one arc minute of the truth.

Table 1 gives, for comparison with the observed value of declination, δ_0, the value of $\delta_e = \pm(\epsilon \pm i \pm s \pm \Delta)$ which lies nearest to δ_0. It is convenient to call δ_e the 'expected declination'.

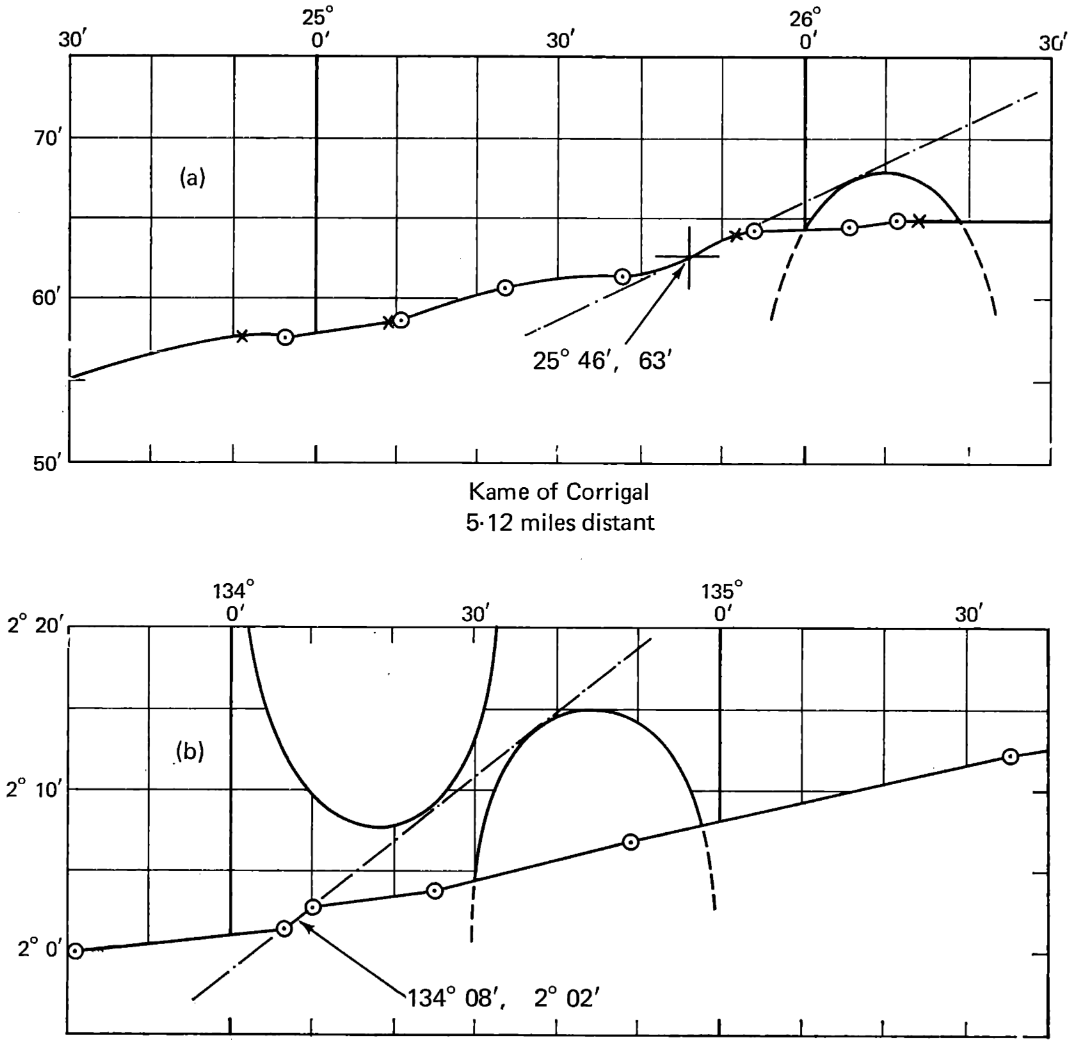
We shall now consider each foresight separately, bearing in mind that to use an observatory satisfactorily[6] with the Moon rising or setting well away from the meridian, the observer must be able to move easily along a line nearly at right angles to the line of sight.

Backsights for the Hellia Notch

Looking at Table 1 we see that each of the cairns *J*, *L* and *M* gives one of the expected values for an observer standing at ground level. These sites lie on a straight line along the nearly level ridge that forms the top of the high ground, and so they provided ideal positions for the observer as he ranged himself into position with the Moon on the foresight. Positions *M* and *L* are both for the lower limb but since *J*, looking over *K*, shows $-(\epsilon - i)$, the observations here were probably made by two observers, one using the upper limb and one the lower. *J* would then be used with the position midway between.[7]

Backsights for Kame of Corrigall

If the same ridge were used for the backsights, then an observer standing on the line and looking over the centre *R* would be in the position for $(\epsilon + i + s - \Delta)$. Similarly an observer looking over *GFED* would obtain $(\epsilon + i + s + \Delta)$, and since this is the greatest possible declination there would be no stations further south for this foresight. Obviously, since cairns had been placed on the ridge for use as backsights for Hellia, confusion would have arisen if further cairns had been built for Kame of Corrigall. This may explain the peculiar manner in which these two Kame of Corrigall lines are indicated. Alternatively, we might assume that the builders intended all three cairns, *M*, *L* and *J* to serve



Kame of Corrigal
5·12 miles distant

Mid Hill
3·74 miles distant

as backsights for Kame of Corrigall as well as for Hellia; this makes the residuals in Table 1 larger but has very little effect on the overall mean. The top of the Salt Knowe seems to have been a backsight for the Kame foresight but the restricted movement here makes it difficult to understand how it was used.

Backsights for Mid Hill

Some seven hours after the Moon rose on Mid Hill it set on Hellia. Nevertheless it would be an advantage to have both foresights. The declination had changed slightly during the seven hours and it might be nearer the maximum. Also, if the weather or daylight prevented one foresight being used, conditions for the other might be better. The orientation of the Comet Stone and the declination it gives shows it to have been a probable backsight for $-(\epsilon - i + s - \Delta)$. Other possible positions on the ground level are cairn *A* and Thomas's cairn *T*. The line *MLJ* indicates the notch on Mid Hill and it is in such a position that it gives the extreme case $-(\epsilon - i - s - \Delta)$. Like *GFED*,

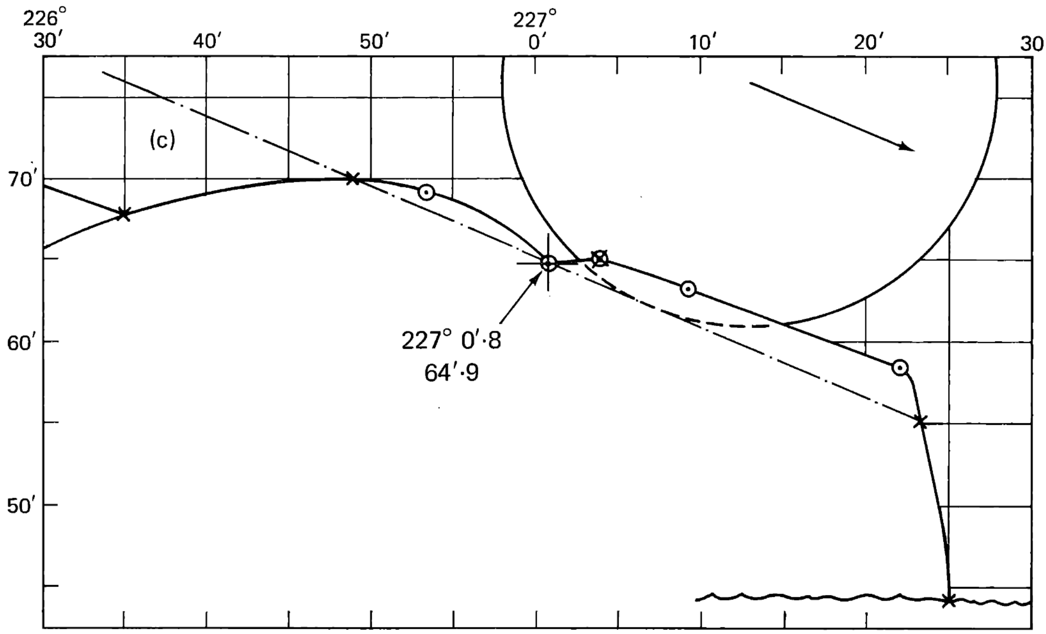


FIG. 3. Measured profiles at the three foresights as seen from the centre of the Ring of Brogar.
(a) Horizon at Kame of Corrigall; Moon rising at major standstill north declination.
(b) Horizon at Mid Hill; Moon rising at minor standstill, south declination.
(c) Horizon at Hellia, Hoy; Moon setting at minor standstill, south declination.
(Points marked with rings and crosses were measured on different days.)

it showed a limit; there could be no other backsight for Mid Hill further to the south-west. But why are nearly-exact declinations obtained also from the tops of cairns *M* and *B*? Perhaps these stations were used in some way which we have not understood. Did a man stand on *M* to give warning that the upper limb was about to emerge, or was *M* made large simply because it was thought that it served all three backsights?

There is cultivated land adjacent to the ring on the north-west side and so we cannot exclude the possibility that there may have been other cairns there for some of the missing backsights for Hellia and Kame; indeed, the small cairns are so vulnerable to cultivation that it is surprising that so many of them still exist. Inside the ring itself there are several *small* stones which seem to be earth-fast. Most are not far inside the ring but there is a group of three in the position marked *P* on Figure 1. These may be superficial, but they are worthy of examination since they give with Mid Hill one of the expected declinations to within an arc minute. The difficulties which the erectors had to overcome before they succeeded in establishing the backsights were very great. Foremost amongst these difficulties was the problem of extrapolating from two or perhaps three nights' work to the final ground position corresponding to the maximum declination for that particular lunation. Only occasionally would the maximum occur at the time of the rising or the setting of the Moon.

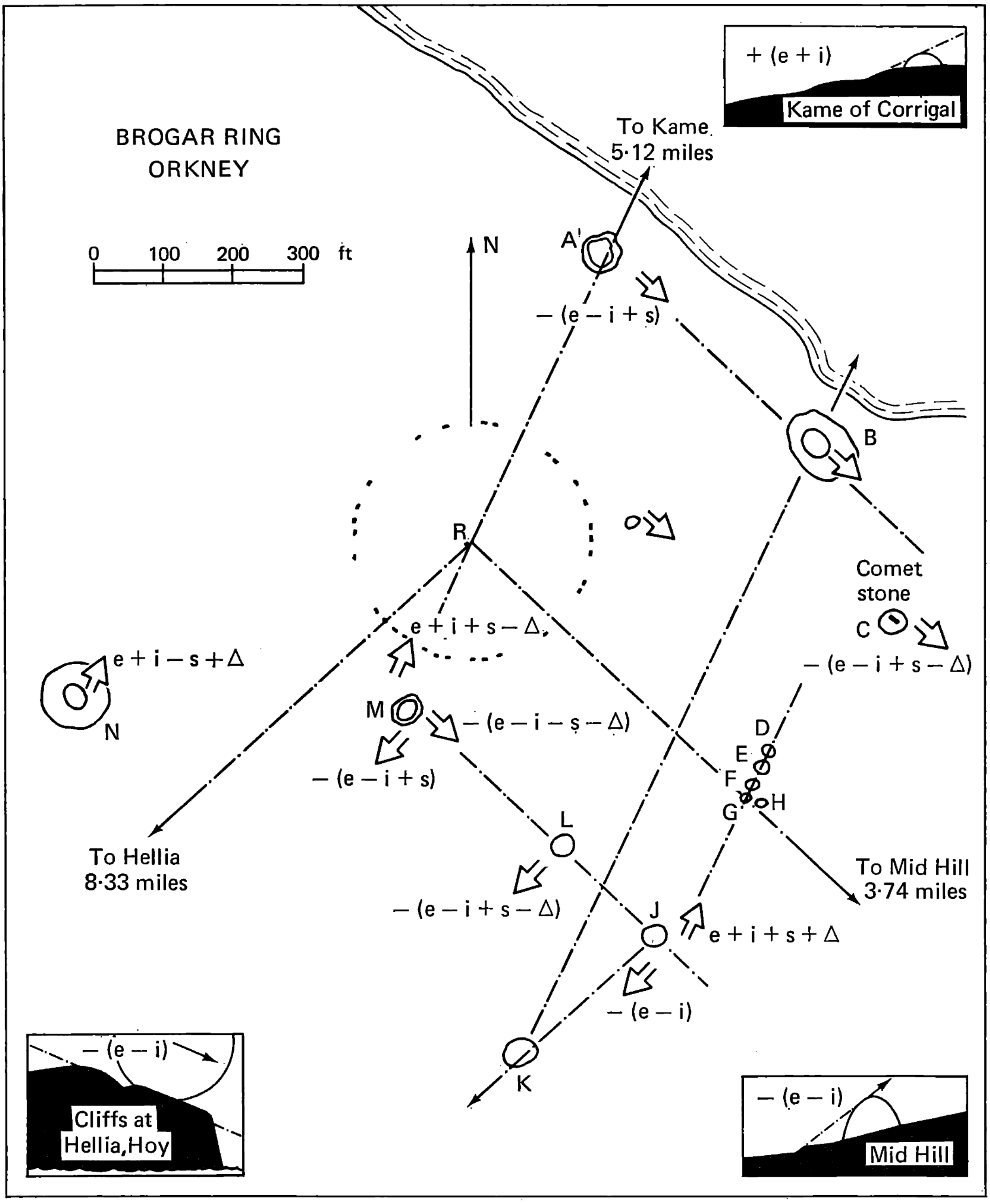


FIG. 4. Schematic indication of the ideal positions for an observer near the Ring.

How well they succeeded is perhaps best seen in Figure 4, which shows by thick blunt-arrow heads the ideal positions from which the expected declinations would be obtained. Note how very close the arrows are to the cairns or other indicated positions. When we remember that for any foresight there was an interval of 18·6 years between each observing period and when we think of the difficulties which had to be overcome, we wonder how long it took to establish this observatory and how much effort was involved.

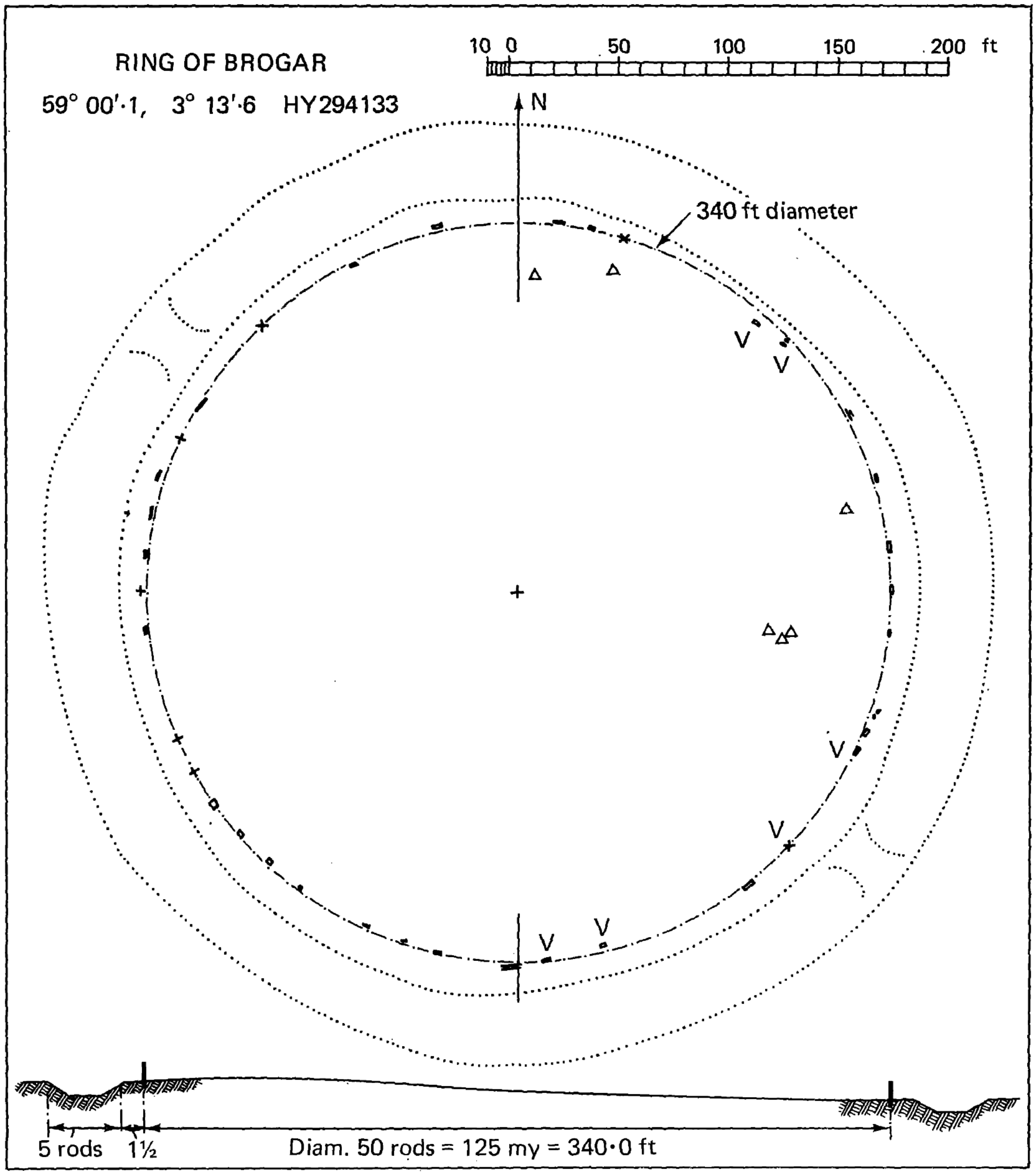


FIG. 5. The Ring of Brogar. The stones marked by Thomas as "prostrate" for which he does not also show a stump are marked *V*; small stones inside the ring are marked Δ; stumps are marked +.

The Declinations

We have given the declinations in Table 1 to one-tenth of a minute, but only a few can be known to this accuracy. For example, for Mid Hill it needs a horizontal movement of only 14 ft to produce a declination change of an arc minute, and it will be seen that cairn *A*, for example, does not now define an observer's position to this accuracy. Even if it did, there is the Megalithic observer's personal equation to be considered. At night the hill outline is not clearly seen till it is silhouetted on the Moon's disc. If the lower limb was used, an overlap of perhaps a minute was necessary before the observer could be sure that the notch was being touched. This perhaps explains the negative values for the residuals in the three cases where at Mid Hill the lower limb was used. At Hellia the observer probably kept the limb just above the bottom of the notch because otherwise he would be liable to place it too low. This practice would tend to make the declination (δ_0) observed by us higher numerically than the expected declination (δ_e). It must be pointed out that we cannot be certain which of the two notches at Hellia was used by the erectors. Before a final decision can be made it will be necessary to measure the larger notch to the left in Figure 3c from each of the positions *J*, *L* and *M*. One side of the notch is about half-a-mile further away than the other, and so estimates of the azimuth and altitude of this notch based on our measurements made at the centre of the ring cannot be reliable. These estimates have however been made, but they did not show as good consistency or agreement as the values for the small notch.

The Obliquity of the Ecliptic

If we know i, s and Δ, then a residual $+ r$ (Table 1) can be made zero by adding r to the assumed value of ϵ. We can therefore treat the residuals as observed corrections to ϵ. Since the mean residual is small, no further adjustment of ϵ is indicated. It does not seem possible to explain what we find at Brogar by using any value of ϵ differing greatly from 23° 52′·9 ± 0′·7. It will be seen that each foresight independently shows a small mean value of r, and while it might be possible to choose a different part of the Hellia profile as the foresight, there are no alternatives to the points used at Kame and Mid Hill.

The date corresponding to the above value of ϵ is about 1560 B.C. ± 100, but this is subject to the reservations explained elsewhere regarding the peculiar manner in which lunar parallax affects the result.[8] The nearest solstitial site which has been accurately measured is that at Cnoc an Maranaich (map reference ND 131332) in Caithness. Here, high up on a ridge, stands a large cisted cairn and nearby is an 8 ft high standing stone, 3½ ft wide by 1 ft thick. It indicates unequivocally a flat V-notch some 4 miles distant. Careful and repeated measurement shows that the declination indicated by this notch is 24° 09′·0 ± 0′·5. Taking appropriate values of semidiameter and parallax,[9] we see that this line was for the upper limb of the Sun when it set with declination 23° 53′·1 (1590 B.C. ± 70).

This supports the hypothesis that accurate observatories, solar and lunar, were built in the north of Scotland at a later date than in Argyllshire.

The Circle

A survey of the ring (Figure 5) was made in 1971 to a scale of 1:240. This proved so interesting that it was decided the following year to make a new survey using steel tapes. The distance of each corner of all the stones was measured from the centre, with allowance for ground slope where necessary. This new survey agreed with the previous year's plan, showing that there were no gross errors. In Table 2 the mean radius to each stone is expressed as $R = 170{\cdot}0 + r$ ft, and the azimuth is written $(6n + \beta)$ degrees where n is an integer. It will be seen that β is generally small, which shows that the stones were intended to be 6° apart starting from geographical north. Application of Broadbent's analysis gives a probability level of about 0·05% for this hypothesis. The mean

TABLE 2. The Brogar Ring

The position of a stone is given by (R,θ) where $R = 170{\cdot}0 + r$ feet and the azimuth θ is written $(6n + \beta)$ degrees, where n is an integer.

n	β	r	Mean r for quadrant	Height (ft)
1	+0·4	+1·0		3
2	−0·5	+0·5		stump
3	−0·9	−0·5		stump
7	−0·2	−6·0		7½
8	−0·8	−4·6	0°−90°	8½
10	+1·5	+1·0		stump
12	−0·3	+1·3	−0·74±0·87	12
14	−0·6	+0·2		5
15	+0·4	+0·4		10
16	+0·9	+0·3		7
18	+1·7	?		stump
19	−1·4	+0·9		9½
20	−4·1	+0·4	90°−180°	10
22	+1·8	+0·0		stump
24	−1·6	+1·4	0·00±0·48	11
28	−1·2	−2·9		10
29	+1·8	−0·1		11
30	+1·0	+2·0		12
32	+0·7	0·0		12
33	+0·5	−0·6		5
34	+0·7	−1·8		10
36	+0·6	−1·7	180°−270°	9
37	+0·5	−1·6		9
38	+1·2	−1·4	−0·48±0·41	9
39	+1·4	−0·6		9
40	+0·1	?		stump
41	+1·0	−0·4		stump
44	+0·7	+1·3		3
45	+0·2	+2·1		stump
46	+0·4	+1·4		15
47	+0·7	+1·7	270°−360°	stump
48	+0·7	+2·8		6
49	+1·2	+0·6	+1·26±0·56	stump
50	+1·6	−0·4		stump
53	−1·1	+0·9		stump
56	−2·0	−0·4		10
58	+0·1	+2·6		13

Overall mean = 0·01±0·30 ft, so diameter = 340·02±0·60 ft.

value of β is about +9 arc minutes which shows that the erectors succeeded in establishing the meridian with this accuracy. This was a remarkable feat because in those days Polaris was not near the North Pole of the celestial sphere, and we can only surmise that some form of apparatus with plumb lines was used for observing circumpolar stars. A similar accuracy was achieved at Callanish,[10] and so it is evident that in these large observatories great care was taken to establish the meridian accurately.

Table 2 also shows the mean value of r in each quadrant. Evidently the theodolite position was within a few inches of the mean centre. The mean of the four mean values of r is + 0·01 ± 0·30 ft, and so the diameter to the centre of the stones is 340·02 ± 0·60 ft. Assuming this to be 50 rods, we obtain 1 rod = 6·800 ± 0·012 ft. We know however from the survey made by Thomas in 1849 that since then some of the stones have been reerected. This unfortunate form of vandalism makes it difficult to be certain about the exact diameter. The greatest damage seems to have been done at stones $n = 7$ and $n = 8$ which are now 6·0 ft and 4·6 ft inside the ring. It can be argued that these two stones ought not to be included in the analysis. Omitting them, we find the mean diameter to be $340{\cdot}66 \pm 0{\cdot}44$ ft, making the rod $6{\cdot}813 \pm 0{\cdot}009$ ft. The values of the Megalithic yard corresponding to the above values of the rod are 2·720 ft and 2·725 ft.

A reason for using a diameter of 50 rods was probably that this gave a circumference of 157·08. The sum of the chords of 6° is $25 \times 120 \sin 3°$ or 157·01, and either of these would have been, on the ground, indistinguishable from 157, thus satisfying the rule that perimeters of Megalithic rings should be integral in rods.

The two circles inside the great Avebury ring are also 340 ft in diameter, but it is not possible to obtain from them a diameter with anything like the accuracy we have shown to be obtainable at Brogar. The value for the Megalithic yard obtained for Britain as a whole is 2·720 ft,[11] and that recently obtained unequivocally in Brittany[12] is $2{\cdot}721 \pm 0{\cdot}001$ ft; now in Orkney we find a value between 2·720 and 2·725 ft. Somehow or other Megalithic engineers were able to carry their unit from Brittany to Orkney with an accuracy of 1 in 1000. We do not know if it was carried as the yard or as the rod.

Conclusion

We do not know where the necessary extrapolation for the lunar observations was carried out. If Brogar had extrapolating sectors like those found in Caithness and Brittany[13] they would probably have been made of small stones which would in recent times have provided ideal and easily removable building material.

The ring itself probably played but a small part in the astronomical activities at the site, but for us it is very important in that it shows that the unit of length employed in setting it out was identical to within 1 part in 1000 with that used on the mainland of Britain and at Le Ménec in Brittany. To establish and to convey this unit over these distances in the second millenium B.C. must be considered a remarkable feat of metrology.

We do not know why Megalithic Man used so many lunar observatories. Probably many were earlier sites later replaced by large fully developed observatories like that discovered in the huge Er Grah site near Carnac, the sites at Temple Wood, Mid Clyth and now at Brogar. But for us the multiplicity is fortunate because eventually we shall be able to collect enough information to make possible a statistical assessment of the dates of erection. We might even be able to resolve the difficulty produced by parallax. But all the foresights will have to be measured with great accuracy and a special study made of local refraction.

Acknowledgements

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