rising sun.[156] Taken by itself it may be tempting to surmise that this astronomical orientation was intentional, but there are twenty-one other Clyde tombs on Arran with measurable orientations, and these face all around the compass, with a wide spread in declinations.[157]

Just as looking at groups of monuments can help to spot those 'one-off' astronomical alignments at individual sites that are most probably fortuitous,[158] so repeated trends amongst groups can begin to provide evidence of a statistical nature that astronomical alignments really were intentional. The bulk of Thom's work on 'megalithic astronomy' was aimed at providing just such evidence. It consisted of the analysis of measurements from large numbers of sites taken together, and it is to this work that we turn in chapter two.

2

Backsights and Foresights

The Work of Alexander Thom and its Reassessment

He made an instrument to know
If the moon shine at full or no.
Samuel Butler, *Hudibras*, 2:3 (1663), 261.

We estimate that the Ballinaby site was used at the spring equinox about 4am and at the summer solstice about 10pm when the temperatures are about 40° and 50°F.
Archibald S. Thom, 1981[1]

In 1977 I visited [Callanish, Kintraw, Ballochroy, Temple Wood (Kilmartin) and Brodgar]. These sites proved psychologically devastating to my tentative acceptance of precision astronomy in ancient Britain. . . . By focusing his attention on the specific astronomical sightlines, Thom neglected to inform his readers of the richer archaeological context of many of the megaliths.
Owen Gingerich, 1981[2]

Thom's approach: the four levels

Alexander Thom began to survey megalithic monuments in the 1930s and continued to do so, whenever time permitted, until almost fifty years later. He did this with considerable vigour and enthusiasm:

> From [his] notebooks it is possible to follow Thom's travels around the country. To take 1955 as an example: in early April Thom was in Perthshire and Angus, having travelled north from Oxford on 28 March (Easter Monday). On his return journey he visited eight sites in the Lake District on the weekend of 15–17 April. In mid-July we find him in Devon and Cornwall, and then in Aberdeenshire, Perthshire and Inverness in August, where at least 19 sites, scattered from Perth to Culloden, were visited in the space of just six days. On Wednesday 13 September he was at Stainton Dale and Fylingdales in Yorkshire, and on the weekend of 24–25 September he visited three sites in Derbyshire. In total, notes were taken at 60 sites; no mean feat when it is remembered that this was the age before motorway travel.[3]

As a result he accumulated survey data from several hundred 'megalithic sites', and it is through analyses of data from many of these sites taken together, rather than from discussions of individual monuments, that by far the most important evidence in favour of 'megalithic astronomy' derives. This evidence is cumulative in nature, and is most conveniently divided into four stages, or 'levels'. Each stage involves analyses that test for astronomical alignments of greater precision than the previous stages, and at each stage evidence emerges of greater observational exactitude than before.[4]

Level 1. The earliest such analysis, published in 1955, involved the declinations 'indicated' by seventy-two structures at thirty-nine megalithic sites.[5] This was extended in 1967 to 261 indications at 145 sites.[6] On the basis of these data Thom suggested the existence of deliberate solar, lunar and stellar alignments set up to a precision of (at least) about half a degree, roughly equal to the diameter of the sun or moon. The solar alignment targets include the solstices, equinoxes and intermediate declinations representing equal divisions of the year into eight and possibly sixteen parts. The lunar alignments are upon the major and minor limits.

Level 2. In 1967, Thom published further analyses of those Level 1 indications falling near the solar solstitial declinations and the major and minor standstill limits, about thirty of the former and forty of the latter.[7] This suggested that the upper and lower limbs of the sun and moon were preferentially observed, and increases the inferred precision to at least about ten minutes of arc, or roughly a third of the solar or lunar diameter.

Level 3. In work first published in 1969,[8] Thom concentrated exclusively on the idea that natural foresights on the distant horizon were used to mark the motions of the moon with great precision, with megalithic structures serving merely to identify the observing position and the relevant foresight. His analysis[9] suggested the use of distant foresights for observations precise to at least 3′, or about a tenth of the diameter of the moon. Just setting up suitable sightlines must have involved co-ordinated observing programmes spanning one or more 18·6-year cycles.

Level 4. The analysis at Level 3 took no account of a number of small corrections that vary from one site to another and one indication to another. In three papers published by Alexander Thom and his son Archie in the late 1970s and early 1980s,[10] each sightline was considered on its own merits, taking into account the time of year and the time of day of presumed use. They concluded that the horizon markers studied were precise

STATISTICS BOX 3

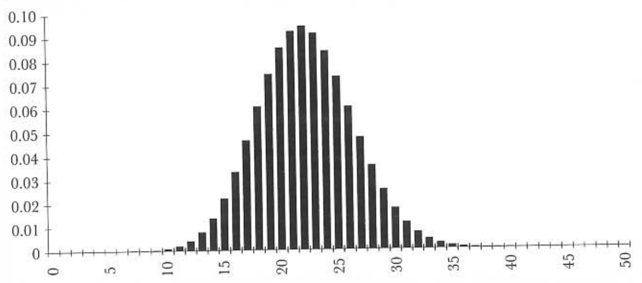
PROBABILITY DISTRIBUTIONS

Statistics Box 1 was concerned with the probability of particular events occurring. Statistics Box 2 introduced general formulae (S2.1 and S2.2) for calculating probabilities that depended on the values of three parameters r, n, and p. Given n and p, for example, the probability that a blindfold marksman will hit exactly r targets (S2.1) could then be calculated and plotted for different values of r, resulting in what is known as a 'probability distribution' over r. r is known in this context as a 'random variable'. The distribution is illustrated in Fig. 2.1 for $n = 111$ and $p = 0{\cdot}2$.

Probability distributions may be discrete (as in this example) or continuous. They are theoretical constructs generated using a particular model (in this case the blind marksman model) which permit us to make precise statements about the anticipated outcome of an experiment—or, more rigorously, the anticipated value of a random variable (in this case the number of hits, r). From such abstractions, we can make more specific inferences about actual data, such as whether the alleged solar and lunar alignments at Stonehenge I are likely to have been intentional.

In order to answer particular questions it is convenient to be able to summarise a probability distribution in various ways. Two well known and particularly useful 'summary statistics' are the mean and standard deviation. The mean of the distribution, μ,[1] yields the 'expected value' of the random variable, the average value that would be expected if a large number of similar experiments were performed. In the example shown in Fig. 2.1, the mean is 22·2. The standard deviation, σ, is a measure of how spread out we would expect the different values obtained in repeated experiments to be, higher standard deviations indicating greater spread.[2] The value for the distribution in Fig. 2.1 is 4·2.[3]

Fig. 2.1 The binomial distribution generated by Bernoulli's law (formula S2.1) for $n = 111$ and $p = 0{\cdot}2$.



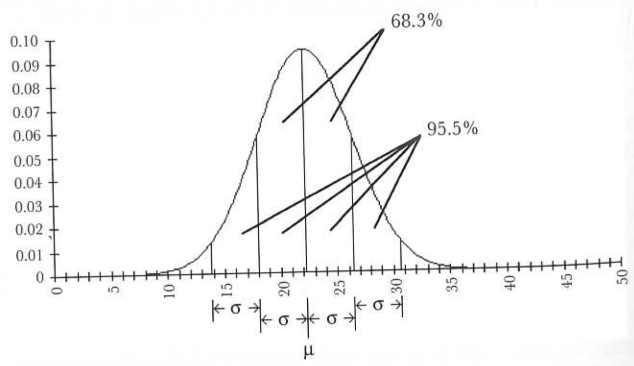
THE NORMAL DISTRIBUTION

While there is no limit to the number of different probability distributions that can be generated to model the expected result of various processes, a relatively small number arise sufficiently often to be widely useful, and their properties have been studied extensively by statisticians. The one that has been by far the most important in the development of modern statistics, and remains the most ubiquitous, is the normal distribution. For each mean and standard deviation there is a single corresponding normal distribution $N(\mu, \sigma)$ whose general form is always as shown in Fig. 2.2, although the numerical values on the axes refer to particular values ($\mu = 22{\cdot}2$, $\sigma = 4{\cdot}2$).

The normal distribution[4] arises as a result of many different models. For instance, the probability distribution described above and illustrated in Fig. 2.1 (known as the binomial distribution) approximates to a normal distribution; the larger the value of n, the better the approximation. This is evident from a comparison of the two figures, where the mean and standard deviation have been deliberately chosen to be the same. But certain general properties of the normal distribution apply whatever the values of μ and σ. It is always true that 68·3% of the area under the graph lies between $\mu - \sigma$ and $\mu + \sigma$. This implies that, in an actual experiment, the probability that the value of the random variable will turn out to lie within one standard deviation of the mean is 0·683; the probability that it will lie outside this range is only 0·317, or under one third. The probability that it will turn out to be outside the wider range $\mu - 2\sigma$ to $\mu + 2\sigma$ is a mere 0·045, or under one in twenty.[5]

When Thom uses gaussian humps in his curvigrams, he is assuming implicitly that the processes of degradation which convert an intended declination δ into a measured declination δ_m will result in a probability distribution for δ given δ_m that is

Fig. 2.2 The normal distribution $N(\mu, \sigma)$. The numerical values on the axes refer to particular values of μ and σ that are the same as the mean and standard deviation of the distribution in Fig. 2.1.



adequately modelled by a normal distribution. Similar assumptions are commonly made and in this case it does not seem unreasonable. In recent years, however, it has become possible for this powerful but simple and elegant analytical tool to be superseded by complex computer simulations for modelling distributions, including those encountered within archaeology.[6]

THE EXAMPLE OF RADIOCARBON DATES

The notion of normal distributions is most familiar to archaeologists in the context of radiocarbon dating. Dates are obtained either by counting the number of spontaneous decays of ^{14}C isotopes to ^{12}C during a measured time period in a given sample of organic material, or by directly measuring the ratio of ^{14}C to ^{12}C isotopes using accelerator mass spectrometry. When an animal or plant dies and ceases to absorb carbon from its surroundings, the carbon within it contains a proportion of unstable ^{14}C isotopes similar to that prevailing in the ecosystem of the time. Subsequently, half of the remaining ^{14}C isotopes will spontaneously decay to ^{12}C during any given period of 5730 years. Using this information the age of a given sample can be estimated.[7]

The results are modelled by a normal distribution. Uncalibrated radiocarbon dates are always quoted within a margin of error, representing one standard deviation from the mean: thus '4530 ± 60 BP' implies that the date estimate is normally distributed with mean $\mu = 4{,}530$ and standard deviation $\sigma = 60$. It is not always appreciated that in over 30 per cent of radiocarbon dates the actual date can be expected to lie outside the quoted range. In this example, there is a probability of just 0·68 that the date lies between 4590 BP and 4470 BP. By doubling the margin of error the probability is increased to 0·95, but this means that there is still a one in twenty chance that the date falls outside the range 4650–4410 BP.

Because ^{14}C dating relies on the assumption that the proportion of ^{14}C in the atmosphere does not vary over time—an assumption known to be false—it is necessary to calibrate radiocarbon dates by some independent means, such as dendrochronology (tree-ring dating). The resulting 'calibration curves' are far from regular,[8] so that while the normal approximation may be adequate before calibration, much more complex probability distributions result on the calibrated timescale.[9]

to better than a single minute of arc; indeed, so precise that it seems they could only have been set up at the end of an averaging process lasting some 180 years.[11]

A number of publications during the late 1970s and early 1980s challenged Thom's results at the different levels from different standpoints. Amongst these were three comprehensive critiques by the present author based upon archaeological reappraisals and first-hand measurements in the field.[12] In this chapter we examine in some detail the data and their interpretation at each of the four levels, and draw general conclusions that will help us to take the discussion forward.

LEVEL 1: SOLAR CALENDAR, MOON AND STARS

The central question at each of the four levels is whether each given set of putative astronomical alignments can quite adequately be explained away as a fortuitous occurrence. The first step in answering it, though, is not to enter into statistical arguments. Assessing the formal statistical significance of any set of results is relatively easy,[13] but it is only worth doing once we have satisfied ourselves that the results will be valid and meaningful; and this will only be true if the sightlines chosen for analysis have been selected fairly in the first place, that is in a manner totally uninfluenced by the astronomical possibilities. Thus it is the question of data selection that will be the first, and main, point needing to be tackled at each of the levels.

Thom summarised the evidence at Level 1 graphically, by plotting a cumulative probability histogram, or 'curvigram',[14] of the indicated declinations. The motivation for this is as follows. The declination that we measure today may not accurately reflect the intentions of the builders: for example the stones may well have shifted in the millennia since a monument was erected. While the measured declination may be the most likely one, it is also possible that the actual intended declination was a little to either side of it. For this reason Thom plotted each indication on the graph not as a point but in the form of a 'gaussian hump' (i.e. a normal curve), representing the spread of probability over declinations close to the measured one. (For more on normal distributions see Statistics Box 3). The humps were then plotted cumulatively in order to reveal whether any declinations were particularly preferred.

Displaying the data in this way has two great advantages. First, the process will tend to even out errors such as those due to deterioration since prehistoric times, and thus stands the best possible chance of showing if there are any obvious trends over and above the 'background noise' of alignments that have no consistent astronomical significance. Second, it makes no presuppositions about the nature of the astronomical targets (if any) that were aligned upon: if particular celestial bodies and events were of interest, then this should result in accumulations of alignments around particular declinations. If we find peaks at certain declinations, we can then seek to interpret the

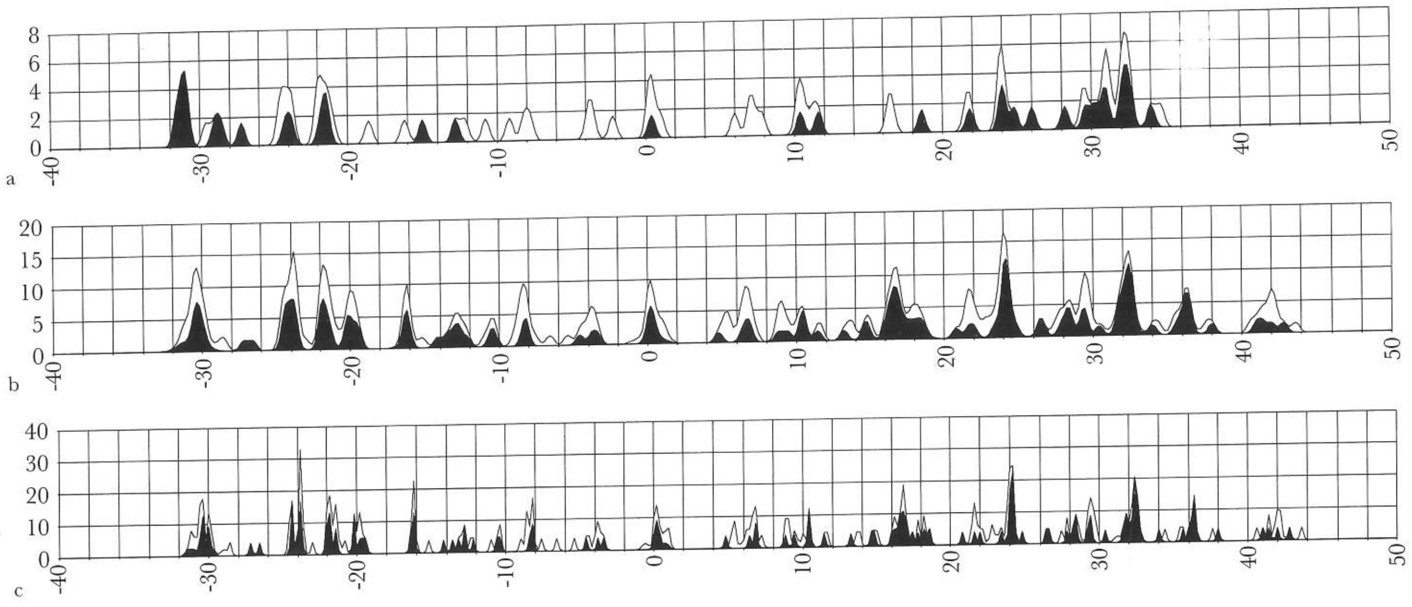


Fig. 2.3 Graphical summary of the indicated declinations in Thom's 'Level 1' data, in the form of 'curvigrams' (cumulative probability histograms).

a. Declinations indicated by seventy-two structures at thirty-nine sites, from the data in Thom 1955, tables 5 and 6. The shaded area represents data from short stone rows and aligned pairs. The unshaded area represents indications defined by a ring centre to an outlier. The area under each constituent gaussian curve is 1.0 and the standard deviation σ is 0·25 in every case.

b. Declinations indicated by 261 structures as 145 sites, from the data in Thom 1967, table 8.1. The shaded area represents 'Class A' alignments considered by Thom to be objective. The unshaded area represents 'Class B' alignments whose selection, by Thom's own admission, contains a subjective element. The area under each constituent gaussian curve is 1·0. σ is taken as 0°·25 except for those lines marked by Thom as less accurate, where it is taken as 0°·5.

c. As (b), except that σ is taken as 0°·1 (and 0°·2 for less accurate lines).

particular astronomical body or bodies to which they might correspond.

Fig. 2.3 is derived from the declination data produced by Thom,[15] and shows both the 1955 and 1967 datasets.[16] The area under each constituent hump is the same, so that equal weight is given to each indication.[17] In fact, the visual effect is dependent on the standard deviation (σ) chosen. For the 1955 data we have followed Thom and taken σ to be 0°·25 in every case, so that each constituent hump is of the same height and width (Fig. 2.3a). In the 1967 dataset Thom distinguished between ordinary data and a few cases where the indicated declination was determined less accurately. In Fig. 2.3b we continue to use σ = 0°·25 for the ordinary data and use 0°·5 for the 'less accurate' data. In Fig. 2.3c we use 0°·1 and 0°·2 respectively, a choice that assumes that the measured declinations are much more accurate reflections of the intended ones, and seems to reflect the values used by Thom in plotting his own graph.[18]

It is clear that there are considerable accumulations of probability at certain declinations and complete avoidance of others. This is quite different from the relatively smooth curve that would be expected if the indications measured had nothing to do with astronomy.[19] Peaks are evident around the solar solstices (±24°) and also to some extent around the four lunar limits (+28°, +18°, −20° and −30°), especially in the south. Thom, however, was struck by the fact that accumulations occur at six other positions representing the sun's declination at eight equal intervals throughout the year, counted from the solstices. This led him to postulate the existence of a calendar of eight and possibly sixteen equal divisions, with indicators of sunrise or sunset on important calendrical 'epoch' dates being erected throughout much of Britain. For the technical details of Thom's 'megalithic calendar' see Astronomy Box 5.

There are also peaks in the curvigrams that do not obviously correspond to significant positions of the sun or moon, including a sharp peak at about +32°, well outside the range of both. Thom interpreted these declinations in terms of bright stars. The problem here is that the declinations of stars change a good deal over a timescale of centuries (see Astronomy Box 6). This means that it is relatively easy to fit a stellar explanation to an orientation by choosing an appropriate date: thus, for example, over a period of 500 years the fifteen brightest stars cover about one third of the horizon.[20] Although Thom's stellar explanation was backed up with statistical arguments,[21] recent evidence from the physicist Bradley Schaefer indicates that atmospheric scattering and haze near to the horizon is a more severe problem than Thom realised,[22] and that all but the brightest stars under the most exceptional conditions will cease to be visible well before they reach the horizon, or only become visible after they have risen considerably above it.[23] Furthermore, according to Schaefer, changes in atmospheric conditions will vary the altitude (and hence the azimuth) of appearance or disappearance significantly from day to day.[24] If this is the case, then orientation upon stars simply could not have resulted in peaks as sharp as those observed in Fig. 2.3, which leaves us with the problem of finding an explanation for some of the most prominent peaks on the chart.

First, however, we must be satisfied that the data have been selected fairly. A number of questions arise here that are not immediately answerable from Thom's publications.[25] First, how were sites chosen for consideration? The 1955 reference list contained 'all the available data'[26] but the general reference list of sites for the 1967 book[27] comprised (only) those which were surveyed and 'contribute to the material of this book'.[28] As is clear from the sequence of site reference numbers used by Thom—A1/1, A1/2 etc.—for each site included about two others, which were present in an unpublished site list, were missed out.[29] Furthermore, not all the sites appearing in the general reference list are carried through to the source list which is used for astronomical indications.[30] Amongst those omitted are types of indication considered important by Thom such as alignments (rows) of standing stones;[31] more are included in the unpublished list but are not carried through to the general reference list.[32]

We must ask why such sites were found unsuitable for inclusion. 'Legitimate' reasons, that is reasons that would not introduce any overall bias, are unrelated to the possible astronomical function of a monument; its being in too bad a state of repair, for example, or weather conditions being too bad for a survey when the site was visited. It is all too easy, however, to conceive of ways in which large-scale bias could have been introduced. Suppose, for example, that monuments were first examined roughly, possibly using a magnetic compass, and only those with indications in astronomically 'interesting' directions were subsequently surveyed.[33] Unfortunately, it is not possible to explore procedural issues such as these on the evidence in Thom's publications.[34]

A second, more tricky question concerns the selection of potential indications at each site. In the 1955 analysis rigid selection criteria were adhered to. Thom considered only indications defined by the line from the centre of a megalithic ring to an outlier,[35] by two slabs in line, or by a row of three or more stones. In the 1967 analysis, however, there are no such clear-cut selection criteria, and subjective judgements are involved.[36] For example, there are a number of cases where the indication in one direction along a stone row has been included, but not the other.[37] If the decision to include or exclude a potential indication was influenced by the astronomical possibilities, wittingly or otherwise, then the data will mislead us.[38]

A further complication arises from the fact that two types of indication are included in the 1967 list. Most of the declinations quoted there are those of a point on the horizon, generally otherwise indistinguishable, in line with the mean orientation of some man-made structure such as a row of standing stones. Some 20 per cent of the quoted declinations, however, are those of candidates for natural foresights—prominent points on a distant horizon such as mountain peaks or notches between hills. The assumption here is that the structure on the ground does no more than roughly point out (preferably uniquely) which foresight is to be used. The problem with this is that at many sites there are a large number of equally prominent horizon features, and the selection of any particular one may well be influenced by the astronomical possibilities.[39]

Furthermore, and finally, we must ask on what grounds a given indication has been taken to be an indicated foresight. This very choice can be influenced by the astronomical possibilities,[40] and there is clear evidence that it has been.[41] For example, the declination (−21°·3) recorded for the indication to the SSE along the three-stone row at Duachy (Loch Seil) in Lorn (part of Thom's A1/4; LN22 in List 2 in the Reference Lists of Monuments on pp. 172–99) is that of the bottom of a depression towards the left of the range of horizon indicated by the actual alignment. This is listed as an indicated foresight and corresponds to sunrise on one of Thom's calendrical epoch dates. However, at Ballymeanoch (Duncracaig), mid-Argyll (Thom's A2/12; AR15 in List 2), the declination given for the four-stone row to the south-east is towards the top of a hill slope. It corresponds to solstitial sunrise (−23°·7). The foot of the slope is ignored as a plausible candidate for an indicated foresight, apparently because its declination (about −26°·3) does not fit an obvious lunar or solar explanation in Thom's scheme. Another example is Comrie (Tullybannocher) in Perthshire (Thom's P1/8; L22 in List 1), where the declination recorded is that of a horizon foresight some 4° to the left of the alignment of the two stones; Thom notes elsewhere that 'This might be lunar to the west where there is a little peak, but it is not a convincing site. The stones do not lie along the line'.[42] Thom himself believed that some monuments, such as the Castlerigg stone circle in Cumbria, incorporated only low-precision alignments while others were intended for far more refined observations.[43] But we must now question whether such a belief was really justified by the evidence. At this stage, the argument looks dangerously circular.

There are other worries. Some archaeological misinterpretations are included amongst the data. For example, Clachan Sands (Clach an't Sagairt), North Uist (Thom's H3/2), a backsight for a calendrical indication,[44] is simply a large natural block with a Latin cross incised near one corner.[45] There is no evidence that the site had any significance in prehistoric times. A supposed 'stone circle' at Upper Fernoch (Tayvallich), Knapdale (part of Thom's A3/4), is a natural formation of large boulders.[46] Another, Auldgirth, Dumfriesshire (Thom's G6/2), is an imitation built (probably) in the early nineteenth century.[47] The dataset also includes a circle-to-outlier line at Castlerigg (Thom's L1/1), in fact 'one of the lines which convinced the author of the necessity to examine the calendar hypothesis in detail';[48] yet the outlier was in fact moved to its present position at the edge of a field in recent times.[49]

But perhaps most worrying of all is the general lack of coherence in the data. While some of this admittedly arises from misidentifications,[50] the main problem is that there is no obvious evidence of consistency in the initial choice of sites and/or geographical areas. The north-eastern Scottish recumbent stone circles represent a group of over ninety similar monuments in north-eastern Scotland, yet only five of them are represented in the 1967 source list for astronomical indications. On the other hand, the dataset includes a variety of types of megalithic monument from all over Britain: stone circles, short rows of standing stones, pairs of standing stones, single standing stones, and longer rows of small stones, as well as various types of cairn, from northern Scotland to Cornwall. The types of indication are equally varied: along the stones of a row, along the flat face of a single stone, from the centre of a circle to an outlier, between the centres of two circles, between two stones on the opposite side of a circle (Fig. 2.5 shows one of three different indications across the ring at Castlerigg included in the dataset), along the passage of a cairn, and several more.[51] This wide variety of astronomical indicating devices seems odd if there really was uniform astronomical, and particularly calendrical, practice throughout Britain.[52] The diversity may well simply reflect how easy it is to fit theories to a site rather than revealing a function that the monuments actually served.[53]

Nonetheless, it would be unwise simply to dismiss the whole of Thom's Level 1 evidence because of these doubts. Instead,

ASTRONOMY BOX 5

DIVIDING THE SOLAR YEAR

THOM'S SOLAR CALENDAR

Thom suggested that prehistoric people divided the time interval from one solstice to the next into eight, or perhaps sixteen, periods of equal length.[1] (The word 'month' should be avoided since these time periods are not directly related to the cycles of the moon.) The start- and end-points of these divisions formed what Thom called 'epochs', dates upon which the sunrise or sunset position would have been of special significance, including the solstices themselves and what we might refer to as the 'megalithic equinoxes'[2] (but see Astronomy Box 8).

In considering these ideas it is necessary to take into account the fact that the sun's distance from the earth is not constant, and for this reason the earth does not travel around the sun at a constant rate. The day-to-day variation in the sun's declination is slightly less than expected from formula (A3.1) during the half of the year when it is farther away from the earth, and slightly greater in the other half, when it is nearer. A formula that expresses this additional effect is

$$\sin\delta = \sin\varepsilon\cos[0{\cdot}9856n + 2{\cdot}07\sin(0{\cdot}9856(n - n_p))] \qquad \ldots \text{(A5.1)}$$

where n_p is the time of perihelion (the point when the earth is closest to the sun) measured in days forward from the June solstice.[3] As in previous boxes, all angles are expressed in degrees. In AD 2000, perihelion occurs on about 3 January ($n_p = 196$). In 2000 BC it occurred on about 24 October ($n_p = 125$). In 4000 BC it occurred around the autumnal equinox ($n_p = 91$).[4]

Owing to this effect, the actual declination δ 'runs ahead of' that of the 'mean sun' given by formula (A3.1), which we now denote by δ_m, during the half-year following perihelion, and 'lags behind it' for the half-year approaching perihelion. The meaning of 'running ahead of' and 'lagging behind' itself depends on the time of year: in the half-year from winter solstice to summer solstice, when the sun's declination is increasing, δ 'runs ahead of' δ_m means $\delta > \delta_m$, but in the other half of the year the opposite is true. This principle is illustrated in Fig. 2.4.

The outcome is to alter the declination of the sun at certain times of year by up to about half a degree. For $n_p = 125$, corresponding to about 2000 BC, the difference between δ and δ_m is greatest when n is between about 47 and 76 and about 227 and 260 (early August to early September and early February to early March), when it exceeds 0°·6. Around the equinoxes, δ exceeds δ_m by a little over 0°·5.

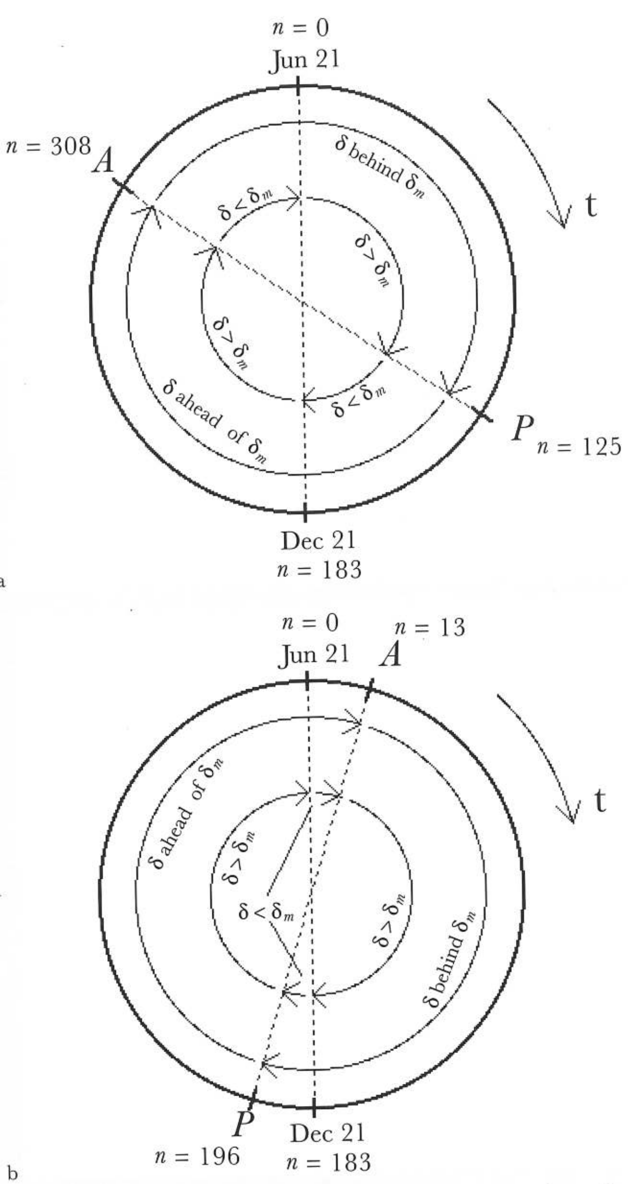


Fig. 2.4 The effect of the ellipticity of the earth's orbit on the sun's declination during the year. The summer solstice ($n = 0$) is shown at the top, and the winter solstice ($n = 183$) at the bottom. Time proceeds clockwise. Perihelion (the point when the earth is closest to the sun) is marked by P; aphelion (the point when it is furthest from the sun) is marked by A.
a. Perihelion at $n = 125$, corresponding to about 2000 BC.
b. Perihelion at $n = 193$, corresponding to the present day.

THE SUN'S DECLINATION AT THE 'EPOCHS'

The observable declination of the sun at the time of an 'epoch' varies slightly from year to year over the four-year leap-year cycle, owing to the fact that the length of the year is not an exact number of days, and a horizon marker can only be set up at the time of sunrise or sunset. In addition, the mean length of a sixteenth-part of the year is 365·25/16 = 22·83 days, which means that three of the sixteen divisions must

Thom's Epoch no.	Mean no. of days from solstice	Approximate date	Mean declination (°)	Minimum declination (Thom) (°)	Maximum declination (Thom) (°)
4	0·00	Jun 21	+23·9	+23·9	+23·9
5	22·83	Jul 14	+22·3	+21·9	+22·2
6	45·66	Aug 6	+17·2	+16·5	+16·9
7	68·48	Aug 28	+9·6	+8·9	+9·5
8	91·31	Sep 20	+0·5	+0·1	+0·7
9	114·14	Oct 14	−8·8	−8·8	−8·2
10	136·97	Nov 6	−16·8	−16·5	−16·1
11	159·80	Nov 29	−22·2	−22·1	−21·8
12	182·63	Dec 22	−23·9	−23·9	−23·9
13	205·45	Jan 13	−21·6	−21·9	−21·6
14	228·28	Feb 5	−16·0	−16·5	−16·0
15	251·11	Feb 28	−8·3	−8·7	−8·2
16/0	273·94	Mar 23	+0·5	+0·2	+0·8
1	296·77	Apr 15	+9·1	+8·9	+9·4
2	319·59	May 7	+16·5	+16·4	+16·9
3	342·42	May 29	+21·8	+22·0	+22·2
4	0·00	Jun 21	+23·9	+23·9	+23·9

have only 22 days, while the rest have 23. Unfortunately, we can not know which three, and this gives greater room for manoeuvre in fitting a theory to the available evidence. In the table below, we show the theoretical mean declination for each epoch in 2000 BC assuming a mean division length of 22·83 days, derived using formula (A5.1). Thom speculated that the number of days in each division was chosen so that non-solstitial horizon markers would fit two epochs at different times of the year as closely as possible. He then calculated the sunrise and sunset declinations that would be obtained as a result. The minimum and maximum declinations in Thom's scheme are given alongside for comparison.[5]

Declinations in the vicinity of the following, then, might be construed as fitting the eight-division calendar suggested by Thom: −23°·9; −16°·8 to −16°·0; +0°·1 to +0°·8; +16°·4 to +17°·2; and +23°·9. These, together with the following, might be construed as fitting the sixteen-division calendar: −22°·2 to −21°·6; −8°·8 to −8°·2; +8°·9 to +9°·6; and +21°·8 to +22°·3.

it is important to see whether, when the selection criteria are clarified and the other criticisms satisfied, statistical evidence still remains to support any of the categories of astronomical alignment claimed by Thom. For example, the archaeological misinterpretations included amongst the alleged indications only represent a small minority of the lines, and simply require identification and removal.[54] Yet, as we have seen, it is not possible to answer these questions merely by re-examining Thom's data as published, because of all the uncertainties about prior data selection. For this reason, an extensive independent survey of megalithic monuments in western Scotland was conducted between 1975 and 1981 under severe methodological constraints. This will be described in chapter three.

Long before this, however, Thom had moved his focus of interest onto higher-precision hypotheses. Fortunately, it is possible to give an adequate re-examination of these ideas, and in particular of the data selection that has given rise to them, without going beyond the sites considered by Thom himself.

LEVEL 2: THE LIMBS OF THE SUN AND MOON

Having produced the overall histograms published in 1967, Thom proceeded to examine more closely those lines with a possible solar or lunar explanation, in order to see whether there was any evidence of greater precision. In the lunar case, he did this by superimposing the four declination intervals centred upon the major and minor standstill limits, in order to examine more closely how each line deviates from the mean

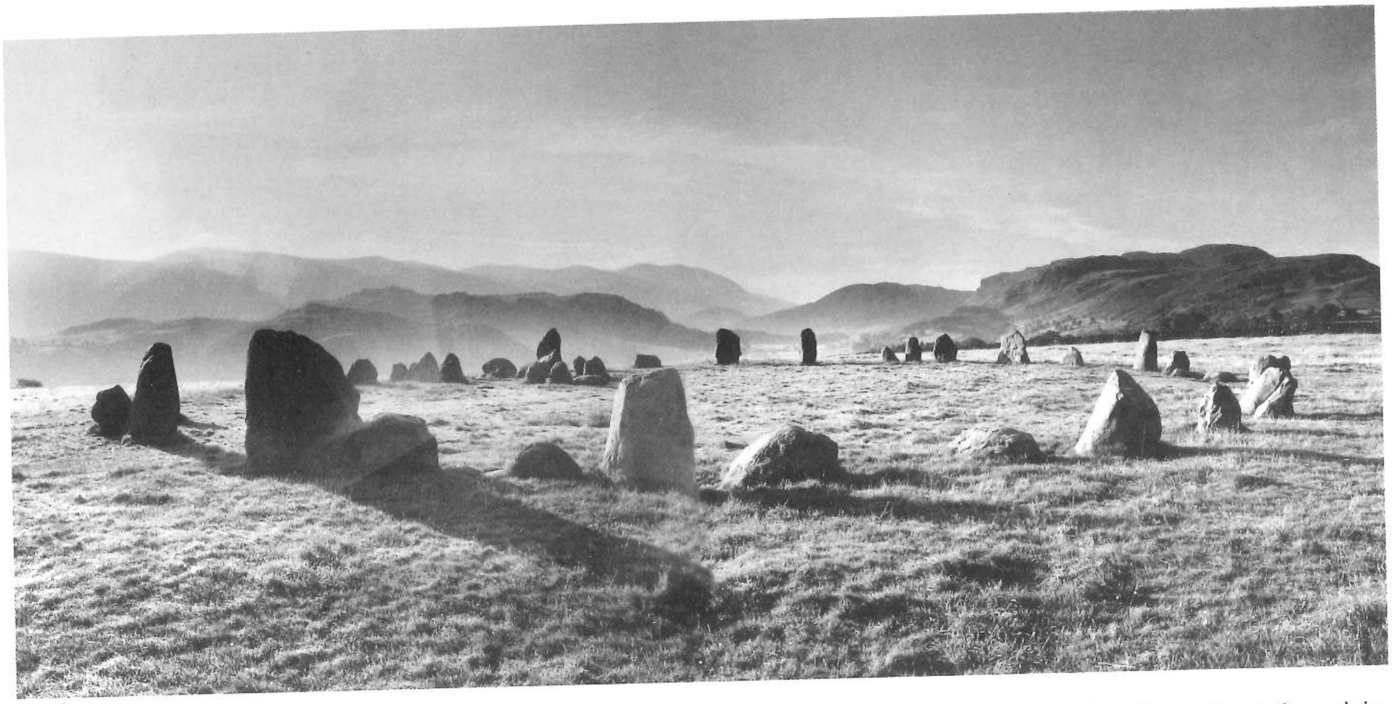


Fig. 2.5 One of three indications across the ring at Castlerigg included in the Level 1 dataset. It is along a diameter towards a horizon notch and indicates the 'candlemas rising sun' with declination −16°·0 (see Thom 1967, fig. 12.10).

limit to which it appears to be related. In Fig. 2.6a we have regenerated the resulting curvigram from Thom's data.[55]

If alignments upon the major and minor lunar limits were deliberate but a precision of about half a degree was the best that was achieved, then we would expect a concentration of humps building up to an overall peak at about the origin. Instead, Fig. 2.6a shows two definite peaks, one at about +0°·25 and one at about −0°·3. As the middle of the graph represents the centre of the moon's disc when the moon is at any one of the lunar limits, and as the moon's semidiameter is about 0°·25, the peaks are suggestive that the upper and lower limbs of the moon were preferentially indicated, increasing the inferred precision to about ten minutes of arc.

The graphs produced by superimposing the solar solstitial alignments are similarly bimodal in form. In the case of the sun, however, the very presence of apparent alignments upon the lower limb seems problematic in itself, since observations of the lower limb of the sun are rendered difficult if not impossible by the glare of the solar disc.[56]

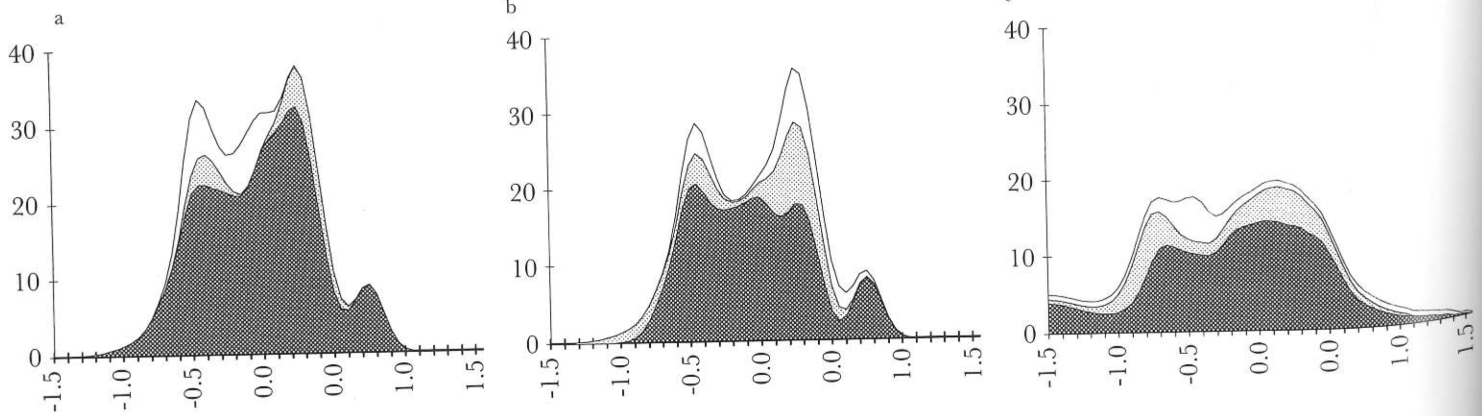
Only the double-peaked shape of the build-up of humps, rather than the actual number amassed, is relevant to the conclusions of Level 2. A formal statistical test could be devised to assess whether the data really do fit a bimodal distribution with peaks at ±0°·25, as would be predicted by the hypothesis that the solar or lunar limbs were preferentially observed, or whether a unimodal distribution centred upon zero would fit the data just as well;[57] but as at Level 1 we must first satisfy ourselves that the data have been selected fairly. Fortunately, doing so is easier than at the lower Level. The

Fig. 2.6 Graphical summary of the indicated declinations in Thom's 'Level 2' data, in the form of curvigrams.

a. Declinations, plotted relative to the nearest major or minor limit, indicated by thirty-eight structures at thirty-four sites, from the data in Thom 1967, table 10.1. The unshaded area represents data of doubtful archaeological status, light shading is used where there is some doubt, and dark shading where there is no doubt. The area under each constituent gaussian curve is 1·0. The standard deviation σ is 0°·1 except for those lines marked by Thom as less accurate, where it is taken as 0°·2.

b. Remaining indications after reappraisal. The darkly shaded area represents data considered reasonable, light shading represents lines considered somewhat dubious, and lines considered very dubious are unshaded. Lines ruled out altogether have been omitted completely.

c. The picture following re-examination and resurvey. Shading has the same significance as in (b). The constituent humps now have a range of standard deviations.



ASTRONOMY BOX 6

VARIATIONS IN THE LONGER TERM

The stars

On a timescale of centuries the declinations of the stars gradually change. This is not because the individual stars move slowly about on the celestial sphere as it rotates: this does happen, but generally on an even longer timescale.[1] It is because, relative to the distant stars, the earth slowly pivots on its axis like a spinning top over a period of some 26,000 years. If we regard the earth as fixed, this means that over the centuries the entire network of stars on the celestial sphere gradually shifts position, so that, for example, different stars are now located near to the celestial poles and different ones now fall on the celestial equator.[2]

Reverting to a 'real' view rather than an earth-centred one for the moment, the solstices occur at the points on the earth's orbit around the sun where one of the earth's poles leans towards the sun. The effect of the earth's pivoting is that the position of the solstices and equinoxes gradually shift around the earth's orbit, each of them completing a circuit in about 26,000 years. Because of this shifting, the phenomenon is known as the 'precession of the equinoxes'.

The sun and moon

The limiting annual and monthly declinations of the sun and moon are not affected by the precession of the equinoxes, but they have changed noticeably over the past few millennia. This is because of the gradual decrease in the obliquity of the ecliptic ε already noted in Astronomy Box 3. Using the analogy of the spinning top, it is as if the amount by which the top is tilted out of the vertical is gradually decreasing. Since 2000 BC each of the limiting declinations has changed by about 0°·5, an amount roughly equal to the width of the solar or lunar disc.

The table shows the declinations of the centre of the solstitial sun ±ε and of the centre of the moon at the major and minor standstill limits (see Astronomy Box 4) at 500-year intervals from 4500 to 1000 BC. The present-day declinations are also shown for comparison. All values are quoted to the nearest 0°·05, greater precision being unjustified for a variety of reasons.[3] To obtain the declination of the upper limb of the sun or moon, add 0°·25. For the lower limb, subtract 0°·25.

Even longer cycles (and climate change)

When publications on positional astronomy, history of astronomy, and archaeoastronomy—this one included—speak of the precession of the equinoxes[4] they mean precession relative to the background stars. This affects the position of the stars in the sky, but in itself has no direct effect on global climate. Palaeoecologists, on the other hand, are concerned with long-term periodicities that *can* have such an effect. One of these is the precession of the equinoxes relative to the earth's perihelion,[5] which itself drifts round the earth's orbit relative to the background stars. For example, when perihelion occurs in June and the magnitude of the obliquity of the ecliptic (which, on very long timescales, oscillates periodically) is close to its maximum, so that the sun is both closest and highest in the sky in northern hemisphere summers, these will be at their warmest, but winters will be at their most cold. This 'climatic' precession is easily confused with what we might call the 'absolute' (or 'axial') precession spoken of in the astronomical and archaeoastronomical literature, but it has a different periodicity.[6]

Date	$+(\varepsilon + i) - P$	$+\varepsilon$	$+(\varepsilon - i) - P$	$-(\varepsilon - i) - P$	$-\varepsilon$	$-(\varepsilon + i) - P$
4500 BC	+28·4	+24·15	+18·15	−19·85	−24·15	−30·2
4000 BC	+28·35	+24·1	+18·15	−19·8	−24·1	−30·15
3500 BC	+28·35	+24·05	+18·1	−19·75	−24·05	−30·1
3000 BC	+28·3	+24·05	+18·05	−19·7	−24·05	−30·05
2500 BC	+28·25	+24·0	+18·0	−19·65	−24·0	−30·0
2000 BC	+28·2	+23·95	+17·95	−19·6	−23·95	−29·95
1500 BC	+28·15	+23·85	+17·9	−19·55	−23·85	−29·9
1000 BC	+28·1	+23·8	+17·85	−19·5	−23·8	−29·85
AD 2000	+27·7	+23·45	+17·45	−19·1	−23·45	−29·5

double-peaked shape could not have been prejudiced by subjective data selection prior to an accurate survey, since rough compass measurements could not have determined the exact values of any declination within one of the four general 'target' areas. Wilfully biased selection, after the careful reduction of survey measurements, could admittedly have influenced the result; but as Thom twice refers to the unexpectedness of the double peak[58] we may assume that no such bias was present. This means that we can adequately reassess Level 2 purely on the basis of the sample of lines provided by Thom. The question is simply whether the characteristic bimodal shape can survive such a reassessment.

A detailed re-examination of the lunar data was undertaken by this author in 1979.[59] This began by selecting from Thom's 1967 dataset those lines with a listed declination within 0°·8 of a mean major or minor limit. The figure of 0°·8 was chosen as the tolerance so as to include the double peak but exclude lines that could be equally well interpreted as calendrical.[60] This leaves thirty-eight lines at thirty-four sites. The sites concerned are included in Table 2.1, where the number of Level 2 lines is shown in column 3. Archaeological information on the monuments is available by cross-reference to List 1.

An archaeological reappraisal was attempted first. This identified one monument (L49) that is probably attributable to the Early Christian period, another (L25) where the proposed alignment is part of an enclosure wall, and a third (L58) where the proposed alignment is part of a row of stones marking a modern parish boundary. The authenticity of another three monuments (L11, L12, L29) is in some doubt.[61] None of these lines was omitted from further consideration at this stage but the doubtful archaeological status of these six sites has been indicated by differential shading in Fig. 2.6a.[62] A worrying feature emerges even amongst the remaining twenty-eight sites whose status as prehistoric monuments is not in question. It is evident from an examination of Table 2.1 and List 1 that the nature of the sites and indications is every bit as diverse here as amongst the Level 1 data as a whole. If these sites really did have something special in common—their lunar significance—it seems likely that they would have other things in common as well. Instead, they very much resemble a random selection from the Level 1 data.

The next stage of the reappraisal was to examine the 'intrinsic' status of the putative lunar alignments, that is, their inherent likelihood as potential astronomical indicators. This revealed that two of the thirty-eight indications simply could not work in the manner claimed: in one case (L9) the claimed horizon can not be seen from the structure postulated to be indicating it, and in the other (L17) the foresight can not be seen from the backsight. A further four foresights listed simply as 'stones' (L14, L25 and two at L49) could not be located at all,[63] making a total of six lines that had to be dismissed from further consideration. Six more cases were considered doubtful or highly doubtful: four (L22, L50, L55, L57) because indications that seem impressive now were once part of a more complex structure, and two (L8, L18) because they involve 'outliers' of doubtful authenticity.[64]

The outcome of these reappraisals is that only twenty-three of the original thirty-eight lines seem wholly reasonable both archaeologically and intrinsically;[65] six are somewhat dubious for one reason or another, three are very dubious and six can be ruled out altogether. The resulting effect on the lunar histogram is shown in Fig. 2.6b. It is already clear that when the dubious lines are omitted (only the darkly shaded area remains), virtually all trace of a double-peaked structure disappears. In other words, the Level 2 evidence does not seem to be withstanding reassessment. This conclusion is reinforced by examining the remaining indications which, like the sites themselves, represent a wide variety of types and show no obvious sign of coherence.[66]

The last aspect of the Level 2 reassessment was to identify and attempt to eliminate any subjective bias that would influence the results as a whole. This involved independent site examinations and resurveys. The biggest problem uncovered by the fieldwork was that the accuracy of an indication, given its nature and present state of repair, was often considerably less than would justify the standard deviation (hump width) used by Thom, and there seemed to be no *a priori* reason for selecting the particular mean declination value quoted by Thom. For this reason, an independent estimate was made of the accuracy of each line, with different standard deviations being assigned to different lines. Horizon profiles were completely resurveyed wherever possible.[67] Putative horizon foresights were ignored, on the grounds that including them where they appear to fit an astronomical explanation but ignoring them otherwise biases the overall result, as we have already discussed in the context of Level 1;[68] thus the reassessed declinations are arrived at on the basis of the alignments of archaeological structures only.

The results are summarised in Table 2.2[69] and plotted in Fig. 2.6c. There is clearly no convincing evidence of a double peak amongst these data, especially when lines of reasonable status are considered alone. From this we conclude that no overall evidence remains on the basis of the Level 2 data for the preferential observation of the lunar limbs.

Level 3: high-precision lunar foresights

Nonetheless, by 1967, Thom himself had become convinced that a great many megalithic monuments deliberately incorporated high-precision lunar alignments. He was also convinced that distant horizon foresights were used in some cases to mark particular rising or setting positions of the moon to high precision. In the work that we identify as Level 3, he developed this idea in detail.

The fullest data set is published in Thom's second book, *Megalithic Lunar Observatories*, and consists of forty horizon foresights at twenty-three sites.[70] The book also contains horizon profile diagrams for all but one of the lines concerned,[71] and site plans and descriptions for a few.[72] A distant horizon feature such as a pointed hilltop or notch defines a position in the sky much more precisely than a structure on the ground, and in his table Thom goes so far as to quote the relevant declinations to the nearest 0′·1, though the nearest 1′ would be more justifiable.[73] At this level of precision there is an added complication in that the parallax correction that must be applied because we do not observe from the centre of the earth (see Astronomy Box 2) is slightly different for different lines. For this reason here (and *only* here and this chapter) it is necessary to use a declination already corrected for this effect. We shall refer to this as the geocentric lunar declination.[74]

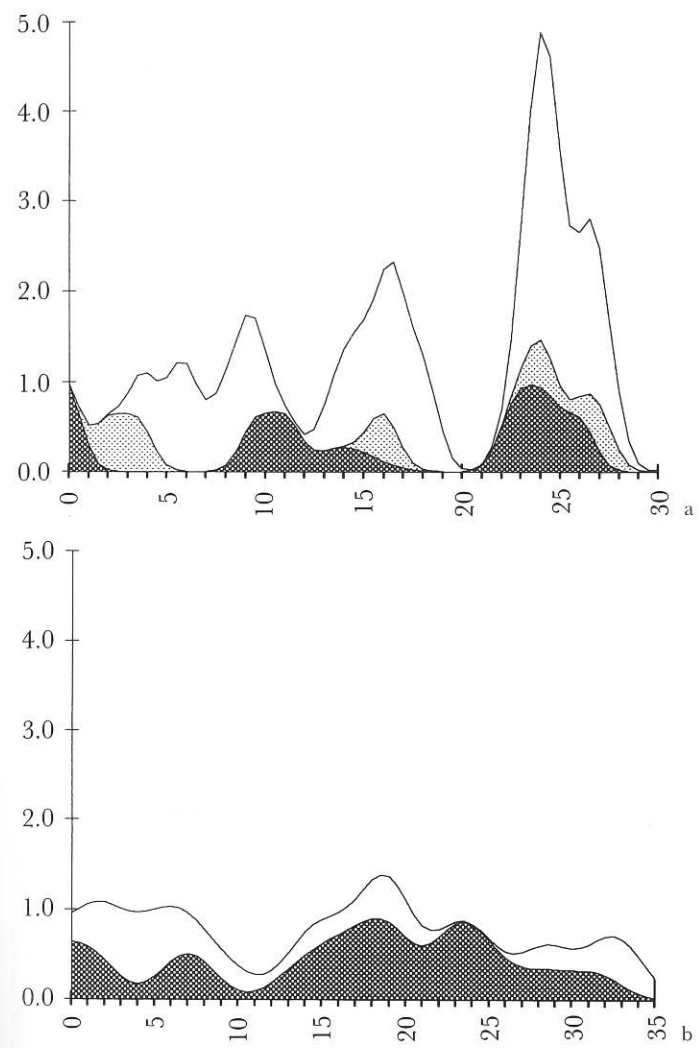


Fig. 2.7 Graphical summary of the indicated declinations in Thom's 'Level 3' data, in the form of curvigrams.

a. Declinations of forty putative foresights at thirty-four sites, from the data in Thom 1971, table 7.1. The graph shows the difference (positive or negative) from the nearest major or minor limit. The unshaded area represents unindicated foresights or lines dismissed out of hand (classified 'Y' or 'Z' in Table 2.3, col. 8). Light shading denotes data of doubtful status (classified 'B' or 'C' in Table 2.3, col. 7 or 8). Dark shading is used for the remainder. The area under each constituent gaussian curve is 1·0. The standard deviation σ assumed is 0′·75 except for two lines where the declination is quoted to 1′ by Thom, and σ is taken as 1′·5.

b. An independent assessment of indicated horizon notches and dips. The standard deviation assumed here is 1′·5 throughout.

Thom's data are plotted in Fig. 2.7a.[75] This curvigram differs from those in Fig. 2.6 in that the two halves are folded together, so as to plot the difference of the measured declination from the mean major or minor limit, whether negative or positive. The results are surprising. There are probability accumulations at around 6′ to 9′ and 15′ to 17′, with an especially large peak at around 24′ to 25′. The semidiameter of the moon is around 16′, which might explain the central peak, but why should so many putative horizon foresights mark positions almost exactly 25′ away from the mean lunar limits?

The answer, Thom suggested, lay in a tiny perturbation in the moon's motions that causes an additional wobble in its declination (Δ) of amplitude 9′·4 and with a period of 173 days (Astronomy Box 7). The moon's semidiameter (s) is about 15′·9,[76] so that if a foresight marked the rising or setting position of one of the moon's limbs at a major or minor limit at the maximum, mean or minimum of the additional wobble, the resulting declination would differ from the mean limit $\pm(\varepsilon \pm i)$ by about 25′·3 ($s + \Delta$), 15′·9 (s alone), or 6′·5 ($s - \Delta$). In addition, marking the centre of the moon at a maximum or minimum of the wobble would give 9′·4 (Δ alone). The correspondence with the observed peaks is manifest.

At the Nether Largie standing stones, mid-Argyll (part of Thom's 'Temple Wood' A2/8; L31 in List 1), according to Thom, the same foresight was used from several different observing positions to mark the moon setting at the major limit (declination $+(\varepsilon + i)$) at different positions of the wobble (see Fig. 2.9).[77] At many other sites only one configuration appears to have been marked. The data used to generate Fig. 2.7a are listed in Table 2.3.

What is being proposed at Level 3 is formally quite distinct from that at the earlier levels, and has to be reappraised in a different way. The focus of interest is now the precise foresight formed by a natural feature on a distant horizon, with man-made structures on the ground doing no more than marking the observing position and pointing out which horizon feature is to be used. An item of evidence in support of this idea, then, consists of three elements: a backsight marker, an indicator of the foresight, and the foresight itself.[78]

The idea immediately runs into serious trouble because, as emerged in the reassessment by this author in 1981, no fewer than twenty-one of the forty horizon features in the dataset are not actually indicated at all (or else the supposed indication is not genuine or is some degrees off line).[79] A further five foresights can not in fact be seen from the backsight because of the intervention of local ground, and one is non-existent. Thus only thirteen of the forty actually represent indicated horizon features in the first place.[80]

Of course, it can be argued that indicators may have disappeared since prehistoric times, or even that they were never necessary anyway, since if people were using horizon features for important astronomical observations they are likely to have known where to look, and only needed the observing position to be marked. The problem is that if we simply speculate that this was the case wherever we find a promising potential foresight, then we are going far beyond what the archaeological record actually tells us.[81] The chances are not inconsiderable that if we went to any arbitrary point in hilly country, even where there is no monument and no evidence of prehistoric activity, we could find at least one or two horizon features interpretable as lunar foresights.[82] In order to test the idea that horizon foresights were used for which no indication (now) exists, we would need a different and much more careful methodology capable of extracting something believable from the data and avoiding circular argument.[83]

The effect of restricting our attention to the indicated foresights in the Level 3 dataset can be seen in Fig. 2.7a, where only they are shaded. Of the thirteen cases, five were considered somewhat doubtful for one reason or another (see Table 2.3), and are shaded more lightly. Amongst these data, little more than a hint remains of the peaks at 25, 16 and 9 minutes from the mean. Nonetheless it is important, as well as informative, to complete the reassessment by examining the question of the fair selection of foresights.

ASTRONOMY BOX 7

THE MOTIONS OF THE MOON, 2
HIGH-PRECISION COMPLICATIONS

This box concerns high-precision phenomena that are only of concern in relation to the discussion of Level 3 and Level 4 phenomena in chapter two. In this context, it is necessary to undertake analyses and frame overall conclusions in terms of geocentric lunar declinations (see Astronomy Box 2), which is why the parallax factor *P* (cf. Astronomy Box 4) no longer appears explicitly.

THE LUNAR BANDS

In Astronomy Box 4 we presented a table of possible lunar 'target' declinations, corresponding to the four standstill limits and, in each case, observations of the centre of the lunar disc or of one or other limb. At a level of precision greater than about 0°·1, this picture has to be modified. The main reason is an additional 'wobble', or perturbation, which shifts the declination of the moon from what we would otherwise expect by up to 9′ in each direction over a period of 173 days.[1] Because of this, we must now consider eight 'lunar bands' on the horizon,[2] within which a variety of specific targets might have been of interest (see Fig. 2.8). The various possible configurations are shown in the table:

MARKING LUNAR TARGETS TO HIGH PRECISION: SOME PRACTICALITIES

In practice, it is extremely difficult to determine any of these targets to high precision simply from a series of observations of the moon rising or setting. There are several reasons for this. First, the moon only approaches either lunistice once a month, and will only be at all close to its monthly maximum or minimum declination for two or three days around this time. Unless a rise or set happens to occur very close to the precise hour of the lunistice, the moon will not be directly observable rising or setting at the declination limit for the month, but will always be some way south (for northern limits) or north (for southern ones). In the worst case, where the lunistice falls mid-way between two risings or settings, the horizon moon will never be seen closer than about 10′ to the monthly maximum or minimum declination.[3]

Second, how close the monthly declination limit is to the actual major or minor limit will depend upon how much earlier or later the lunistice in question is than the standstill. Third, there will be an additional displacement owing to the 173-day wobble, and this will change significantly from month to month. In short, the moon will only be directly observable, say, setting at $+(\varepsilon + i + \Delta)$ to within two or three arc minutes if the time of setting coincides with (i) the lunistice to within about five hours, (ii) the major standstill to within about twenty weeks, and (iii) the maximum of the 183-day wobble to within about twenty days.

	Upper limb	Centre	Lower limb
Northern major limit, wobble north Northern major limit, mean wobble Northern major limit, wobble south	$+(\varepsilon + i + s + \Delta)$ $+(\varepsilon + i + s)$ $+(\varepsilon + i + s - \Delta)$	$+(\varepsilon + i + \Delta)$ $+(\varepsilon + i)$ $+(\varepsilon + i - \Delta)$	$+(\varepsilon + i - s + \Delta)$ $+(\varepsilon + i - s)$ $+(\varepsilon + i - s - \Delta)$
Northern minor limit, wobble north Northern minor limit, mean wobble Northern minor limit, wobble south	$+(\varepsilon - i + s + \Delta)$ $+(\varepsilon - i + s)$ $+(\varepsilon - i + s - \Delta)$	$+(\varepsilon - i + \Delta)$ $+(\varepsilon - i)$ $+(\varepsilon - i - \Delta)$	$+(\varepsilon - i - s + \Delta)$ $+(\varepsilon - i - s)$ $+(\varepsilon - i - s - \Delta)$
Southern minor limit, wobble north Southern minor limit, mean wobble Southern minor limit, wobble south	$-(\varepsilon - i - s - \Delta)$ $-(\varepsilon - i - s)$ $-(\varepsilon - i - s + \Delta)$	$-(\varepsilon - i - \Delta)$ $-(\varepsilon - i)$ $-(\varepsilon - i + \Delta)$	$-(\varepsilon - i + s - \Delta)$ $-(\varepsilon - i + s)$ $-(\varepsilon - i + s + \Delta)$
Southern major limit, wobble north Southern minor limit, mean wobble Southern major limit, wobble south	$-(\varepsilon + i - s - \Delta)$ $-(\varepsilon + i - s)$ $-(\varepsilon + i - s + \Delta)$	$-(\varepsilon + i - \Delta)$ $-(\varepsilon + i)$ $-(\varepsilon + i + \Delta)$	$-(\varepsilon + i + s - \Delta)$ $-(\varepsilon + i + s)$ $-(\varepsilon + i + s + \Delta)$

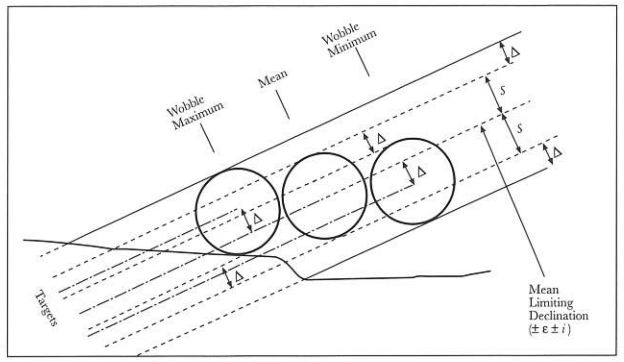


Fig. 2.8 A 'lunar band' and the targets within it. Adapted from Thom 1981, fig. 1.7.

An additional problem, hidden when we talk in terms of geocentric lunar declinations but important in practice, is the monthly variation in the lunar parallax,[4] which serves in practice to impose a variation in declination of ±3′·5 over a period of a month, on top of all the cycles already mentioned. This would further reduce the attainable precision in locating any particular target.

Even this is not all. Whether the critical risings or settings are directly observable also depends upon the phase of the moon (the limb being observed needs to be illuminated) and whether the event in question occurs during daylight hours. For many horizon markers, these together will eliminate three possibilities out of four.[5] Finally, and certainly not least, there is the possibility of bad weather.

A number of authors have tackled these issues in detail[6] and they agree that prehistoric observers probably could not have established the exact period of the 18·6-year lunar node cycle, or the existence of the 173-day wobble, without programmes of observations lasting at least several node cycles, i.e. several scores of years, and some means of recording their results. They certainly could not have done so without some means of extrapolating between nightly risings or settings close to the lunistice in a given month.

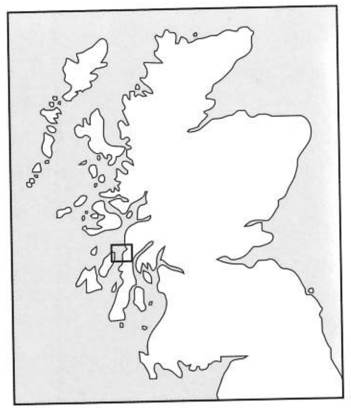
FURTHER COMPLICATIONS AT THE HIGHEST PRECISION

At higher precision still, as is postulated at Level 4, several other effects need to be taken into account. These include the gradual decrease in ε (see Astronomy Box 6) of about 3′ every 500 years; a sinusoidal variation in the lunar parallax which alters the apparent declination of the moon by up to 3′ over a 179-year cycle;[7] differences in mean refraction corrections owing to the fact that particular events can only be observed at particular times of year and day;[8] and the fact that the magnitude of day-to-day variations in refraction owing to the daily changes in weather conditions may be much greater than supposed by Thom (see Astronomy Box 3).

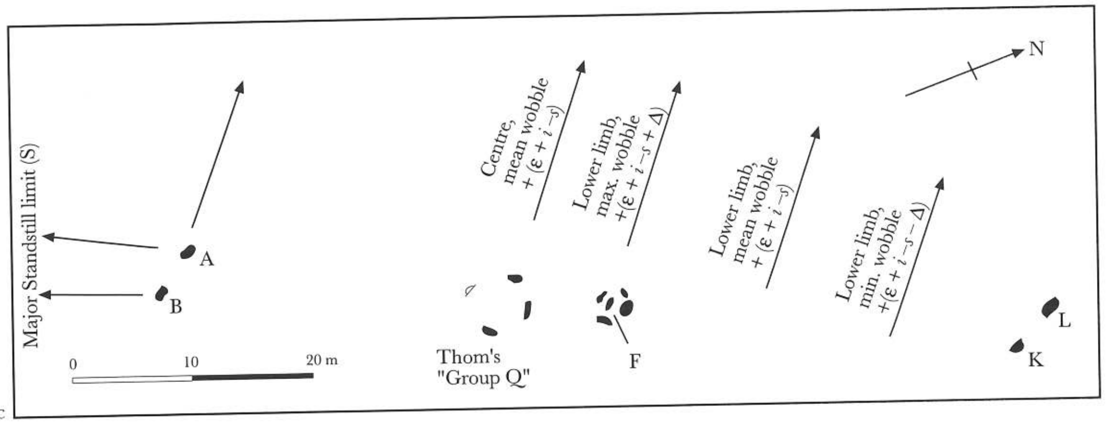
There is in fact strong evidence that Thom did not select horizon features fairly, that is without regard to the astronomical possibilities. This can be seen amongst the profile diagrams presented by Thom himself, both where a horizon indication exists and where it does not. For some examples see Fig. 2.10.[84] In the case of the indicated foresights, eliminating such preselection means trying to identify for each 'line' the entire range of horizon that might have been indicated, and then to identify every feature that could be construed as a potential foresight without regard for its declination. This second step is particularly problematic, since it involves a hypothetical judgement: what features might Thom have been prepared to consider as putative foresights if their declinations had been 'interesting'? A relatively straightforward choice, and one that reflects a form of foresight frequently proposed by Thom, is to include just notches, hill junctions and the bottoms of dips. The result of selecting all such features, and only all such features, falling within the indicated horizons from Level 3, is shown in Fig. 2.7b (for the data see column 13 of Table 2.3).[85] These data show no trace of Thom's peaks.

A number of other criticisms have been made of the Level 3 data and analysis.[86] As at the previous levels, there is little consistency in the types of backsights, indicators and foresights (see Table 2.3). At some sites, much more plausible indicators exist than the lunar ones proposed, yet seem to have no astronomical significance at all.[87] Some foresights are too near to the observing position, so that vegetation poses considerable uncertainties and the precision to which the observing position must have needed to be specified is a problem.[88] Others are so distant and at such a low altitude that atmospheric conditions would render them invisible virtually all of the time.[89]

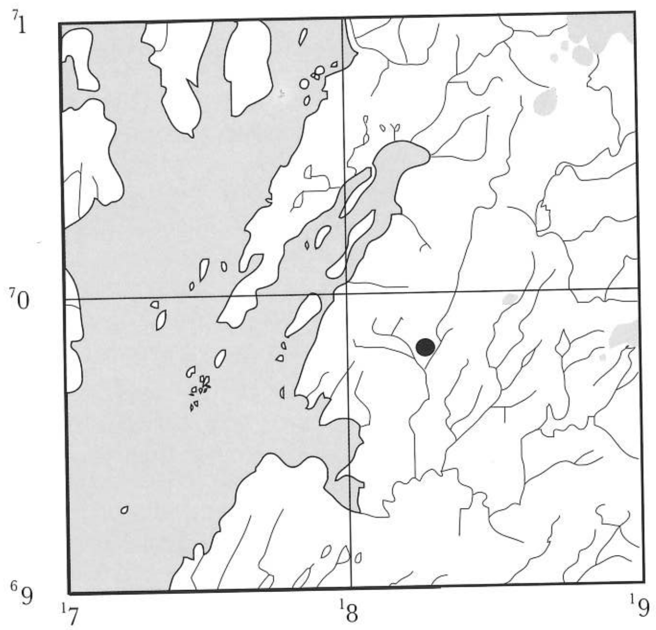
As if all this were not enough, there are considerable practical difficulties in actually observing the moon rising or setting at a major or minor limit at any of its wobble configurations. The main problem is that the moon only rises or sets roughly once a day, during which time it has moved considerably, so that in a given month the lunistice (see Astronomy Box 4) will generally fall between two consecutive risings or settings, and the moon will never actually be seen at its monthly maximum (northerly) or minimum (southerly) declination. In the worst case, it may get no nearer than about 10′ (Astronomy Box 7). Fully acknowledging this, Thom proposed that prehistoric observers could set up a backsight for a significant lunar event without actually observing it, but instead by extrapolating between the observed risings and settings. This could be accomplished by marking on the ground an 'extrapolation length', which depends upon the site and sightline, but is fixed in each case. By relating observations on two or three consecutive nights nearest a lunistice to this extrapolation length, the



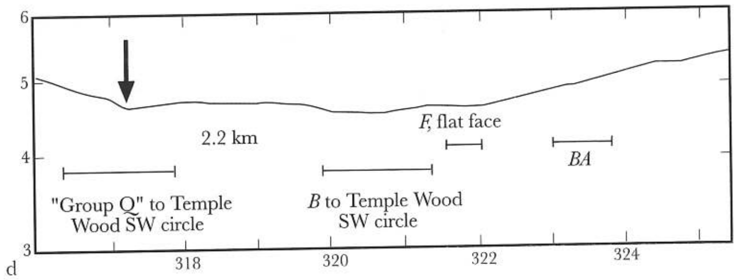
a



c



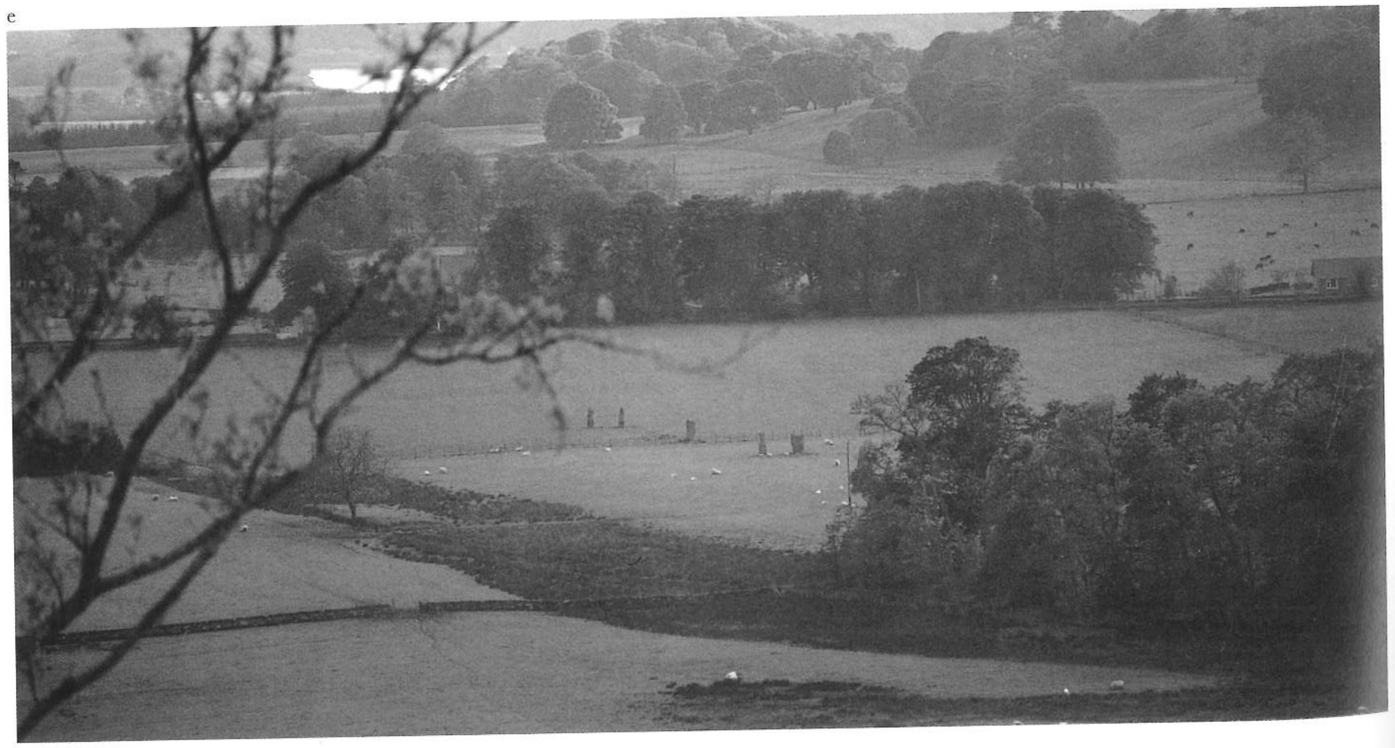
b

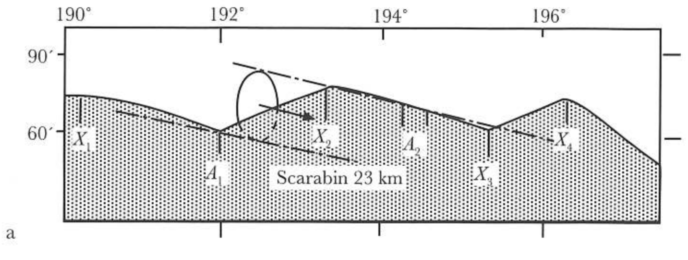


d

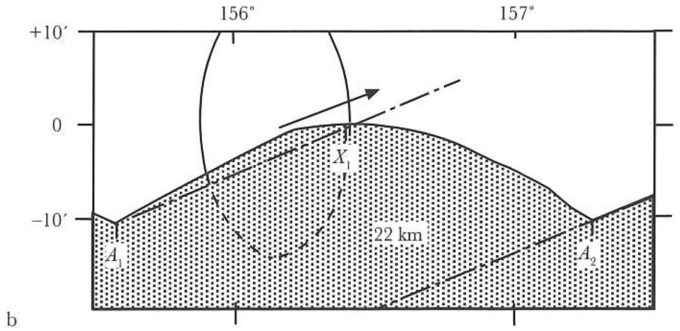
Fig. 2.9 Nether Largie, mid-Argyll.
a,b. Location of the Nether Largie standing stones.
c. Plan of the stones, showing the putative positions for observing Thom's notch in the north-west and the declination obtained in each case. Based on RCAHMS 1988, 136 and Thom 1971, fig. 5.1.
d. The horizon profile to the north-west. Thom's foresight, a small notch, is marked with an arrow. The horizontal bars show the directions 'indicated' by various alignments of standing stones, as determined during independent fieldwork published in 1981. The scales show azimuths and altitudes in degrees. Based on Ruggles 1981, fig. 4.3c.
e. The Nether Largie stones viewed from the north-east.

e

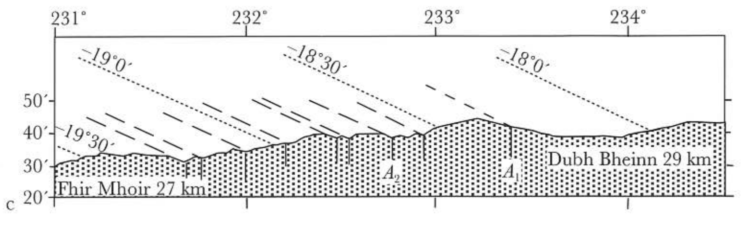




a



b



c

Fig. 2.10 Evidence for the preselection of foresights by Thom according to the astronomical possibilities.

a. Dirlot (L4) (unindicated). Profile diagram after Thom 1971, fig. 9.5. The moon is drawn, following Thom, setting with its centre at declination $-(\varepsilon + i)$. The bottom of a dip (A_1) and a small section of hill slope parallel to the moon's setting path (A_2) were included as potential foresights in Thom's analysis. Three hilltops (X_1, X_2, X_4), the bottoms of two further dips (one off to the left, X_3) and one prominent hill junction (off to the right) lying in the moon's path close to its major limit have all been missed out. A_1 and A_2 respectively yield declinations $-17'$ and $+14'$ away from the mean lunar limit, close to $-s$ and $+s$ respectively. According to a survey by the author in 1979 the eight potential foresights, from left to right, yield declinations $-29'$, $-16'$, $-18'$, $+12'$, $+12'$, $+11'$, $+31'$, and $+19'$ away from the mean lunar limit, a selection that includes many values that fall between the peaks in Fig. 2.7a.

b. Unival (L16) (indicated). Profile diagram after Thom 1971, fig. 6.15. The moon is drawn, following Thom, rising with its centre at declination $-(\varepsilon + i)$. The bottoms of two dips (A_1 and A_2) were included as potential foresights in Thom's analysis. The hilltop between them (X_1) and the bottoms of two further dips off to the left, lying close to the indication as well as in the moon's path close to its major limit, have both been missed out. A_1 and A_2 respectively yield declinations $-2'$ and $-27'$ away from the mean lunar limit, the latter close to $-(\Delta + s)$. According to a survey by the author in 1979 the five potential foresights, from left to right, yield declinations $+15'$, $+7'$, $-5'$, $-5'$, and $-34'$ away from the mean lunar limit. For an independent surveyed profile diagram, showing the additional dips and without the vertical exaggeration used by Thom, see Ruggles 1981, fig. 4.3a.

c. Kintraw (L30) (indicated). Independent resurveyed profile diagram after Ruggles 1983, fig. 7. This shows eight hill junctions, notches or bottoms of dips, which are given equal weight in the reappraisals by this author. Only points A_1 and A_2 were included as potential foresights in Thom's analysis. For the measured declinations see Table 2.3.

observing point for a theoretical limit could be determined and marked on the ground.[90]

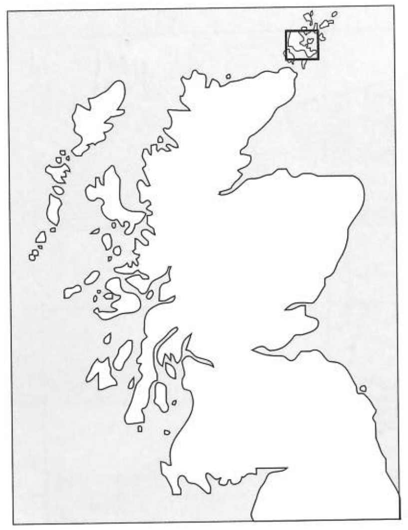
According to Thom,[91] an extrapolation length associated with a lunar foresight was marked at nine sites. These are listed in Table 2.1. However, reassessment of the evidence showed that either the alleged foresight or the marker of the extrapolation length are of doubtful status in all but two cases,[92] and even these two remaining cases have little in common: at one site (L31), the marked extrapolation length is roughly perpendicular to the sightline and at the other (L38) they are parallel.[93] In addition, it transpires that Thom was wrong to assume that the extrapolation length was fixed for a given sightline; in fact, the use of a fixed extrapolation length would result in errors at least as great as the amplitude of the wobble itself.[94] Finally, *both* monthly maxima on either side of a standstill must be successfully determined in order for a particular sightline to be set up. Failure will result in a delay of nineteen years. Because six observations on particular days must be made, and because of the uncertainties of lunar phase, daylight and bad weather (see Astronomy Box 7), it is unlikely that a new sightline could successfully be erected more than once every seventy-five years on average.[95]

In short, the evidence against lunar observations of the high precision envisaged at Level 3 is quite overwhelming. But perhaps the last words on the subject should come from modern astronomy. First, Thom failed to take into account yet another cyclical variation in the moon's declination, due to variable parallax, amounting to about 6′ over a period of 180 years. Even if the 173-day wobble was observed, this effect should blur out any peaks such as those apparent in Fig. 2.7a.[96] Second, as we have mentioned in chapter one, evidence has emerged more recently that day-to-day variations in atmospheric refraction may be much greater than Thom assumed, rendering observations to a precision greater than about 6′ infeasible anyway (see Astronomy Box 3).

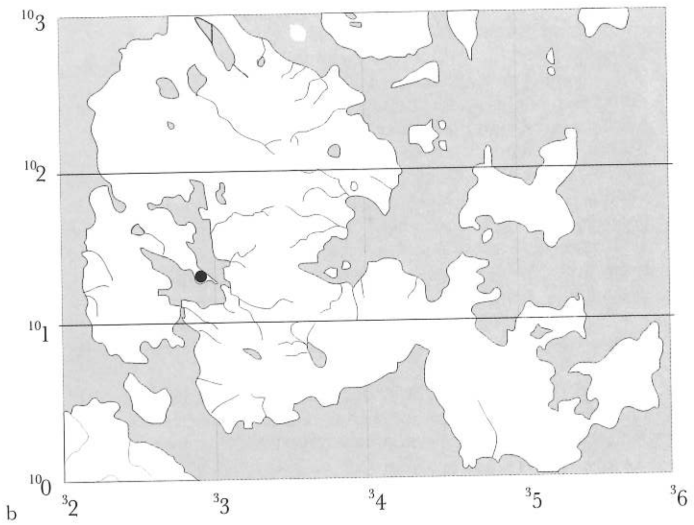
Level 4: the very highest precision

While the reassessments described above were being undertaken, Thom (now working together with his son Archie) had gone on to examine a sample of putative lunar foresights even more painstakingly than before. The dataset at this level consists of forty-four examples, which overlap substantially with those at Level 3, but also include seventeen lines from eight new sites (see Table 2.1).[97] By taking into account the particular astronomical and atmospheric corrections for each foresight at the time of year and day when it would necessarily have been used, rather than assuming mean parallax and refraction corrections as at Level 3,[98] the Thoms concluded that horizon markers were precise to within as little as a single minute of arc.[99] These claims prompted further, detailed reassessment by this author.[100]

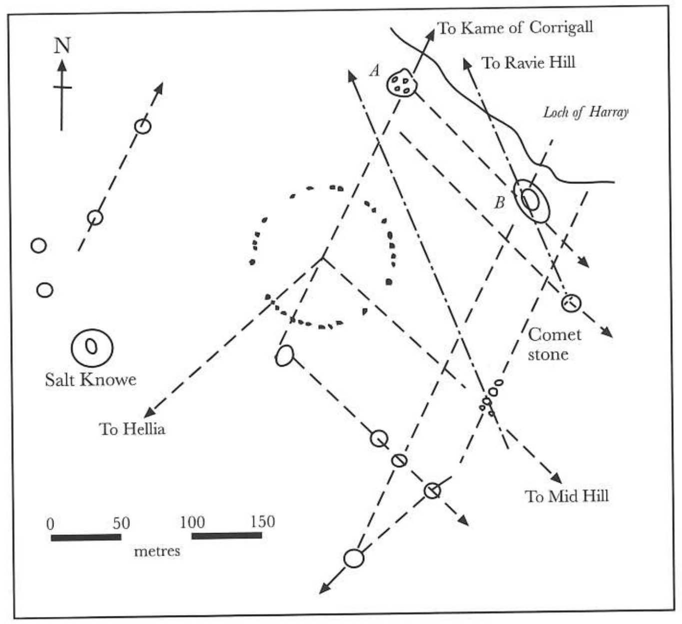
The most notable new site to enter at Level 4 is the Ring of Brodgar in Orkney (see L2 in List 1). This impressive henge and stone circle is arguably one of the most evocative prehistoric monuments in Britain, standing on a neck of land between two freshwater lochs, and in sight of the equally impressive Stones of Stenness as well as of Maes Howe chambered tomb.[101] For the Thoms, who first described the site in 1973, it also formed 'the most complete megalithic observatory remaining in Britain', with the outlying 'Comet Stone' and various large and small mounds in the vicinity forming



a



b

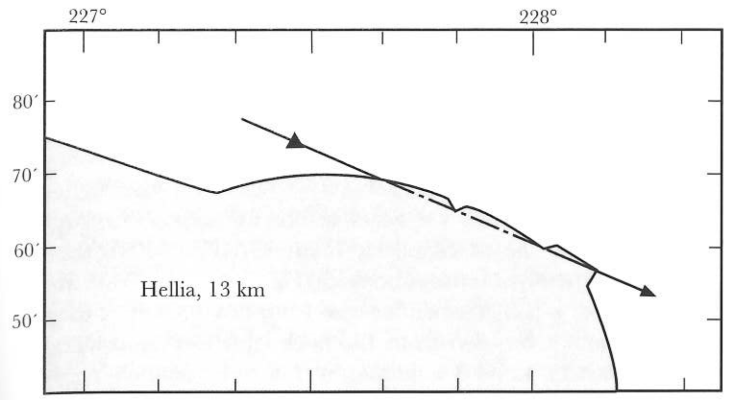


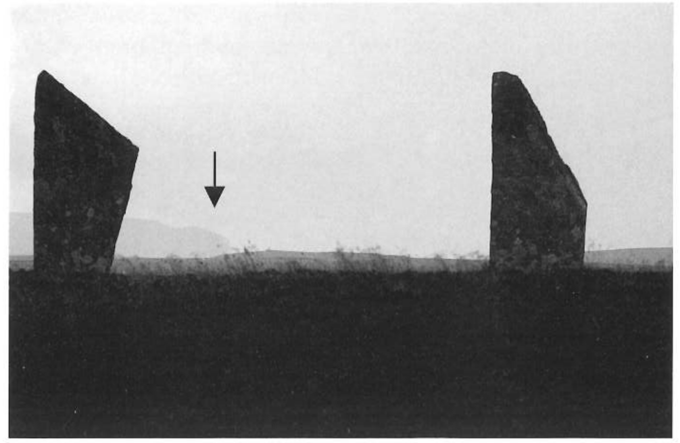
c

Fig. 2.11 Brodgar, Orkney.
a,b. Location of the Ring of Brodgar.
c. Plan of the Ring and mounds at Brodgar, showing the putative alignments to the four lunar foresights. Based on Thom and Thom 1975, fig. 3.
d. The Ring viewed from the south-west.

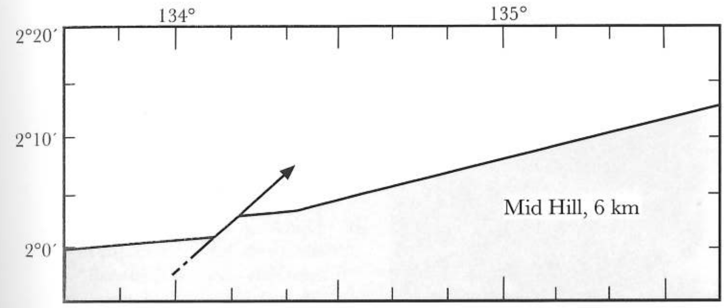
Fig. 2.12 (*facing page*) The Thoms' lunar sightlines at Brodgar. Profile diagrams (after Thom and Thom 1978a, fig. 10.2; 1973, fig. 2; 1975, fig. 2; and 1977, fig. 1 respectively) are shown on the left, and photographs with the alleged foresight marked are shown for comparison on the right. Note that the vertical scale is exaggerated in the profile diagrams.
a Hellia.
b. Mid Hill.
c. Kame of Corrigall.
d. Ravie Hill.

d

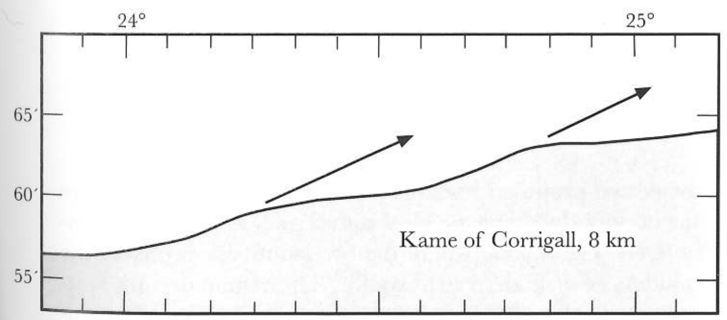




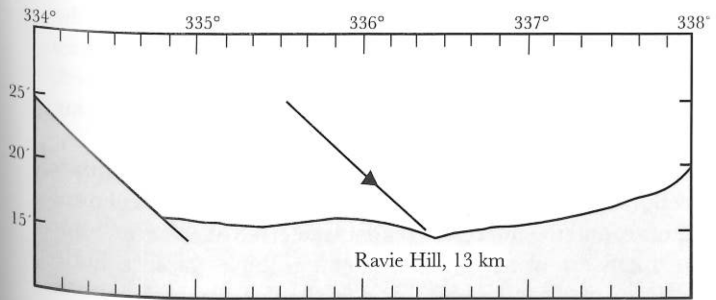
a

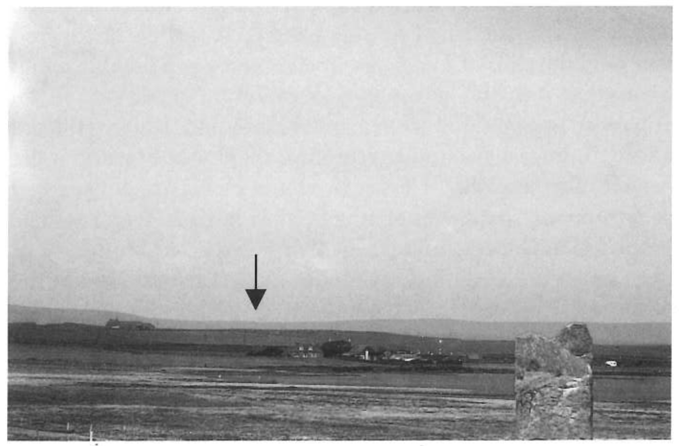


b



c





d

use: this turns out to be about 1700 BC, or possibly about 1500 BC.[104] The construction of the henge and stone circle, which according to the Thoms was carefully placed here in order to take advantage of the astronomical possibilities, predates even the earlier of these dates by several centuries.[105]

A now-familiar story is repeated when we examine the status of the remaining sightlines at Level 4. Three can be ruled out as intentional: the one at Stenness (L3), where the backsight was constructed some 1500 years before its supposed astronomical use;[106] one at Skipness, Kintyre (L40), where the backsight is merely a natural boulder (Fig. 2.13a); and one at Callanish, Lewis (L9), carried forward from Level 3, where the foresight cannot be seen from the backsight. Only fourteen of the remaining Level 4 sightlines, it transpires, actually represent cases where structures remaining today accurately backsights for four separate horizon lunar foresights (Figs. 2.11 and 2.12).[102] No fewer than nine lines from Brodgar are included in the Level 4 reassessment, together with one from nearby Stenness.

Fig. 2.13 Dubious backsights and indicators for alleged lunar sightlines of the highest precision.
a Skipness, Kintyre, which is a natural boulder rather than a genuine prehistoric monument. The proposed foresight is a deep notch amongst the hills of Arran in the background (A. Thom and A. S. Thom, 'Another lunar site in Kintyre', *AA* no. 1 (*JHA* 10) (1979), S97–8).
b. Dunskeig, Kintyre. A doubtful site; probably the remains of a relatively modern field wall. The alignment of the two stones does however indicate the hills of Arran, which include the lunar foresight.

The presence of as many as four distinct lunar foresights at the one site seems difficult to explain away by chance until the foresights are examined on the ground. It is then discovered that only the cliffs of Hellia are at all imposing; Mid Hill, albeit noticeable with the naked eye, is merely a small step in an otherwise straight hill slope; and Kame and Ravie Hill are utterly unimpressive and almost impossible to spot without the benefit of a theodolite. Certainly, all but Hellia are outweighed in prominence by scores of other visible horizon features. The proposed indicators, mainly involving despoiled mounds and hence ill-defined, are unconvincing. A detailed critique of the proposed sightlines is given elsewhere,[103] but for the archaeologist there is a simpler objection to the Thoms' interpretation. At this level of precision, the small change in ε over the centuries (see Astronomy Box 6) becomes significant and one can deduce a rough date (to within a few centuries) of presumed indicate the proposed horizon foresight.[107] Amongst these are some of doubtful archaeological status, such as Dunskeig, Kintyre (L41) (Fig. 2.13b), where the two stones are probably the grounders of a modern field wall.[108] The remainder are scattered geographically, represent a diverse collection of monuments and indicating structures,[109] and show strong evidence that the selection of putative foresights within indicated horizons was strongly influenced by the astronomical possibilities.[110]

Turning to the practicalities of the observations, it is clear that many of the criticisms made at Level 3, to do with the complexity of the moon's motions and the practical difficulties in observing and marking them, still stand at Level 4. Indeed, the precision is now so great that observing programmes lasting 180 years are now needed, by the Thoms' own admission.[111] At this level their technical arguments are complex,[112] and they are not considered further here. They require a technical response, and the interested reader is referred elsewhere.[113] But two things are worthy of brief mention. First, the fact that ε gradually changes means that the date of presumed use is deduced from the data for each of the sightlines at Level 4, as at Brodgar. Additionally, at this level the Thoms introduce a 'graze effect' which purports to make our measurement of sightlines even more precise by taking into account the bending of light rays passing close above intervening ground.[114] In practice, however, the extent of this effect for different sightlines is also deduced from the data.[115] In both cases, the values of the relevant parameters are adjusted so as to provide the best fit to the data, but the argument is circular: in reality, the more different parameters that can be adjusted in order to provide a good fit to the measured data, the easier it is to fit something very close to whatever we measure. Surely this, rather than anything actually achieved in Neolithic or Bronze Age Britain, is the reason for the staggeringly small statistical residuals obtained by the Thoms.

Concluding remarks

To sum up, we have seen that apparent trends in the crucial data at Levels 2, 3 and 4 can quite adequately be explained away by selection effects and the large number of free parameters that can be adjusted to provide a close fit between the high-precision lunar theory and the measured data. In any case, once we reach Level 3 there are enormous—almost certainly insurmountable—practical difficulties involved in observing and marking the moon's motions to the precision claimed. Taken together, these factors lead us to the unavoidable conclusion that lunar motions were *not* in fact observed and recorded to high precision in prehistoric times. For these reasons the idea of lunar observations and markers precise to a few minutes of arc will concern us no further in this book.

It should be pointed out that what we have just said does not conflict with the Thoms' statement that 'at no stage have we made any attempt to pull the values this way or that way to produce a better fit'.[116] We are certainly not suggesting that the Thoms were deliberately misleading people by carefully choosing only those lines which best fitted the theories they were trying to prove. Rather, the problem is one of implicit methodology: the values used in the Thoms' analyses are ones favourable to the lunar hypotheses that have already been singled out from less favourable data by their prior selection. This serves to emphasize that in collecting data on possible astronomical alignments, methodology is a critically important consideration.

The extent to which astronomical orientations and indications of a rougher nature were incorporated into megalithic structures was a question that, in the early 1980s, had to await the outcome of reassessments at Level 1.