THE JOURNAL OF NAVIGATION

VOL. 30 JANUARY 1977 NO. 1

THE DUKE OF EDINBURGH LECTURE

THE eighth Duke of Edinburgh Lecture was presented at the annual general meeting of the Institute held in London on 27 October 1976 with the President, Sir Edward Fennessy, C.B.E., in the Chair.

The Duke of Edinburgh Lectures are presented normally not more than once every two years, at the Annual General Meeting, on subjects related generally and culturally, rather than technically, to navigation. Professor Thom discusses the extent of Megalithic man's knowledge of astronomy and shows that, starting with the Sun at the solstices, a calendar was produced and a sensitive method of observing developed and applied to the much more complicated movements of the Moon in the sky. These observations showed up the effect of the small wobble of the lunar orbit due to the perturbing effect of the Sun. From Shetland to Brittany, several very large lunar observatories presumably built for eclipse prediction are to be found.

Megalithic Astronomy

Professor A. Thom and Archibald S. Thom

WHEN we started surveying Megalithic sites in Britain we used a cloth tape, but after some years it was realized that it was necessary to be more precise and now we use a steel tape for the important sites. Similarly with astronomy; at first we considered it sufficiently accurate to work to $\frac{1}{4}°$ but now we know that it is advisable to work always to within a minute of arc. This is because we have found out that the erectors of the stones sometimes used distant foresights, either artificial or natural, and by using these they could get an accuracy of better than a minute. The method of observing was for the operator to watch the edge of the celestial body grazing a foresight or running down the edge of a hill. He moved sideways until he got exact coincidence and then marked the position. This first came to our attention when we measured up the site at Ballochroy on the west side of Kintyre.[1] From these stones the upper edge of the midsummer solstitial Sun is seen to twinkle down the slope of Ben Cora towards which the largest stone is orientated. Looking along the line of the stones we see the end of Carra island and this similarly gives the position of the Sun at the winter solstice. Forty miles to the north at Kintraw there is another site giving perhaps greater accuracy than Ballochroy. The Sun, having set behind Ben Shiantaidh, just reappears momentarily in the notch to the right as seen from the Kintraw site. But for us the importance of the site lies in the fact that in order to see the phenomenon it is necessary to cross the gorge and climb the steep hillside. Here is an artificial platform along which the observer moved as he made his observations. Dr. E. W. Mackie has shown that small stones placed near the base of a small standing stone on this platform were deposited by man and not washed down from above. One day after the solstice the Sun has lost only about 12 seconds in declination, so that an observing technique has to be really precise to determine the solstice with accuracy. In fact refraction changes must have worried the observers. On the other hand, at the equinoxes the Sun's declination was changing by about 24 minutes per day and so its movement along the horizon was comparable with its diameter.

Let us consider how they could determine the equinox. Suppose they had a line which showed the position of the setting Sun on a day in the spring and suppose they had arranged matters so that this same line showed the setting Sun on a day exactly half a year later in autumn. This would not be exactly *our* equinox today because the Earth is describing an ellipse about the Sun, and a little calculation shows that the declination of the Sun which corresponded to Megalithic man's equinox was about $+\frac{1}{2}°$. This is most fortunate for us because we find that the half dozen equinoctial lines for which we have particulars give a declination with a mean value of about $\frac{1}{2}°$. This is most encouraging. It shows us that we are on the right track towards deciphering the calendar. Suppose we now calculate the Sun's declination at a time midway between the winter solstice and the spring equinox. We find that it is about 16·2°. Very close to this declination we find a number of lines (MSB Fig. 9.2).[2] This is about the date of Martinmas and Candlemas. Similarly for the May Day and Lammas declination we find a group of lines but with rather less accuracy. Thus we have established eight of Megalithic man's calendar dates. Proceeding in the same way we find that altogether he divided the year into sixteen parts which we shall call months. These months were either 22 or 23 days long and we believe that we know which months were 22 and which were 23. I do not want to spend any more time on the calendar but wish to pass on to a much more interesting subject, namely Megalithic man's knowledge of the Moon's movement.

In a lunar month the Moon's declination passes from maximum positive declination to maximum negative and back again. The limits of movement are not constant however, but go through a long period oscillation occupying 18·6 years. This is the period of the rotation of the nodes of the lunar orbit that is inclined to the ecliptic at an angle $i = 5° \ 08{\cdot}7'$. Astronomers believe that this angle has remained constant for many thousands of years and we have in fact shown[3] that Megalithic man's observatories give us a value very close to this.

There is a solar perturbation on the inclination of the lunar orbit. This produces a small wobble of amplitude about 8′ with a period of 173 days or half an eclipse year. The explanation of the connexion between eclipses and the perturbation is not geometrical but depends on the dynamics of the system.

Megalithic man had no transit circles or theodolites but he observed the Moon when it was rising or setting. It is fairly obvious that the wobble in the Moon's orbit would only be apparent when the 18·6 year cycle was at its maximum or minimum. We call these the major and minor standstills.

Perhaps in the fourth millenium B.C. Megalithic man began to record the positions on the horizon of the rising and setting Moon. As his techniques became more accurate he would find that the standstill positions were not constant but that they were subject to a periodic movement. It seems to have been into the second millenium before Megalithic man began to record this small movement that was due to the solar perturbation. The principal object of this lecture is to show just how we know this.

The key to the problem of determining the time when the Moon was on a foresight was given by Tycho Brahe who pointed out that the maximum of the perturbation occurs when the node is in conjunction with the Sun or when it is in opposition. Looking at Fig. 1. we see that, neglecting the perturbation of the orbit, the maximum declination of the Moon will occur when it has a longitude (distance from the first point of Aries) of 90°. Obviously the greatest of these maxima will be that which occurs when the node is near the first point of Aries. Since, as we have just seen, the node must be in opposition or conjunction, for maximum declination the Sun's longitude must be zero or 180°. The Moon being at 90° to the Sun will be at the first or third quarter. Similarly it can be shown that the minimum of the perturbation wobble occurs at one or other of the solstices (Fig. 2). These for us are most important conclusions; among other things they enable us to find 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 is the required hour in the astronomical convention which places zero hour at midday. We choose the time when it rose in the hours of darkness and proceed to estimate the temperature and so the astronomical refraction.

The two largest Megalithic lunar observatories in Europe are those in

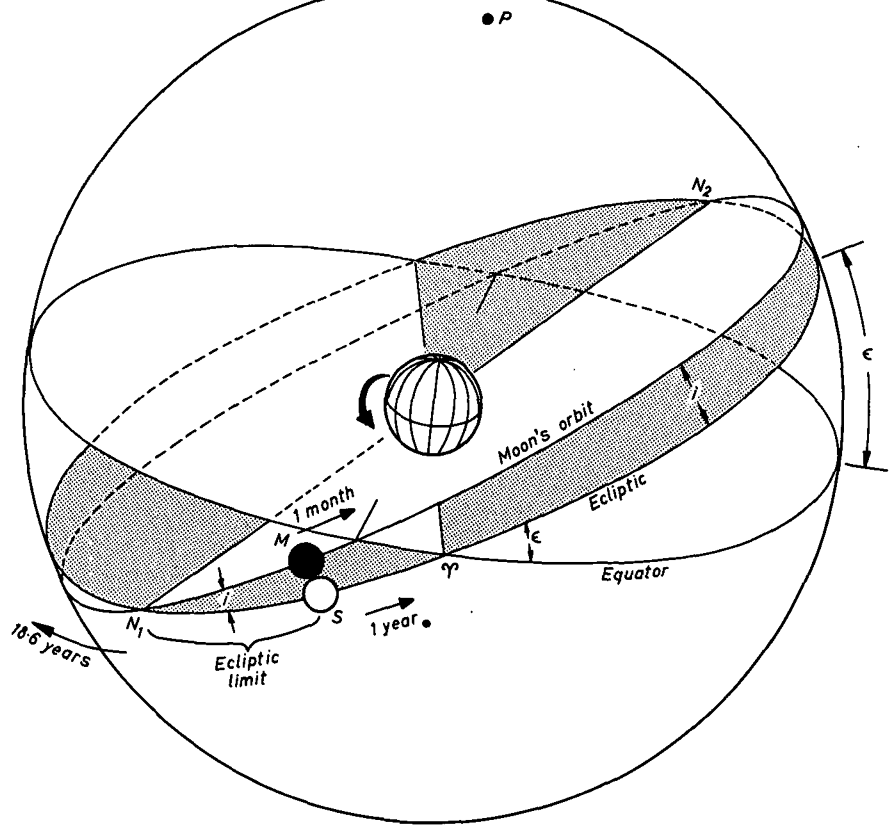

FIG. 1. The celestial sphere (S Sun, M Moon, P Pole, N_1N_2 line of nodes of lunar orbit, ϵ obliquity of ecliptic, i inclination of lunar orbit)

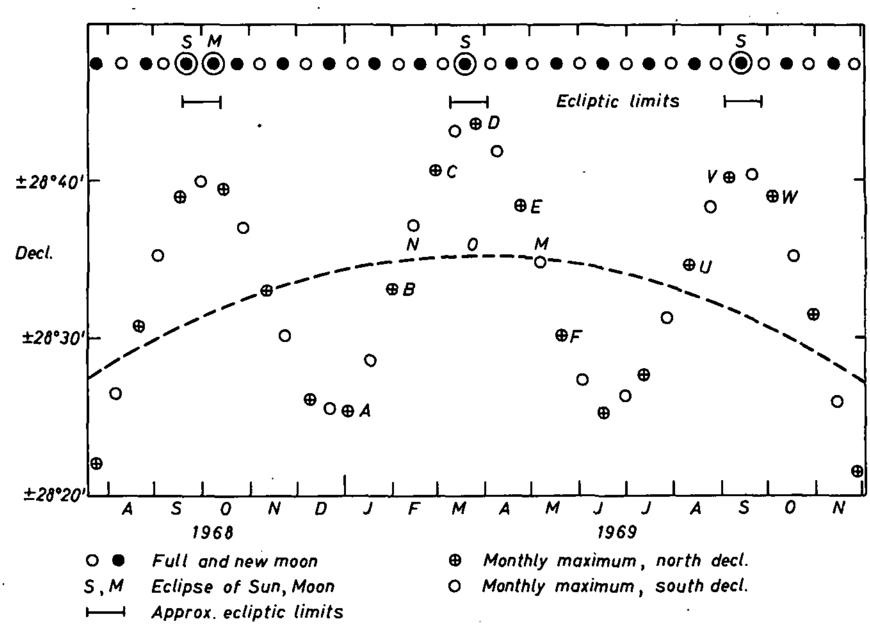

FIG. 2. Declination maxima (north and south) at the 1969 standstill (note that eclipses happen at solstices and equinoxes)

Carnac and Stonehenge. These two operate on a different principle. In Stonehenge we look outwards to the foresights which are on the distant hills. In Carnac we look *in* to a universal foresight so placed that from eight distant positions round it the Moon will rise or set behind the stone at one or other of the standstills. It appears that there was an earlier observatory in Carnac centred on Le Manio stone erected on the hilltop near the east end of the alignments. This was being superseded, or was superseded, by the observatory centred on Le Grand Menhir near Locmariaquer. This latter stone had a mass of over 300 tons and was originally about 70 ft long. It now lies broken into four pieces. It seems possible that this accident occurred comparatively recently as Roman remains were found below the large end piece. As this foresight stood on a low hill it is not at first obvious why it had to be so large, but the ground is irregular and a little thought shows that it is necessary to have a tall stone. It would have been useless to build a mound and put a smaller stone on top because the mound would have obscured some lower lines of sight. We believe that we have located the positions to be occupied by the eight necessary backsights. In every case there is a level stretch on which the observer could move about. We have been criticized for stating categorically that Le Grand Menhir was a universal foresight but the position has been so carefully chosen for this purpose that it is difficult to believe that it was not so intended. It must also be remembered that nearby we have the smaller observatory centred on Le Manio and for this stone there are 5 or 6 *existing* backsights which give the lunar declination with accuracy.

The observatory at Stonehenge was placed upon a long, wide ridge sloping down to the north-east. The position of the observatory on this ridge was chosen so that another ridge over a mile away to the north-east would appear on the horizon and so could have carried artificial foresights for the rising solstitial Sun. As C. A. Newham pointed out to us, had Stonehenge been placed a few feet higher the distant hills would have come into view behind the ridge and so its use for carrying foresights would have been nullified. Thus Stonehenge was in the first place a solar observatory.

C. A. Newham was the first to point out that the so called 'stations' and the station stones indicate the Moon's setting at the major standstill. We accordingly began to look for distant lunar foresights and we believe we have located several. The positions we have surveyed are:

(i) Gibbet Knoll near Market Lavington.
(ii) An old mound inside Figsbury Ring.
(iii) On the present site of Conybury Tumulus.
(iv) On a site near Hanging Langford Camp.
(v) On Chain Hill.

It will be seen on the O.S. map that an old trackway runs straight from Stonehenge past Druid Lodge aiming at Chain Hill and, while we found nothing on Chain Hill, the track has the correct azimuth. It is interesting that three of these sites have an intervening ridge which almost cuts them out. We have seen above that Stonehenge could not be sited any higher and these foresights are too far away for instructions to be shouted during location. Perhaps an intermediate foresight was placed on the intervening ridge when the Moon was setting or rising and transferred in daylight to the distant foresight.

The Brogar Ring in the Orkneys is probably the most important lunar observatory of all. Its importance lies in the fact that outside of the ring there are over a dozen small cairns and fortunately these have not been entirely ploughed away. An examination of Fig. 3 shows that these cairns indicate clearly four directions and when we examine the horizon in these directions we find four foresights: the cliffs at Hellia (Fig. 4), the small notch at Mid Hill (Fig. 5), the notches on Kame (Fig. 6) and the small notch on Ravie Hill (Fig. 7). We have gone back year after year to this site, surveyed it fully and measured precisely the coordinates of these

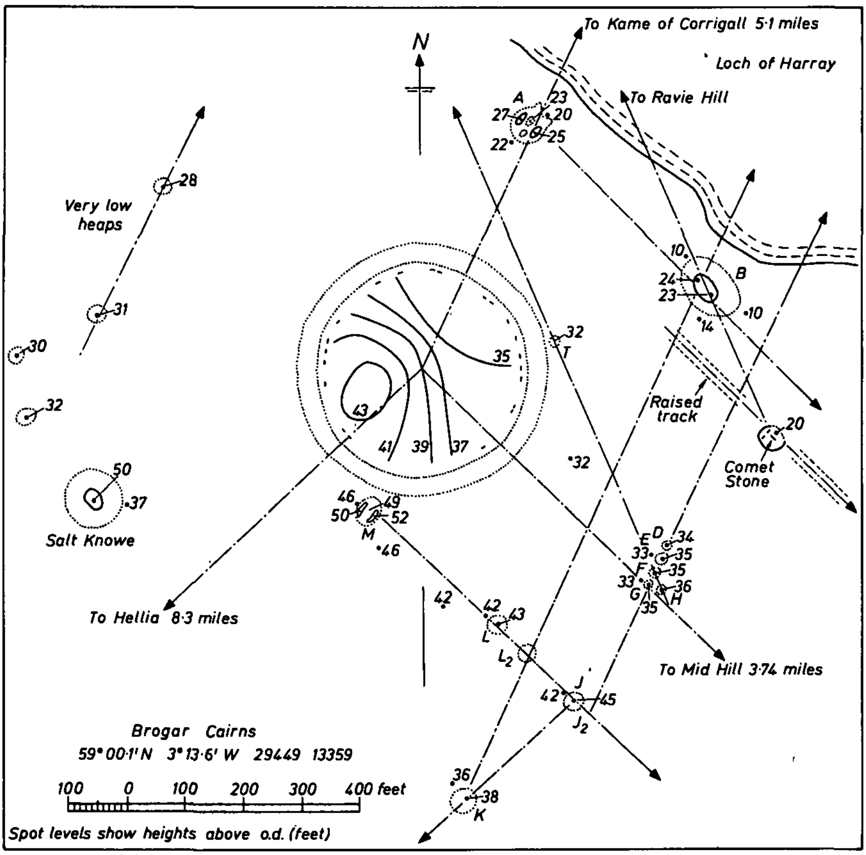

FIG. 3. Brogar cairns. Mid Hill is indicated by four lines, Kame by four, Ravie Hill by two and Hellia by one

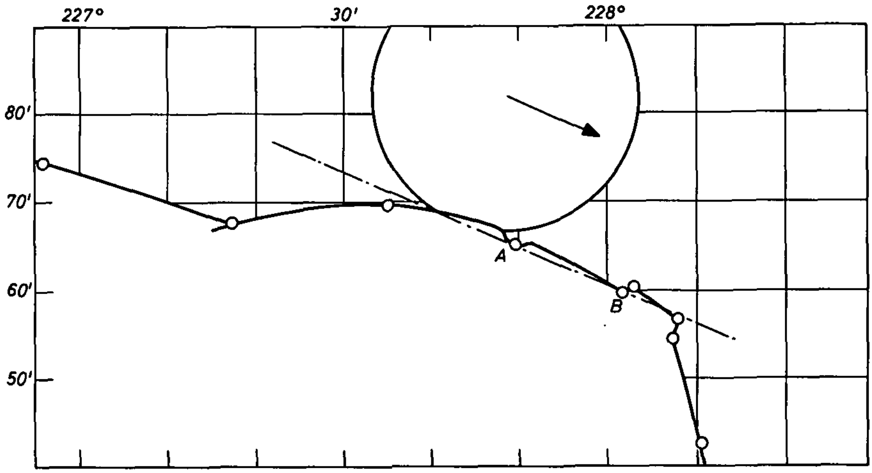

FIG. 4. Moon setting on the cliffs at Hellia as seen from *J* over *K*

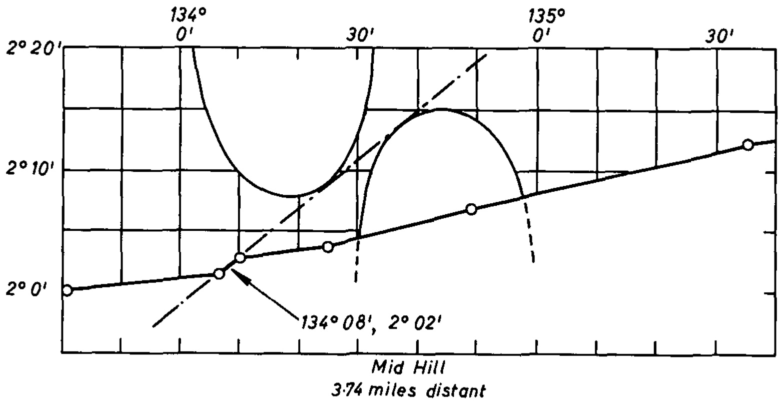

FIG. 5. Moon rising on foresights on Mid Hill

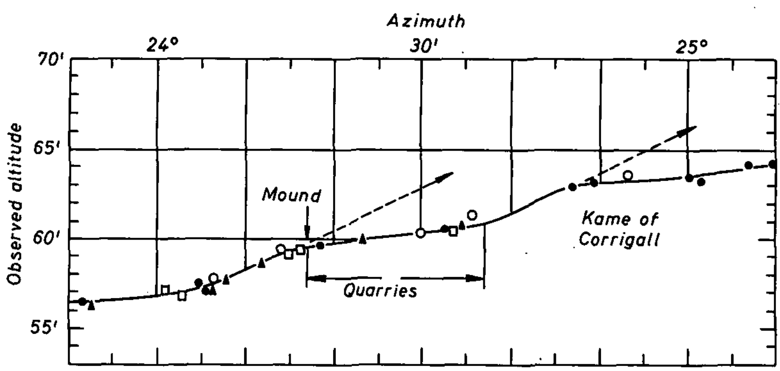

FIG. 6. Foresights on Kame of Corrigall

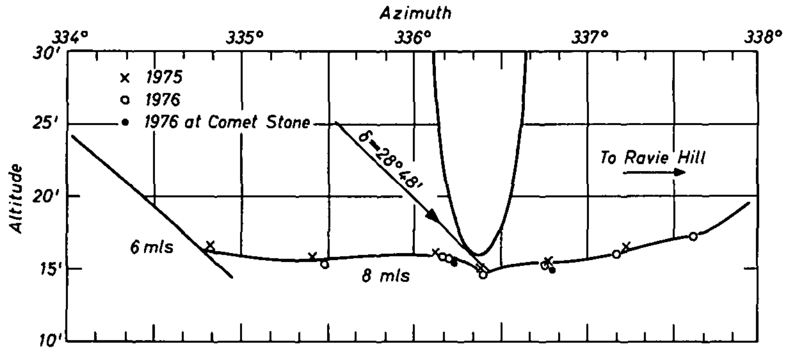

FIG. 7. Moon setting on small notch at Ravie Hill

four foresights from different positions. It will be seen that the coordinates of the Mid Hill notch, for example, are different when observed from the Comet Stone or along the line of foresights on the ridge. As we have seen, it is possible to calculate the time of year and the time of day when the Moon was on one of these foresights and so we can estimate fairly closely the temperature. This allows us to make a good estimate of the refraction. Astronomical theory enables us to obtain the best values of the lunar parallax, the semi-diameter and the perturbation Δ.

Full particulars are given in Table I. With the azimuth, altitude, refraction and parallax we have calculated the declinations of the various sight lines. In the row headed 'Nominal' we give the probable algebraic values of the declination. Corresponding numerical values of the observed declination are given. It will be found that these are within about a minute of the theoretical values. This is perhaps best shown by calculating the value of the obliquity of the ecliptic assuming the observed declination, the inclination of the lunar orbit, the semi-diameter and the perturbation.

We give in Table I particulars for eight of the Brogar lines. These were chosen so that each had some indication amongst the cairns that we were using the intended foresight. Only at one place in Kame (lower and upper) is there any ambiguity. For every line except the Comet Stone to Mid Hill there were two backsights and we used the one further back, except in the case of KL_2B where we used L_2 because the top of the ridge which contains ML_2 and J forms an ideal platform on which side movement was possible. The azimuth and altitude for every line have been checked and rechecked and we consider these values to be correct to a minute and in most cases better than to a minute. We give the 'nominal' values of the declination but these cannot be used directly because S the semidiameter and Δ the perturbation are not constant.

It was impossible for Megalithic Man to observe the Moon accurately when there was no Δ in the nominal value. No monthly declination maximum occurs at N (Fig. 2); and only by chance near M. Accordingly

TABLE I. RESULTS OF MEASUREMENTS AT BROGAR CAIRNS

Foresight	Hellia	Hellia	Mid Hill	Mid Hill	Kame lower	Kame upper	Ravie Hill	Ravie Hill
Backsight	J over K	M	M over L_3	Comet C	L_2 over B	J_2 over GFED	C over B	GF over T
Nominal	$-(\epsilon - i)$	$-(\epsilon - i + S)$	$-(\epsilon - i - S - \Delta)$	$-(\epsilon - i + S - \Delta)$	$(\epsilon + i + S + \Delta)$	$(\epsilon + i + S + \Delta)$	$(\epsilon + i - S)$	$(\epsilon + i - \Delta)$
Azimuth	227° 50′	227° 13′	133° 27′.8	135° 07′.8	24° 27′.5	24° 40′.0	336° 23′	336° 47′
Altitude (Min/arc)	65·2	65·0	120·1	128·8	58·4	61·5	15	14
Hour Angle	51°	—	311°	—	208°	—	153°	—
Long. Moon	−90°	−90°	−90°	−90°	+90°	+90°	+90°	+90°
Long. Sun	90°	90°	0	0	180°	180°	0	270°
Month	Sept.	June	March	March	Sept.	Sept.	March	Dec.
Hour	3 a.m.	3 a.m.	3 a.m.	3 a.m.	8 p.m.	8 p.m.	4 a.m.	10 a.m.
Temp.	49°F	49°F	39°F	39°F	51°F	51°F	39°F	40°F
Long. Sun	180°	180°	—	—	—	—	270°	—
Month	Sept.	Sept.	—	—	—	—	Dec.	—
Hour	9 p.m.	9 p.m.	—	—	—	—	10 a.m.	—
Temp.	50°F	50°F	—	—	—	—	40°F	—
Refraction	23′.6	23′.7	18′.6	18′.0	24′.4	24′.0	31′.7	31′.5
Parallax	57′.2	52·2	56·7	56·7	56′.7	56′.7	57′.2	57′.7
Declination (from Az. and Alt.)	−18° 43′.3	−18° 58′.4	−18° 19′.5	−18° 50′.0	29° 25′.7	29° 25′.4	28° 48	28° 54
Semidiameter	—	15′.5	15′.4	15′.4	15′.4	15′.4	15′.5	—
Perturbation (Δ)	—	—	7′.1	7′.1	7′.1	7′.1	—	9′.0
Deduced Obliquity (ϵ)	23° 52′.0	23° 51′.6	23° 50′.7	23° 50′.9	23° 54′.2	23° 54′.5	23° 54′.9	23° 54′.4

we have assumed that lines with no Δ show the middle position for $(\epsilon + i + \Delta)$ and for $(\epsilon + i - \Delta)$. As one of these occurred at the equinoxes and one at the solstices we have tabulated particulars for these lines for both cases. For example for Hellia we give the case of the longitude of the Sun 90° and 180°. We have, as already described, found the time of day and hence the refraction. Where there are two values of the refraction, that is when there is no Δ, we give the mean. From astronomical theory we have estimated the mean parallax, semidiameter and perturbation for each case. There is now sufficient information to calculate from the spherical triangle the declination, and this is tabulated.

To determine the obliquity of the ecliptic we now equate the declination to the nominal value given in line 3 and then solve this for ϵ, using the appropriate values of i, S and Δ. It will be seen that the values obtained from the north lines are all greater than those obtained from the south. In fact the mean for the north is 23° 54·7′ and for the south 23° 51·35′. Had we used refraction values greater by about 1½ minutes the two would have been equal.

It may be that in fact we are using too low a value of astronomical refraction, but in view of work done at Stonehenge it seems much more likely that the reason is that the ray grazing over the ridge at the foresight is bent so as to increase the refraction by rather over a minute. In an earlier paper published in *Vistas in Astronomy* we showed, by a least squares analysis of all the sites which we knew at that time, that we were using too low a value for the astronomical refraction; but we did not then realize the effect of the graze on the ridge increasing the refraction. We have omitted from the table eight other lines which have no indication. These are Hellia from L, Hellia from the Salt Knowe, Mid Hill from A over B, Mid Hill from G, Kame upper from top of Salt Knowe, Kame lower from ridge over RA, Kame lower from Salt Knowe at ground level, Kame upper from T. Including these lines in the analysis makes practically no difference in the conclusion. The standard deviation is still low.

It seems that the erectors were able to set out lines with an accuracy of about half a minute. We do not know how they did this because there were other difficulties to be overcome. Dr. A. T. Sinclair of the Royal Greenwich Observatory has provided us with lunar positions back to 2100 B.C. and from these we see that the declinations were very scattered.[4] There is also a long period effect on parallax which we have described[5] and this must have given a great deal of trouble.

It was because of the high accuracy which we obtained that we thought it necessary to go back to Brogar year after year and remeasure the foresights until we were perfectly certain that the altitudes and azimuths were correct. We believe that without knowing the date at which the cairns were built we have obtained the best possible values for parallax, semidiameter and perturbation. We had to neglect various factors but this was inevitable as these depended upon the exact date of erection.

The mean value found above for the obliquity of the ecliptic is 23° 53.0′

The obliquity had this value about 1530 B.C. Unfortunately this method of dating cannot be accurate. The rate of fall of the obliquity is so small that an error of 1′ produces an error of 140 years. Bearing in mind the long period oscillation in the parallax and the general scatter in the known lunar declinations we see the inaccuracy of the method. Nevertheless after comparison with the Greenwich declinations we can say that the date of the Brogar cairns is later than about 1750 B.C.

A totally different method of presenting the results is shown in Fig. 8. This gives the value (independent of sign) of the difference between the observed declination and $\pm(\epsilon \pm i)$. It will be seen that these fall into five clumps. Can anyone suggest seriously that this grouping has come about accidentally?

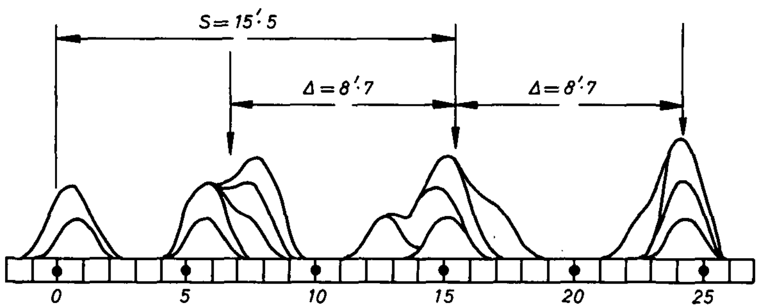

FIG. 8. Difference between observed declinations at $\pm(\epsilon \pm i)$

We have seen that Megalithic man could observe the standstills to an accuracy of about a minute of arc, but before he could use this method he had to overcome several difficulties. Probably the greatest of these was to find a method of extrapolation from two or three nights' observation to the maximum declination. The difficulty comes about because the Moon's movement in declination is so rapid that it can come to a maximum and decline again between the two observing times, which were of course restricted to the times of setting or rising. It would only be occasionally that the observation would be made sufficiently near to the maximum declination.

Let us assume that the observer has placed two stakes representing two consecutive evenings' observations and let us assume that the maximum declination occurred in the interval. Let us put $2p$ as the measured distance between the stakes and let G be the declination deficiency on the ground for half a day, that is the amount the declination has fallen below its maximum in half a day. Suppose that he place a third stake at C, midway between the first two, then it is necessary for him to move from C a distance equal to $G + p^2/4G$ in order to obtain the position which he would have had to occupy to observe the maximum. Obviously if p is zero then he simply has to move G. How could he find the value of $p^2/4G$?

Obviously not with a slide rule, but perhaps by a graphical construction. There are several such constructions available. One of these consists of having a sector drawn out with radius $4G$. There are in Caithness a number of such sectors set out on the ground in small stones. We have shown[6] that three of these have the correct radius for use in extrapolation, when the Moon was rising or setting on the foresight. There are in Brittany at least two places where we find sectors which can be similarly used. In Brittany at Keriaval we also find a series of parallel lines and we have shown how these could have been used for extrapolation: the distance between the outside lines is the correct amount.

Of course we cannot prove that these sectors *were* used for extrapolation but no other acceptable use whatever has been proposed. We have published[7] small reproductions of large accurate surveys which we have made of the huge alignments in the Carnac area. We have also published a method whereby Le Menec alignments might have been used for extrapolation, from three nights' observation, allowing for the fact that G is not constant. The suggested method certainly gives the correct answers but we cannot claim that this was the intended use. Nevertheless the Carnac alignments lie close to the large lunar observatories which we have shown to exist there. We have published the geometry of all these alignments and it seems to us that it is only a matter of time till someone stumbles on the solution, that is till someone finds out just what the alignments were for. We think that the Caithness alignments form an important clue. Anyone attempting to solve the problem must be prepared to go into the field and experiment so that he knows just how Megalithic man worked. He must be prepared to discard the methods of thought which have been produced by his scientific training and try to put himself completely in the position of Megalithic man. The worker on this subject must be prepared to face up to several problems, but first of all he must try to find the method which would explain how our published observations can lead to results such as those shown in Fig. 8. We have failed to find any explanation other than that these were genuine lunar observatories.

In looking at a standing stone one must always bear in mind that it may be the last remnant of what was originally a large structure. For example all that remains of the large circle in the Lake District, the Grey Yawds, is today a single large stone in a field. We were told by a farmer how he had removed a large outlier to a circle and we were told by a mason how he had cut up a stone to make 'twa damn fine lintels'. Many sites are being removed today to make way for roads and other engineering structures. For example, in the grounds of Moncrief House in Perthshire the roadmakers have just removed an important circle which turned out to have an inner circle and a hearth. They said they were going to move it bodily and reerect it in the same shape. This is worse than useless. There are unfortunately throughout the country many examples of this kind of vandalism going on at present. There is also the damage which has taken place over the centuries by growing trees, &c. For example in the Dyce circle in Aberdeenshire we saw a stone which had been lifted in the roots of an overturned tree. Then there is the damage done by well-meaning people who reerect the stones without any idea as to where they had been. Is it any wonder that we have difficulty today in interpreting many of the patterns ?

We do not know for what the rings were really intended. Most of them seem to have no astronomical significance but in several cases (Brogar, Stonehouse, Temple Wood) they are found in association with the lunar observatories. They are certainly earlier and probably show the stances for observing the standstills without the refinement which came later. For example, the Ring of Stenness in Orkney is now dated to about 3000 B.C. Probably the nearby large Ring of Brogar was a little later and the surrounding cairns forming the lunar observatories, as we have seen, must have been later still.

We have visited a number of the Megalithic sites in Shetland and found one or two extremely interesting. In the island of Unst, which is the most northerly island in the British Isles, we found a very large stone about 13 ft high and from it there were three lines, two solstitial and one lunar. We measured up the so-called Druid Temple at Staneydale on the

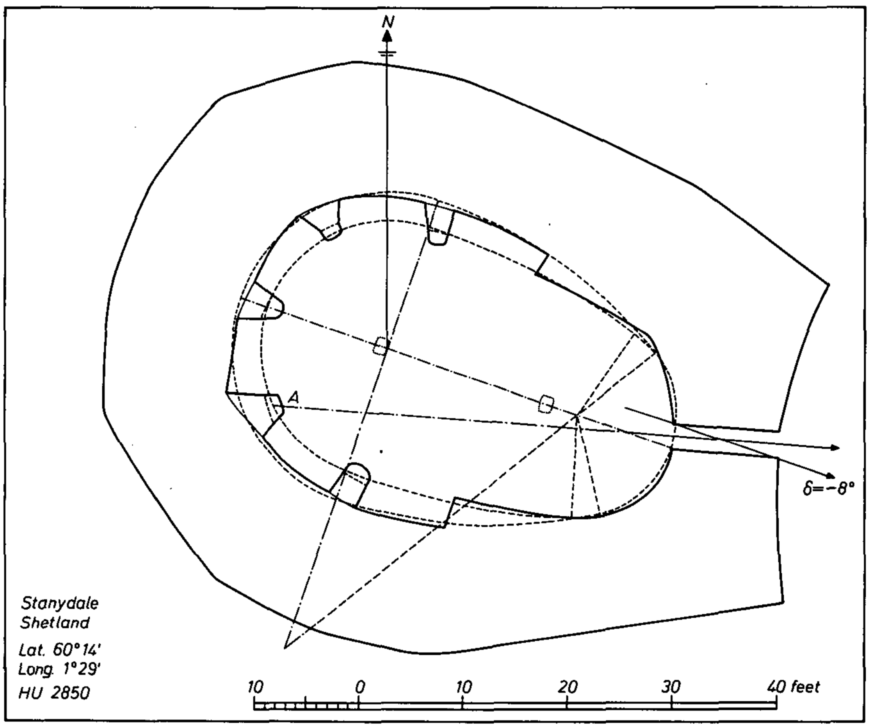

FIG. 9. Staneydale Temple

Shetland mainland and we think this was most likely a solar temple. We give a survey in Fig. 9 and it will be seen that the inside plan is based on two Megalithic egg shapes. Megalithic eggs are defined as being based on an integral Pythagorean triangle and having the perimeter integral in megalithic rods. Both of these satisfy the conditions. It is to be noticed that the passageway looks out to the rising point of the Sun at the spring equinox. The first ray which can enter the temple as the declination of the Sun increases is exactly one Megalithic month before the equinox. It is interesting that the two timber posts which carried the roof were of spruce, brought presumably from Norway.

For an observer in the north of Unst in Megalithic times at the standstill the Moon herself would be circumpolar for a night or two. We have just seen that Megalithic people observed from the island of Unst and this behaviour of the Moon cannot have escaped them. Knowledge of it would circulate through the whole civilized Megalithic world and must have affected their reasoning. It could easily have led them to believe that the world was round.

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