CHRISTMAS LECTURE

OBSERVING THE MOON IN MEGALITHIC TIMES

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In 1954 a paper of mine was published in the *Journal* (**64,** 396) on the solar observatories of Megalithic Man. There I showed that Megalithic Man had marked by menhirs the positions from which the limb of the setting solstitial Sun appeared to run down the slope of a distant mountain. An analysis of the most definite of the sites for the summer and winter solstices allows the unknown temperature effects on refraction to be largely eliminated, and yields a value of the obliquity of the ecliptic with an accuracy of 1′ or better. The value obtained in 1954 was about 23° 54′, and a recent redetermination with more and better data, gave almost exactly the same result. The agreement was perhaps fortuitous: nevertheless, we see that the method is capable of considerable accuracy.

I have shown elsewhere (*The Solar Observatories of Megalithic Man*, Oxford, 1967; *Vistas in Astronomy*, **11,** 1, Oxford, 1969) that other solar sites tell us that these people had a highly developed calendar, and that for time keeping they used slabs set in the meridian as well as indicators showing the rising or setting points of certain first-magnitude stars. There is a mass of evidence that they observed the Moon, but the movements of the Moon in the sky are so much more complex than those of the Sun, that we must digress to explain them briefly.

The lunar orbit is inclined at $i = 5° 08' 43''$ to the ecliptic. The line of the nodes rotates relative to the equinox in 18·613 years. So in this period, the inclination of the orbit to the equator goes through a complete cycle between $(\epsilon+i)$ and $(\epsilon-i)$ where ϵ is the obliquity of the ecliptic. Tycho Brahe discovered that the inclination of the orbit is subject to a small oscillation of amplitude $\Delta = 9'$, and with a period of half an eclipse year, *i.e.* a period of 173·31 days. This is well brought out in figure 1, on which each ring shows the monthly maximum of the Moon's declination, positive and negative. Dynamically it can be shown that the inclination is at a maximum when the Sun is passing a node, *i.e.* at the time when eclipses can happen. It so happened that the maxima of both cycles coincided in 1969, and so produced a particularly high peak, which will not be equalled for many millennia. It will be seen that for about a year, the declination maxima do not range over more than 20′. For lack of a better name, we shall call this a 'standstill'. A minor standstill will occur 9·3 years later.

It has become increasingly obvious that our forefathers *c.* 1700 B.C. were well aware of the effect of the 9′ perturbation on the maxima of the Moon's

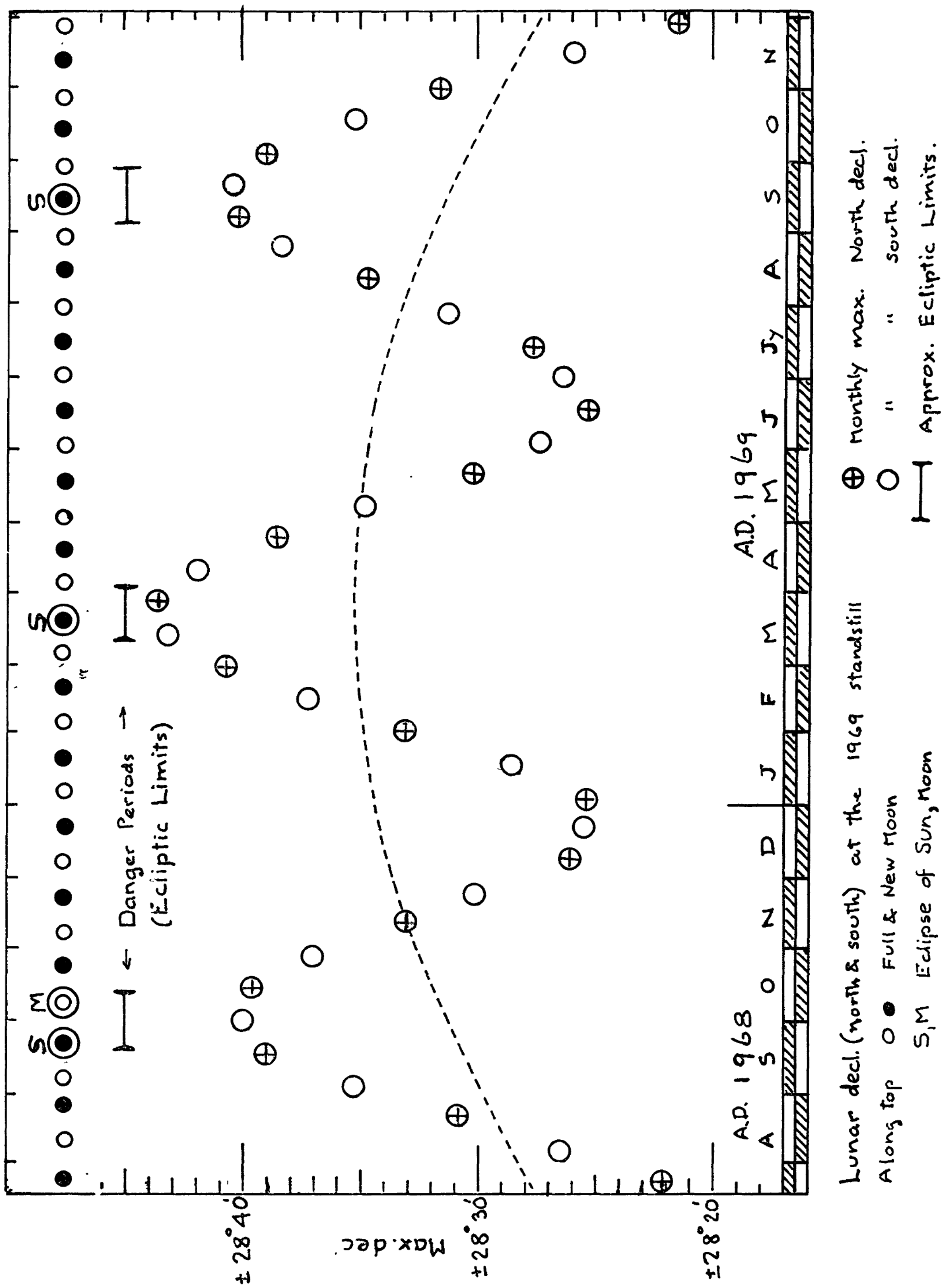

FIGURE 1. Lunar declination (north and south) at the 1969 standstill.

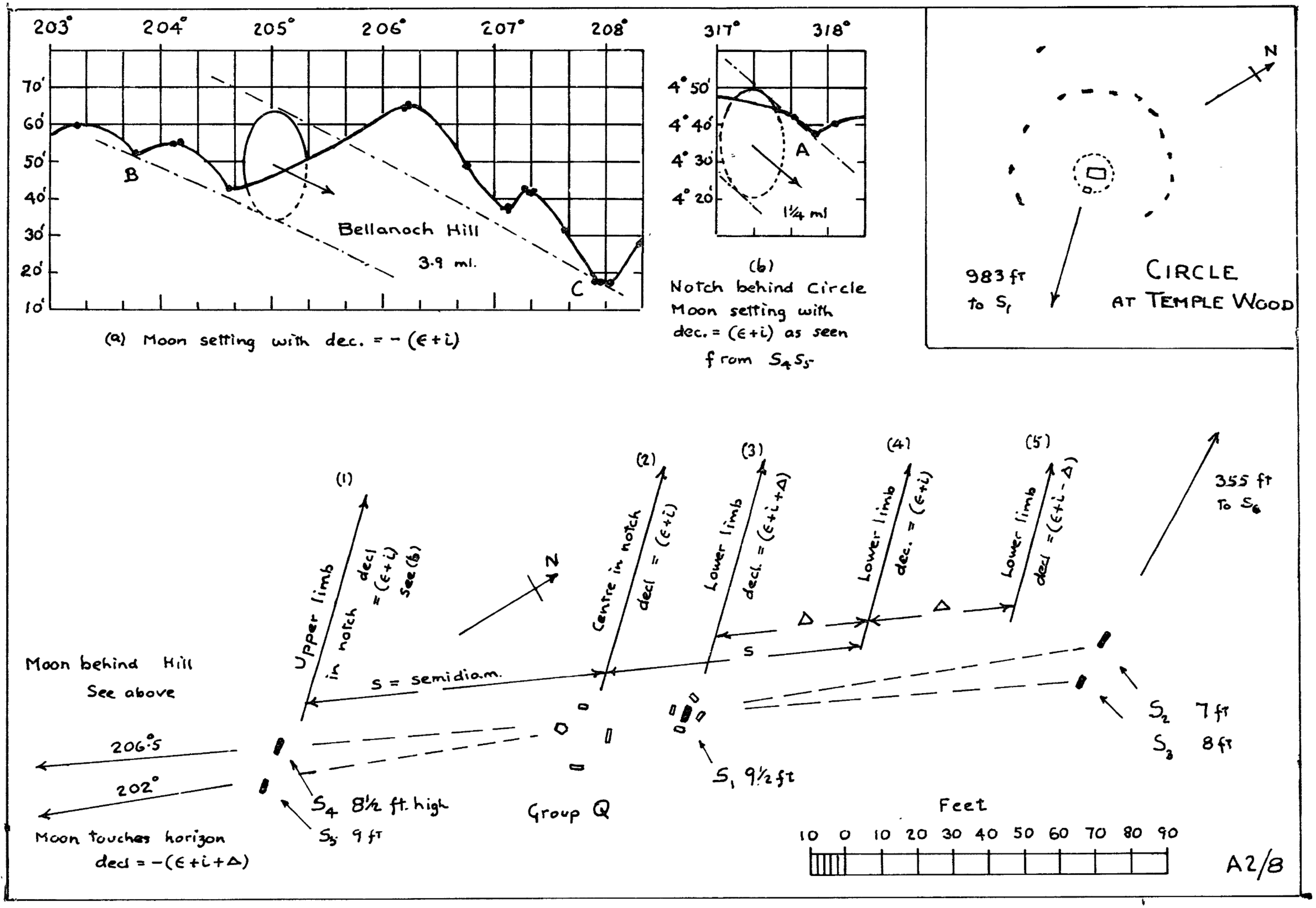

FIGURE 2. Alignments near Temple Wood, NR 827979, showing positions for observing the Moon, *c.* 1700 B.C. (1) Upper limb setting in notch A when dec. $= +(\epsilon+i)$; (2) centre setting in notch A when dec. $= (\epsilon+i)$; (3) lower limb setting in notch A when dec. $= (\epsilon+i+\Delta)$. Note also that looking along the row to Bellanoch Hill shows lower limb in notch B when dec. $= -(\epsilon+i)$, and shows upper limb in notch C when dec. $= -(\epsilon+i)$. The arrows show the stances, assuming $\epsilon = 23° 54'{\cdot}3$, $i = 5° 8'{\cdot}7$, and $\Delta = 9'{\cdot}0$.

declination. If they applied the same observing methods to the Moon at the standstills as they used for the Sun at the solstices, the perturbation would show up clearly.

There are many places where an alignment or a flat slab indicates the foresight, and in most of these the limits of the perturbation are defined either by the foresight being double, or by a double or triple backsight. Many of the sites are in a ruinous condition but, fortunately, there are a few still complete enough to show how they worked. One of the best is at Temple Wood in Argyllshire (figure 2). Looking from the menhirs in the direction indicated by their orientation, we see above and behind the circle, a small but unambiguous north A in the horizon (see inset *b*). Very careful determinations of the azimuth and altitude of the notch provided the values in the table, which also contains particulars for the foresights B and C (inset *a*) at Bellanock Hill. The hill is indicated by the general alignment, as shown in the figure. The 'observed declination' was calculated using night-time refraction and mean parallax. The 'expected' declinations assume $\epsilon = 23° 54'{\cdot}3$, $i = 5° 08'{\cdot}7$, $s =$ mean semi-diameter $= 15'{\cdot}5$, and $\Delta = 9'{\cdot}0$. These values were also used to put the arrows on the figure showing the stances from which the expected declinations would be obtained.

TABLE

DECLINATIONS MEASURED AT TEMPLE WOOD

Backsight	*Foresight*	*Azimuth* ° ′	*Altitude* ° ′	*Dec. observed* ° ′	*'Expected' Dec.* ° ′
S_4, S_5	Notch A	317 52·5	4 37·2	29 19·1	$\epsilon+i+s$ = 29 18·5
Group Q	Notch A	317 12·6	4 37·7	29 2·5	$\epsilon+i$ = 29 3·0
S_1	Notch A	316 59·0	4 37·7	28 56·5	$\epsilon+i-s+\Delta$ = 28 56·5
S_1	Notch B	203 46·0	0 52·0	−29 20·0	$-(\epsilon+i+s)$ = −29 18·5
S_1	Notch C	207 56·0	0 18·0	−28 48·0	$-(\epsilon+i-s)$ = −28 47·5

Observation of the position of the Moon's centre was not directly possible, but could be made indirectly by bisecting on the ground the positions found for the 'upper' and 'lower' limbs where upper and lower refer to declination and not to altitude. Since the ground at the group Q is slightly low, we should expect the position so found to be slightly to the left of the arrow (2).

The site at Mid Clyth in Caithness (figure 3), like that at Temple Wood, has distant foresights for the south declinations and a small, nearer notch for the north. Here the notch is smaller, but smallness is an advantage provided there is no ambiguity. Another somewhat similar example is found at Dirlot, also in Caithness.

I have demonstrated the accuracy of the sites. Now I must show how these people overcame the difficulty imposed by the fact that they could observe only once a day. Suppose that the Moon happened to attain its maximum declination at a time midway between the observing times. Then the declination at the times of marking the stances would be *12′* below the maximum. Let us write *G* for the corresponding distance on the ground. (There would be no difficulty in finding *G* for any foresight, provided there was enough room at the backsight.)

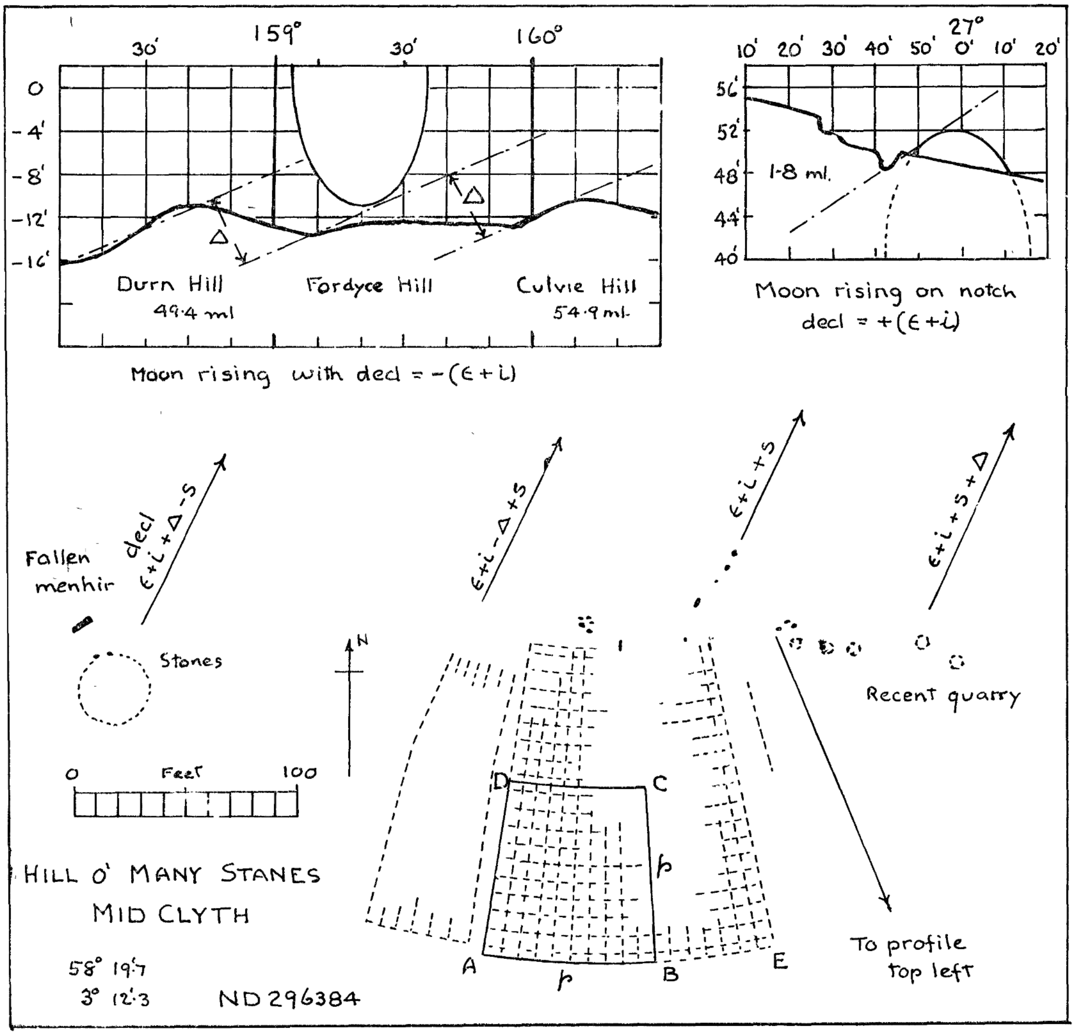

FIGURE 3. The stone rows at Mid Clyth.

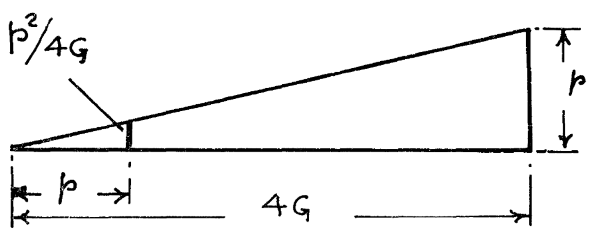

FIGURE 4. Construction for finding $\eta = p^2/4G$.

Now suppose that the stances found on the ground on two successive nights, straddling the maximum, were separated by $2p$. There are two ways of extrapolating to find the position for the maximum. They could advance from the point midway between the stakes marking the stances by a distance $G+\eta$, or they could advance from the most advanced stake a distance y. It is not difficult to show that, with ample accuracy, $\eta = p^2/4G$, and $y = m^2/4G$, where $m = 2G-p$. A graphical construction for finding η (or y) is shown in figure 4.

I am convinced that this method was used at Temple Wood because traces of the two necessary lengths $4G$ are still to be seen, but in Caithness a modification of the same idea was adopted. The stone rows at Mid Clyth are indicated to scale in figure 3. The radius is very nearly $4G$ for the notch, so that the procedure indicated on the grid gives η as the difference between AB and CD. The base AE of the main sector is exactly G. But p on the grid need never be greater than G because, when it is, m can be used to give y. At Dirlot, at Camster, and at Loch of Yarrows, we find stone rows set out in a tapering grid of the correct radius for the assumed foresight.

We do not know what mental process was used by these people when they grappled with, and solved the problem of, extrapolating to the maximum. We do, however, know from an analysis of the geometry of Avebury, that they understood the geometry of the flat arc, and this is what the observer would get if he stepped back a constant distance each night. It is probable that this procedure allowed them in the first place to make the problem geometrical, or perhaps a few trials showed them that they were not dealing with a linear function. The geometrical cult which was spread throughout Britain may have enabled them to take the next step leading to the triangle and sector solutions.

Since there are altogether 40 known foresights, covering both $\pm(\epsilon+i)$ and $\pm(\epsilon-i)$, it is possible to analyse by least squares the observed declinations, and to separate ϵ and i. We find $\epsilon = 23° 53'{\cdot}5$ and $i = 5° 08'{\cdot}9$. This value of i is very close to the known value. The value of ϵ cannot be used for dating without careful thought, for a reason now to be explained. Lunar parallax depends on the position of the Moon in its orbit relative to perigee. The difference between the mean anomalistic month (parallax period) and the mean Draconic month (dec. max. to dec. max.) is only 0·34 days (*Handbook*). So parallax can be at (say) a maximum for months on end at the declination maxima and, in fact, it will then be 93 years before there can be a parallax minimum at a declination maximum that occurs at a standstill. Suppose that at an observatory like Temple Wood we calculate the declinations obtained from the north and the south foresights *without applying parallax*, and find these to be δ_N and δ_S (δ_S is, of course, negative). Let p be the mean parallax, and suppose that the parallax which existed when the north foresight was set up was $(p+\pi)$ where π is roughly 3′. Then that for the south foresight would be about $(p-\pi)$. The real observed declinations are $\delta_N+(p+\pi)d\delta/dh$ and $\delta_S+(p-\pi)d\delta/dh$ where h = altitude. Since both of these ought to be numerically equal to $(\epsilon+i)$ we get

$$(\epsilon+i) = \delta_N + (p+\pi)d\delta/dh$$
$$-(\epsilon+i) = d_S + (p-\pi)d\delta/dh$$

from which $2\,p\;d\delta/dh = -(\delta_S+\delta_N)$ and $2(\epsilon+i) = (\delta_N-\delta_S)+2\pi d\delta/dh$. The first of these tells us that we must expect to find mean parallax at a site, and in fact we do. The second tells us that we cannot find π at a site unless we know *a priori* the value at $(\epsilon+i)$, *i.e.* the date, or conversely we cannot deduce $(\epsilon+i)$ unless we know, for example, that π was zero. It is here that the solstitial sites help us. They tell us the value of ϵ. Assuming that both types of observatory belong to the same era, we find that π is small, and so deduce that the observations preceding the erection of the stones were spread over at least a century. The other possibility, that by chance the observations were all made at a standstill when mean parallax obtained, seems very unlikely.

It is not necessary to describe here the ways in which the observatories could be used to find the middle of the eclipse danger times, or to show the constancy of the 173·3-day period.

In conclusion I wish to say that the important profiles have been measured and remeasured with independent determinations of azimuth by a theodolite/Sun/time technique, in order to make certain of the deduced declinations. The accuracy I have demonstrated is there, and to attain this kind of accuracy the erectors must have used some extrapolation method. Why look further when we find computers lying beside lunar sites?