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INDICATED DECLINATIONS AT THE CALLANISH MEGALITHIC SITES

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In this paper we present detailed surveys of horizon profiles indicated by standing stones at the Callanish Megalithic sites, and by inter-site lines. A brief description of the sites and of previous work concerning their possible astronomical significance is given in Section 1. A new code of practice is suggested in Section 2 in an attempt to lay the basis for a fresh body of statistical data on astronomical alignments at Megalithic sites. In Section 3 we establish certain dualitative criteria according to which horizons are considered to be indicated by the stones. The surveying techniques are described in Section 4. Profile diagrams showing indicated declinations are then described for all selected horizons, in Section 5 for on-site lines and Section 6 for inter-site lines. Tables and histograms of rough and accurate indications, in a form suitable for statistical analysis, appear in Section 7.

1. THE CALLANISH SITES

The largest Megalithic site at Callanish, Isle of Lewis (Site I) was described by Callender.[1] He also noted the existence of three nearby circles of large standing stones (Sites II, III & IV), of which descriptions and photographs were later presented by MacKenzie.[2] Some details of a site of small stones (Site V) and of the site some way away on Great Bernera also appear in MacKenzie's paper. Thom[3] investigated the sites around the head of Loch Roag, introducing the nomenclature used above, and including two further sites: two standing menhirs (Site VI) and a ring of small boulders (Site VII). Recently a Glasgow University group[4] have pointed out more nearby sites, extending the nomenclature as far as Site XII, and designating the Great Bernera site VIII. This group has produced a topographic survey of the whole Callanish complex. Mrs Ponting, of Callanish, has since noted the existence of more possible sites.[5] Brief descriptions of the sites are given in Table 1.

Astronomical speculations concerning Site I date back at least to the paper by Callender.[1] Somerville[6] produced a site plan and discussed indications; Hawkins[7] has produced declinations using Somerville's plan (as modified by Thom[8]) and contours from the 1-inch Ordnance Survey map. Somerville[9] also considered inter-site indications, and Thom[10] lists declinations to an accuracy of 0·1 degree for indications at Site I and certain inter-site lines, calculated either from preliminary surveys or from the Ordnance Survey.

In this paper a detailed survey of indications at and between the Callanish sites is presented. The sites considered are I–VI, XI & XII. These are the sites containing standing menhirs, excluding the Great Bernera site which cannot be seen from any of the others.

2. CODE OF PRACTICE AT MEGALITHIC SITES

The work of Thom, as described in his books,[11] has achieved wide recognition. Debate about his results has been rife, involving archaeologists,[12,13,14] astronomers[15] and statisticians.[16,17,18,19] Here we discuss only his claims about astronomical alignments. These have already been set in context against astronomical knowledge in ancient literate societies by Baity[20] and in a recent symposium.[21]

Thom's results are built up from many years of site work at hundreds of Megalithic sites. Some of his most powerful evidence is contained in his histograms of observed declinations.[22] If the criteria used in selecting the lines are well-defined, a valid statistical analysis can be performed to estimate the significance of the results. Thom tried to define selection criteria in his earlier work,[23] but his later criteria[24] depend on subjective judgements. So in order to eliminate any possibility of bias a check must be carried out *a posteriori*. MacKie[12] has attempted to draw up a list of tests to do this.

The possibility of archaeological verification of the theories at a particular site remains, and has been attempted at Kintraw.[12,25,26] Although of great

TABLE 1. The Callanish sites.

Number	Grid ref NB	Brief description	Refs
I	213 330	Circle of large menhirs, heights about 3 to 4m, surrounding a tumulus and great menhir (5·5m); five lines of menhirs lead away from the circle, two ("the avenues") approx. northwards and one each approx. east, south and west.	1, 6
II	222 326	Five large menhirs from 2 to 3m high in a ring surrounding a cairn.	2, 3
III	225 327	A complex of menhirs up to about 2·5m in height, consisting of a ring surrounding four of the larger menhirs.	2, 3
IV	230 304	Five large menhirs from 2 to 3·5m high in a ring surrounding a cairn.	2, 3
V	234 299	Five small menhirs about 0·5m high, three of which are close (within 5m) and in a line. A large boulder (dimensions about 1m) is roughly on this line about 50m away.	2, 3
VI	247 303	Two menhirs, the larger about 1·5m high, about 10m apart on a small hillock.	3
VII	232 302	A ring of small boulders, about 5m in diameter.	3
VIII	164 343	Great Bernera. Two large menhirs, heights about 2 and 3m, the smaller curved at the top, one small (1m) menhir and a large sunken stone with a flat face extant, probably a fallen menhir.	2, 3
IX	234 297	Two stones (possibly fallen menhirs) and a small cairn 4m in diameter.	4
X	230 336	An area of outcrops and freshly cleaved stones and menhirs, none standing.	4
XI	222 357	A single menhir about 1·5m high.	4
XII	216 350	A single menhir set in a concrete plinth in a small housing estate.	4

importance, findings such as these obtained in a retrospective way cannot be used in a statistical analysis, however attractive the theory at a particular site may then be. Statistical verification is important in settling the questions of Megalithic astronomy. The most direct method involves independent production of histograms similar to Thom's by resurveying sites in a systematic manner. The choice of lines to be surveyed must not be biased by theories that have already been proposed.

Thom postulates that Megalithic Man observed the detailed motions of the Sun and Moon using distant horizon profiles, rather than the more vague alignments between stones suggested, for example, by Hawkins[7] at Callanish Site I. Hawkins considers indications within about one degree of significant declinations to be astronomically important. His work of a similar nature at Stonehenge[27] has been adequately commented upon by Atkinson[28] and Hawkes.[29] To avoid the pitfalls inherent in this approach, indicated horizon profiles are the primary consideration in this paper. The method proposed is to lay down a set procedure for deciding which horizons might have been indicated, and to follow it at each site visited. Apart from an early attempt by Thom,[23] this has not been done in any previous work to which we have referred.

The Callanish sites were chosen as a first test for this approach. Horizon profiles had been surveyed only in a preliminary manner by Thom,[30] added to which new sites have been discovered since Thom's visit.[4]

3. CLASSIFICATION AND SELECTION CRITERIA

Constraints are proposed which will limit the number of possible indications on the ground to be considered. Five classes are proposed in Section 3.1 to represent in order of plausibility the most obvious ways in which an horizon might have been indicated. If indications of a certain class appear at a particular site, any lower class (less plausible) indications are not considered. This is done in preference to assigning a given statistical weight to each class of indication. It would obviously be ludicrous to assign equal weight to, say, all lines between any two stones, when at Site VI there is one such line and at Site I there are hundreds.

Further practical constraints on indications in the best class are proposed in Section 3.2. These are designed with the most accurate astronomical observations in mind (see Section 7). All indicated horizons not excluded are surveyed.

Different practical constraints for inter-site lines are proposed in Section 3.3.

3.1 *Class of Indication* (*Single Sites*)

Five classes are proposed as follows:

Class I: Lines along three or more stones, excluding stones in circles and stones already included in longer lines.

Class II: Lines along two stones, excluding stones in circles and lines between two outliers of a circle.

Class III: Lines from associated features (centres of circles, cairns) to outlying menhirs. Again the outlier must not be part of a circle.

Class IV: Lines between stones which include outliers or stones in circles.

Class V: Indications by flat faces of a single menhir, excluding the shorter faces of slabs.

Comments

(i) When does a rough line of stones become too inaccurate to be considered a single alignment? Laying down an objective criterion for this is a difficult problem. Fortunately no borderline cases were encountered at Callanish. A possible criterion could be based on the angular spread in constituent lines of stones.

(ii) It seems unlikely that a particular stone in a circle or ring should be used to indicate horizons, and for this reason such stones are excluded from the most plausible classes. However the possibility that such stones were later incorporated into circles has been allowed for in Class IV.

(iii) Horizons indicated by flat faces of single menhirs are put in the lowest plausibility class. In contrast to all the other cases, these indications depend critically on changes in orientation and weathering of the stones; they are only considered where a single menhir is present which has not obviously greatly moved.

(iv) Often stones in alignments are roughly oriented in the direction of the alignment. No effort has been made to weight such a situation more favourably than a similar alignment in which the stones are randomly oriented.

3.2 *Constraints on On-Site Lines*

Of the highest class indications appearing at a site, those falling into any of the three categories below have been rejected.

Local Horizon (L): The indicated horizon is less than 1km distant.

Menhirs Obscured (M): The nearest menhir obscures all further ones, wherever the observer stands on the line with the stones clearly in view.

Horizon Obscured (H): The part of the horizon being indicated is obscured by a stone or stones of the alignment, wherever the observer stands on the line with the stones clearly in view.

Comments

(i) Observations from any position other than directly along the line of the indication have not been considered. Given that the observer had to stand on the line to identify the horizon concerned, the most elementary hypothesis is that he observes from this position rather than keeping his eye on the horizon while moving somewhere else.

(ii) (L) excludes nearby horizons on which changes in ground level and vegetation are significant, and for which only very small changes in observer position may be sufficient to upset an accurate observation.

(iii) In sighting along stones, it is desirable to be able to see at least their tops or sides. If the stones vary greatly in size, (M) will eliminate the less convincing direction, *i.e.* from the larger stones to the smaller.

(iv) If (H) applies, the observer must stand to one side and extrapolate to determine the direction indicated; an unconvincing and inaccurate procedure.

(v) (M) and (H) will be affected by damage to the stones and by changes in ground level at the site since their erection. The latter is particularly noticable in the peat soil of the Callanish area. Rather than estimating the peat growth, the present situation is evaluated and ground level change ignored. In the case of uniform change a small number of false lines will have been introduced, but no genuine ones eliminated.

3.3 *Constraints on Inter-Site Lines*

All inter-site lines have been considered except those falling into the categories below.

Invisible to the Naked Eye (V): The "indicating site" (the site over which observations are made) is not visible by naked eye from the observing site in conditions of sun or shade.

Local Horizon (L): The indicated horizon is less than 1km distant.

Comments

(i) The visibility constraint (V) is problematical. Thom[31] mentions the possibility of lighting up a foresight by fire, in which case sites not visible with the naked eye could be used to indicate foresights. Even ignoring this possibility, lines may have been included which are visible in sunlight but not in the conditions prevailing when a solar or lunar event is observed; others may have been missed because the alignment has not been inspected in a wide enough variety of weather conditions. Criterion (V) is more dubious than any of those for on-site lines. However, sites visible from each other are a comparative rarity, so this criterion is of limited applicability.

(ii) The same remarks apply as in Section 3.2 (ii).

4. SURVEYING TECHNIQUE

The chosen horizon profiles were surveyed during June and July 1975 using a Watts 20″ vernier theodolite. When possible, the theodolite was stationed over concrete marker posts left by the Glasgow group,[4] thus reducing the amount of groundwork needed to locate our stations with respect to the stones. Many of the points measured on profiles were chosen arbitrarily on slopes and so could not be relocated for repeated measurement, but checks of the theodolite adjustment errors were made on site as well as before and after the expedition.

When weather permitted, azimuths were determined from observations of the Sun, timed using the MSF Rugby standard time signal. It was occasionally necessary, when surveying from many different stations in a limited time, to rely on azimuths of Reference Objects determined during previous or subsequent visits to the same station. The azimuth circle could be read to 10″ and pointing errors were less than 10″. A series of Sun observations typically gave Plate Bearing Zero to $\pm 20''$. Hence there was a probable error in azimuth of 30″. Scale reading errors in altitude were larger, at 20″, but this was swamped by

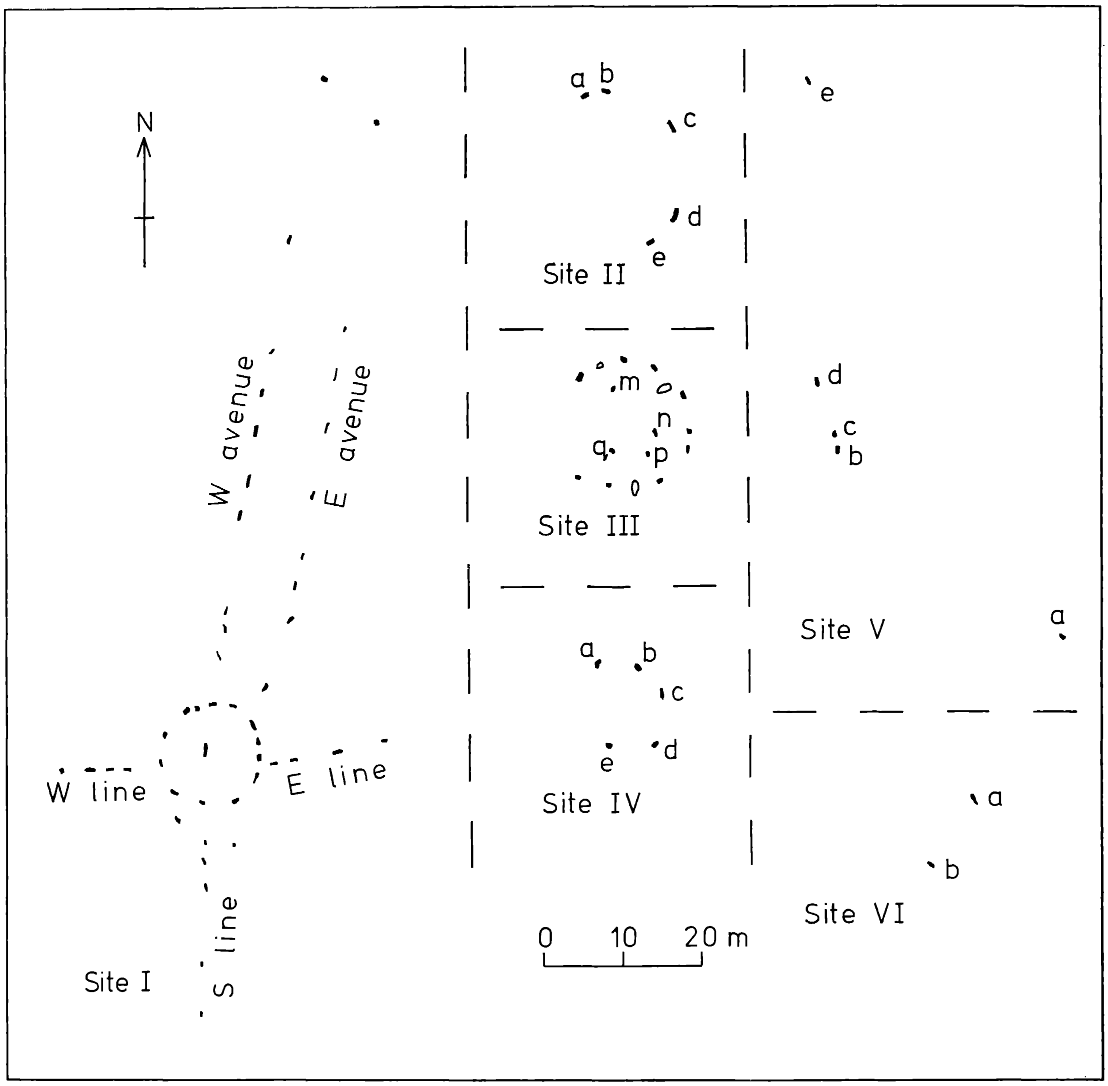

FIG. 1. Site plans for Sites I–VI (I after Somerville; II, III and IV after Thom; V as surveyed by the authors; VI sketch plan).

the 30″ uncertainty in the astronomical refraction correction needed to calculate declinations.[32] Several observations in varying weather conditions, including observations directly above and below intervening cloud, failed to reveal any of the terrestrial refraction effects mentioned by Thom.[33] When levelling and pointing errors were included, the probable error in altitude was ±40″.

Particular care was taken when the theodolite tripod was separated from a firm foundation by several feet of peat. Appreciable tilting occurred when observers moved near the tripod.

The parallax corrections needed to transform horizon profiles into those seen from the sight lines concerned were seldom large, but small uncertainties were present in the correction for some less distant horizons. Thus the probable errors in our quoted declinations are mostly better than ±1′.

5. INDICATED PROFILES (ON-SITE LINES)

The profile diagrams (available from J. G. Morgan, Jesus College, Cambridge, CB5 8BL, on payment of $10·00) are traced from photographs and calibrated by surveyed horizon points. Azimuths are marked at one-degree intervals and the altitude limits given. Surveyed points are marked by vertical bars. Allowance has been made for astronomical refraction but not here for astronomical

TABLE 2. On-site lines considered.

Tables give reference number for Table 4 or reason for excluding line (see Section 3.2). Where more than one of L, M & H occur for the same line, L overrules M overrules H in the table.

(a) Lines of Class I at Site I (stone numbers from Somerville [6])

Western avenue to north	(10–19)	1
Western avenue to south	(19–10)	L
Eastern avenue to north	(1–8)	2
Eastern avenue to south	(8–1)	L
Southern line to north	(24–28)	3
Southern line to south	(28–24)	L
Western line to west	(20–23)	4
Western line to east	(23–20)	H
Eastern line to east	(30–33)	5
Eastern line to west	(33–30)	M

(b) Lines of Class IV at Site II

To \ From	*a*	*b*	*c*	*d*	*e*
a	·	M	M	M	6
b	L	·	M	M	7
c	L	M	·	H	8
d	M	M	M	·	L
e	M	M	M	M	·

(c) Lines of Class II at Site III

To \ From	*m*	*n*	*p*	*q*
m	·	9	10	11
n	L	·	L	L
p	M	12	·	L
q	M	13	14	·

(d) Lines of Class IV at Site IV

To \ From	*a*	*b*	*c*	*d*	*e*
a	·	M	M	M	15
b	H	·	H	M	16
c	M	M	·	M	17
d	M	M	H	·	H
e	M	L	L	M	·

(e) Lines of Class I at Site V

bcd	18
dcb	19

(f) Lines of Class II at Site VI

ab	20
ba	H

(g) Lines of Class V at Site XI

North side of menhir to west	21a
North side of menhir to east	L
South side of menhir to west	21b
South side of menhir to east	L

parallax (which is important in the case of the Moon). Discussion of possible astronomical significance is left to Section 7.

The indicated horizon is taken to be the range of points that might have been indicated by the stones, taking into account possible changes in the indication due to weathering and movements of the stones. The indicated horizon is marked on the profile diagrams by a horizontal bar, and details are given in Table 4. Fallen or moved stones can be included by taking an enlarged indicated horizon obtained using all possible original positions for stones involved. Owing to lack of time no fallen stones were considered in our Callanish survey, although the stone at Site XII, possibly moved, has been included in this way.

Site plans are given for Sites I–VI in Figure 1. We use Somerville's numbering scheme[6] for the stones at Site I. Table 2 lists all lines of the highest class (see Section 3.1) occurring at each site. Those lines not considered for reasons (L), (M) or (H) (see Section 3.2) are marked accordingly, and references to Table 4 are given for the remainder. A comparison with those lines considered by previous authors is presented in Table 6, and specific comments follow.

Site I

A complex site such as I is difficult to fit into any statistical scheme designed to test for alignments at the more common small sites. The scheme in Section 3.1, however, allows us to ignore the stones in the great circle and consider only the five radial rows of stones, ignoring also any chance alignments of three or more stones occurring across the site.

The southern profile said by Hawkins[7] to indicate significant lunar declinations is in fact obscured by an outcrop of natural rock just to the south of the site. Hawkins's work was done using Somerville's[6] (insufficiently accurate) survey and contours from the 1″ Ordnance Survey map; the 50ft contour interval is too coarse to reveal the outcrop. The importance of actually visiting a site and doing surveying work there cannot be too highly stressed.

Somerville[6] points out a lunar declination indicated by the line from Stone 9 to Stone 34. Not only does this line involve just two stones, but it is excluded by being an (M) line in any case; Stone 9 is larger than Stone 34 and one has to stand in front of 9 to observe the other stone and the horizon.

Site II

Following Section 3.1 (ii), the low class lines considered cover the possibility that an alignment of two stones was later incorporated into a circle. The only included lines are from the smallest stone in the circle.

Site III

Thom[3] marks the central four stones at this site as being an inner ring lying on an ellipse. As four points do not uniquely define an ellipse, we have instead considered all lines between them, ignoring (as required by Section 3.1) the stones in the outer ring. In fact, two of the six lines line up well with a stone in the outer circle, and thus two of the three good alignments of three stones occurring at this site have been taken into account; the other such line, *eql*, involves two stones in the outer circle.

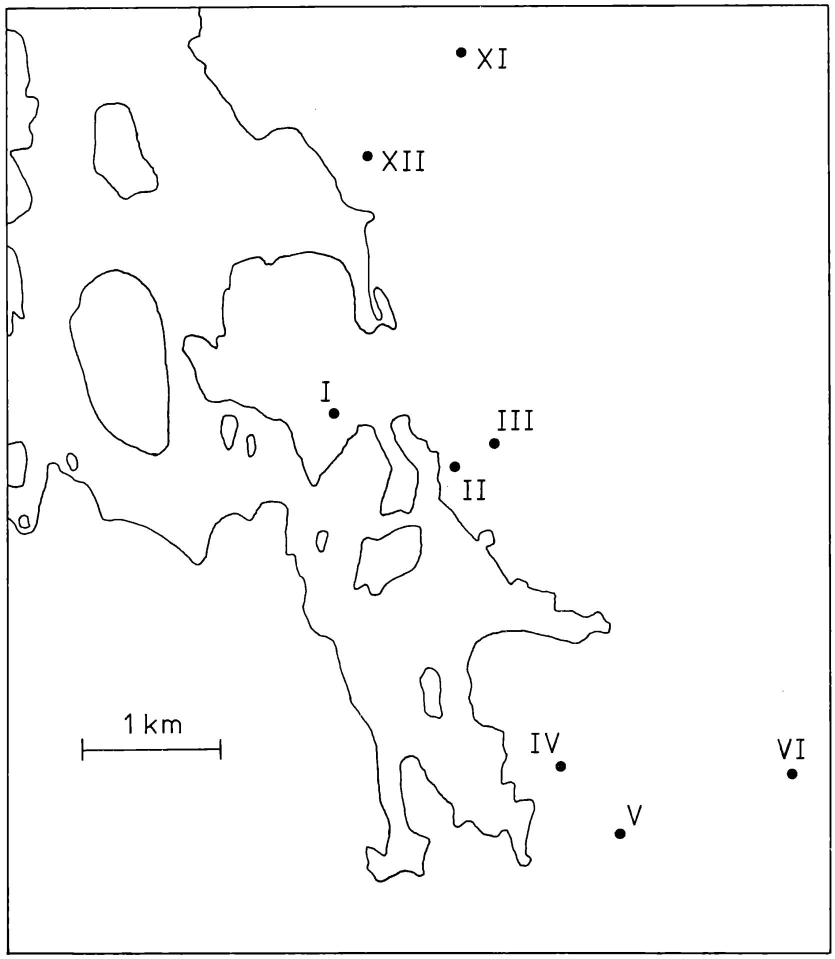

FIG. 2. Map of the locality of Sites I–VI, XI, XII.

Site IV

The situation is similar to that at Site II.

Site V

The two directions along the line of three stones were considered. Thom,[3] taking his information from a sketch plan and the Ordnance Survey, notes that unless obscured by a local horizon, the SSE profile gives a lunar declination. All but the eastern end of Thom's profile is in fact obscured as seen from Stones *b*, *c* and *d*, although visible from Stone *a*. Remark Section 3.2 (i) thus applies in our analysis.

Site VI

The line *ab* to the south was included, for although Stone *a* is the larger and on the edge of the ridge, it is possible to sight to *b* by standing directly behind *a*.

Site XI

This menhir has two reasonably flat faces; the relevant alignments were taken into account.

Site XII

No flat face alignments were considered here because of the possible disturbance of the stone.

6. INDICATED PROFILES (INTER-SITE LINES)

For notes on the profile diagrams see Section 5. The indicated horizon for inter-site lines is taken to be the horizon range above the indicating site.

A map of the area is given in Figure 2. In Table 3, those lines not considered for reasons (V) or (L) (see Section 3.3) are marked accordingly, and references to Table 4 given for the remainder. Again, Table 6 contains a comparison with previous work.

Observing Positions

The observing positions were taken to be as follows:
At Site I from the Great Menhir (Stone 29);
at Sites II–IV from the ring centres;
at Site V from Stone *c*, except the line to Site IV which is only visible from Stone *e* and was taken from there;
at Site VI from Stone *a*;
and at Site XI from the menhir.

At Sites II–IV the observing position cannot be defined to better than about 1m, but this inaccuracy would only be important in the case of accurate declinations (see Section 7.3) of horizon features little more than 1km away.

Sites Forming the Horizon

In two cases (Sites I and VI as seen from Site II) the stones of the indicating site lie on the horizon. At such large distances, the use of other menhirs as foresights is quite accurate, and these lines are included. Somerville[9] found Site VI to be on the horizon as seen from Site IV, but in fact this is not the case. A more distant hill forms the horizon.

Site XI to Site I

From the menhir at Site XI, the Sites I–VI lie on a plain with the mountains of Harris forming a dramatic background horizon. Glen Langadale appears as a deep and impressive cleft in these mountains; Site I lies below the cleft and slightly to the west of its base, with the avenues and south row roughly oriented towards this.

Site XI to Site XII

On the assumption that Stone XII might have stood almost anywhere in the present small housing estate, the horizon above most of the housing estate was considered.

TABLE 3. Inter-site lines considered.

Table gives reference number for Table 4 or reason for excluding line (see Section 3·3).

To \ From	I	II	III	IV	V	VI	XI
I	·	25	27	29	33	38	42
II	22	·	28	N	34	39	43
III	23	L	·	30	35	N	44
IV	V	N	V	·	36	40	V
V	V	V	V	31	·	41	V
VI	24	26	N	32	37	·	V
XI	V	V	V	V	V	V	·
XII	V	V	V	V	N	N	45

N: denotes no line of sight.

7. REDUCTION OF THE RESULTS

7.1 *Accurate and Rough Indications at Sites*

Three types of indication can be distinguished. Vague solstitial alignments exist at certain sites, such as New Grange[34] and the orientation of the avenue at Stonehenge.[35] The precision of these alignments is no better than several degrees, and their acceptance as deliberate implies only an awareness of the change in the rising and setting positions of the Sun during the year, and direct use of this. These are not our primary consideration.

Thom postulates[11] that Neolithic Man had an accurate knowledge of the movements of the Sun and Moon. The evidence comes from his histograms[22] of alignments supposed to be accurate to about 0°·1.[10] We refer to these as "rough" alignments.

As MacKie[12] points out, the ability to distinguish the solstice from the next day requires a foresight of about 30 arc seconds accuracy. Thom envisages this to have been achieved by the use of accurately defined horizon features, for which evidence is provided by a few sites such as Ballochroy,[36,37,38] Temple Wood[39] and Kintraw.[25] At other sites, such as Cefn Gwernffrwd, Dyfed,[40] good horizon features just miss a significant declination, and any deliberate indication must be considered only rough.

In order to permit statistical testing for both rough and accurate indications, the former are presented in Section 7.2 and the declinations of indicated horizon features presented separately in Section 7.3. The selection criteria of Section 3.2 are designed with accurate indications in mind. For rough indications, horizons (or artificial foresights) closer than 1km (L) or horizons obscured by menhirs (H) could be acceptable. Thus some plausible rough indications will have been excluded.

7.2 *Rough Indications at Callanish*

A histogram of indications based on the profiles of Sections 5 & 6 has been obtained as follows. For each profile a fixed weight of 100 has been distributed uniformly over the range of declinations on the indicated horizon. For this purpose declinations were quantized into 0°·1 bins. We use this method instead of the Gaussian humps used by Thom[22] as we envisage an equal likelihood of any declination in the range being indicated. The data are presented in Table 4 and the resulting histogram in Figure 3. No attempt has been made at this stage to smooth the abrupt cut-offs at the ends of the declination ranges, even

TABLE 4. Details of profiles.

		Az. limits		Dec. limits		Mean C.F.	0°·1 bins	Corrected wt/bin
1	Site I: W ave to N	7·5	10·8	32·1	32·5	0·099	5	2·0
2	Site I: E ave to N	9·8	12·1	32·2	32·5	0·119	4	2·9
3	Site I: S line to N	359·5	359·9	32·4	32·4	0·003	1	0·3
4	Site I: W line to W	266·1	268·5	−1·8	−0·6	0·526	13	4·0
5	Site I: E line to E	78·8	79·6	5·8	6·3	0·520	6	8·7
6	Site II: *ea*	335·1	335·4	28·6	28·8	0·250	3	8·3
7	Site II: *eb*	343·0	343·2	30·5	30·7	0·180	3	6·0
8	Site II: *ec*	9·2	9·7	32·4	32·6	0·103	3	3·4
9	Site III: *nm*	316·7	317·7	22·0	22·3	0·387	4	9·7
10	Site III: (*h*) *pm*	335·2	335·9	28·9	29·1	0·250	3	8·3
11	Site III: (*k*) *qm*	3·2	3·5	33·0	33·2	0·036	3	1·2
12	Site III: *np*	200·6	201·4	−29·4	−29·1	0·218	4	5·4
13	Site III: *nq*	248·2	249·3	−10·5	−10·0	0·500	6	8·3
14	Site III: *pq*	276·3	277·6	3·3	4·0	0·524	8	6·6
15	Site IV: *ea*	351·3	351·7	31·5	31·6	0·091	2	4·6
16	Site IV: *eb*	17·8	18·6	30·1	30·4	0·193	4	4·8
17	Site IV: *ec*	43·2	44·7	22·4	23·0	0·395	7	5·6
18	Site V: *bcd*	343·9	344·6	30·6	30·7	0·167	2	8·4
19	Site V: *dcb*	161·9	163·0	−29·6	−29·3	0·208	4	5·2
20	Site VI: *ab*	213·0	215·8	−25·8	−24·5	0·333	14	2·4
21a	Site XI: N side to W	230·8	234·1	−19·3	−17·7	0·440	17	2·6
21b	Site XI: S side to W	237·8	240·9	−15·8	−14·3	0·470	16	3·0
22	Site I to Site II	109·7	111·3	−11·1	−10·2	0·502	10	5·0
23	Site I to Site III	99·8	100·7	−5·1	−4·6	0·522	6	8·7
24	Site I to Site VI	124·7	125·0	−17·9	−17·7	0·452	3	15·1
25	Site II to Site I	288·0	292·6	9·4	11·7	0·502	24	2·1
26	Site II to Site VI	128·7	129·0	−19·5	−19·2	0·432	4	10·8
27	Site III to Site I	278·9	283·5	4·5	7·0	0·520	26	2·0
28	Site III to Site II	247·2	251·0	−10·8	−9·2	0·501	17	3·0
29	Site IV to Site I	322·5	324·0	24·3	24·8	0·352	6	5·9
30	Site IV to Site III	344·0	344·4	30·5	30·6	0·170	2	8·5
31	Site IV to Site V	134·7	135·4	−21·3	−21·0	0·400	4	10·0
32	Site IV to Site VI	88·5	89·0	0·8	1·3	0·526	6	8·8
33	Site V to Site I	321·3	322·0	23·7	23·9	0·360	3	12·0
34	Site V to Site II	333·0	333·1	27·7	27·8	0·272	2	13·6
35	Site V to Site III	337·7	338·1	28·9	29·2	0·228	4	5·7
36	Site V to Site IV	313·4	314·7	20·7	21·4	0·406	8	5·1
37	Site V to Site VI	65·1	65·6	12·7	13·0	0·490	4	12·2
38	Site VI to Site I	304·2	304·8	16·8	17·1	0·452	4	11·3
39	Site VI to Site II	308·9	309·1	18·8	18·9	0·432	2	21·6
40	Site VI to Site IV	268·0	268·4	−0·4	−0·2	0·526	3	17·5
41	Site VI to Site V	243·8	247·8	−13·2	−11·0	0·492	23	2·2
42	Site XI to Site I	194·8	195·0	−30·7	−30·5	0·160	3	5·3
43	Site XI to Site II	176·0	176·1	−31·8	−31·8	0·042	1	4·2
44	Site XI to Site III	170·4	170·5	−31·0	−31·0	0·102	1	10·2
45	Site XI to Site XII	218·3	219·0	−23·6	−23·4	0·364	3	12·1

Col. 1 : reference number as on diagrams.
Col. 2 : description of line.
Cols 3, 4: limits in azimuth of the indicated horizon.
Cols 5, 6: limits of declinations occurring on the indicated horizon.
Col. 7 : mean compression factor (see Fig. 4) for the indicated horizon.
Col. 8 : number of 0°·1 declination bins used for construction of the histograms (Figs 3 and 5).
Col. 9 : weight added to each bin in the indicated range after applying the compression factor (see Section 7.2).

though a qualitative judgement was involved in defining these.

Whilst illustrating the method, there are insufficient lines to produce a significant result. However, a few comments can be made.

Random indications will not produce a uniform distribution of declinations. Those most probable lie close to the colatitude, because a large azimuth range in the north produces only a small declination range; similarly in the south. The colatitude at Callanish is $+31°\cdot8$ and this effect is apparent in Figure 3. A further weighting (a "compression factor" d Dec/d Az) must be applied to the raw data to cancel this effect. Unfortunately this is different for sites at different latitudes and for profiles at different altitudes at the same site. The adjustment must be made before data are combined. The typical values of the compression factor for Callanish are given in Figure 4. These have been applied to the raw data of Figure 3 to produce the final histogram shown in Figure 5.

Solar solstitial alignments: The declinations of the midsummer solstitial Sun around 2000B.C. were

$$\epsilon - s = +23°\cdot65 \text{ (lower limb)},$$
$$\epsilon = +23°\cdot9 \text{ (centre) and}$$
$$\epsilon + s = +24°\cdot15 \text{ (upper limb)}.$$

At midwinter the values are the negatives of these with the limbs reversed.

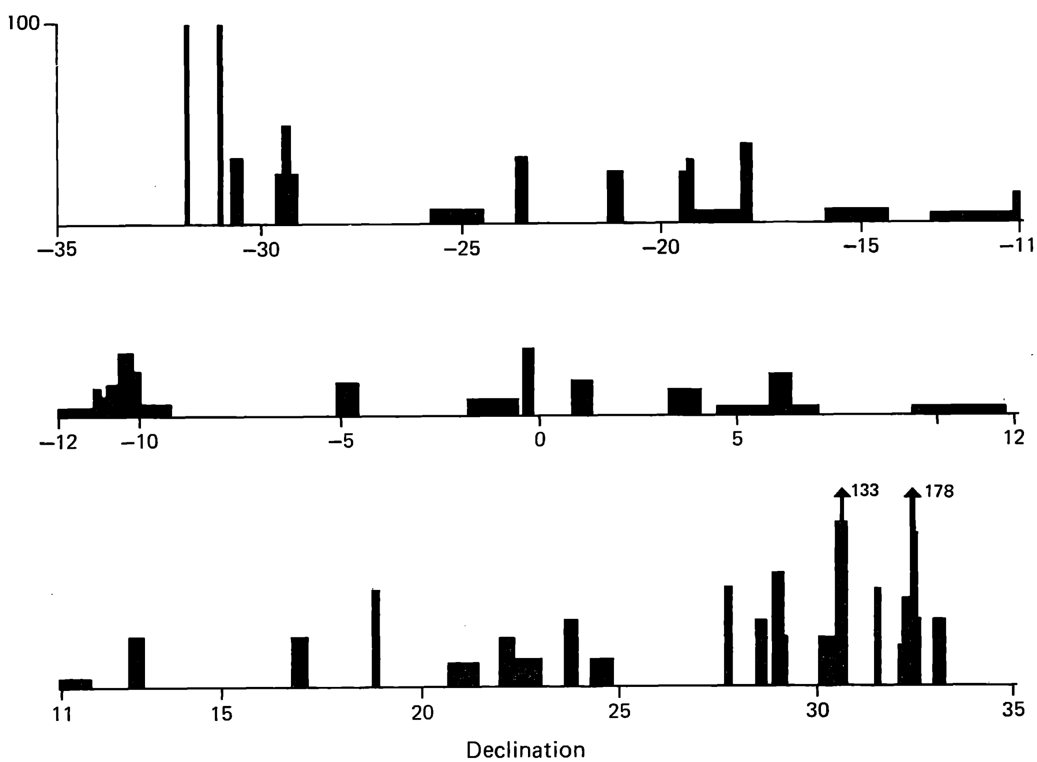

FIG. 3. Histogram of rough indications at Callanish (declinations here and in subsequent figures are measured in degrees).

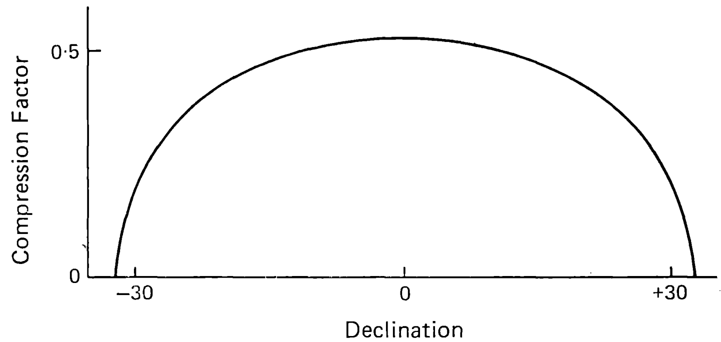

FIG. 4. "Compression factor": typical values for Callanish.

These declinations decrease in magnitude by about 0°·1 per millennium. The notation follows Thom:

ϵ = inclination of the Earth's orbital plane to the equator
s = semidiameter of the Sun (or Moon).

We conclude that two alignments at Callanish may have indicated solstices in a rough manner:

Site I viewed from Site V $+(\epsilon - s)$; and
Site XII viewed from Site XI $-(\epsilon - s)$.

Site I misses indicating the upper limb of the midsummer Sun as seen from Site IV by 0°·2.

TABLE 5. Indicated horizon features.

Site	Line	Class	Apparent declination °	′	Parallax (using HP = 57′·7) ′	Lunar geocentric declination °	′
I	None						
II	*eb*	1	+30	32	57·0	+31	29
	to I(29)	2	+10	28	50·0	+11	18
III	*nm*	1	+22	01	52·2	+22	53
	nm	1	+22	13	52·2	+23	5
	np	1	−29	24	56·3	−28	28
	to II	2	−10	49	50·1	−9	59
	to II	2	−9	53	49·9	−9	3
	to II	2	−9	16	49·8	−8	26
	to I	2	+5	38	49·2	+6	27
IV	*eb*	1	+30	12	56·7	+31	9
	ea	2	+31	29	57·7	+32	27
V	*bcd*	1	+30	34	57·0	+31	31
	dcb	1	−29	32	56·2	−28	36
	to III	2	+28	52	56·0	+29	48
VI	*ab*	2	−24	51	54·1	−23	57
	ab	2	−24	48	54·1	−23	54
	to V	2	−11	41	50·2	−10	51
XI	N side	2	−15	14	50·8	−14	23
	to I	2	−30	32	57·0	−29	35

Lunar standstill alignments:[41] The declinations given in Figures 3 & 5 are apparent declinations as seen from the surface of the Earth. To change to geocentric declinations a correction must be applied, which depends on the astronomical body being observed and is only important in the case of the Moon. It is dependent on the latitude of the site and the altitude and azimuth of the Moon. The correction curve for Callanish for zero altitude is given in Figure 6. Lunar geocentric declinations are also plotted in Figure 5. These, and not apparent declinations, must be used in testing for possible lunar significance.

The relevant values around 2000B.C. are

		limb $(+s)$	centre $(+0)$	limb $(-s)$
Major standstill:	$\pm(\epsilon+i)$	$\pm29°\cdot3$	$\pm29°\cdot05$	$\pm28°\cdot8$
Minor standstill:	$\pm(\epsilon-i)$	$\pm19°\cdot0$	$\pm18°\cdot75$	$\pm18°\cdot5$

where i is the inclination of the Moon's orbital plane to the ecliptic. If the additional perturbation $\pm\Delta$ is taken into account, each of these values varies by a further $\pm0°\cdot15$; however, the variation in the Moon's parallax due to the eccentricity of its orbit is comparable with Δ.

We conclude that four alignments may have indicated lunar standstills in a rough manner, with the listed lunar positions occurring within the indicated declination ranges:

Line *dcb* (to south) at Site V $-(\epsilon+i-s-\Delta)$;
North side of menhir to west at Site XI $-(\epsilon-i-s)$ and $-(\epsilon-i-s-\Delta)$;

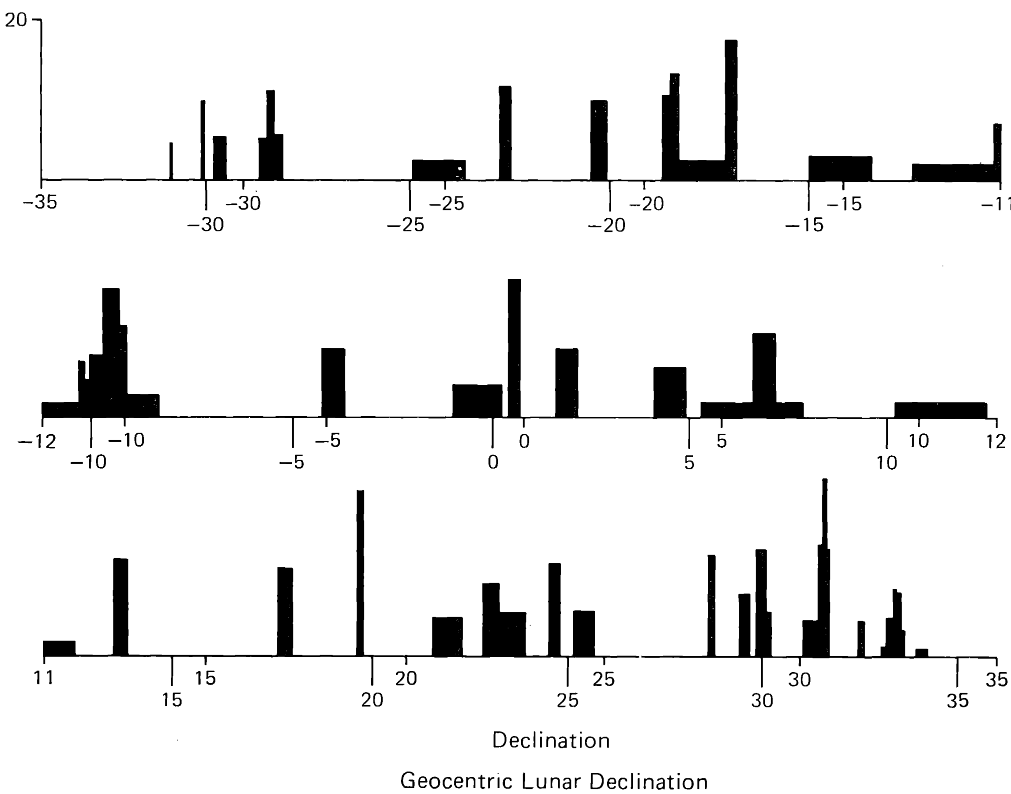

FIG. 5. Corrected histogram of rough indications at Callanish.

TABLE 6. Lines obtained by previous authors.

Column headings: 1: Reference.
2: Site and line.
3: Apparent declination quoted by author.
4: Author's interpretation.
5: Our reference in Table 4, or reason for not considering the line.
6: Our declination range compared with that quoted by the author.
7: Our interpretation of astronomical significance.
8: Our comments.

[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
6	I: E av to N	32° 26′ 37″	Capella 1800BC	1	Wider	None	ANSTL
6	I: W av to N	32° 28′ 12″	Capella 1800BC	2	Wider	None	ANSTL
6	I: S line to N	Not quoted; az. 359°−1°	Line to true N	3	–	None	T
6	I: W line to W	0° 35′ 19″	Sun (equinox)	4	Difft	None	ANCLD
6	I: E line to E	6° 43′	Pleiades 1750BC	5	Difft	None	NSFLH
6	I: Stone 9–34	28° 10′ 25″	Moon $+(\epsilon+i)$	Cl	–	None	ANE
9	II: Line to I	Not quoted	No significance	25	–	None	*
9	III: Line to I	Not quoted	No significance	27	–	None	*
9	III: Line to II	Not quoted	Sun (May Day)	28	–	None	C
9	IV: Line to VI	0° 12′	Sun (equinox)	32	Difft	None	BCN
9	IV: To boulder	−15° 57′	Sun (Nov 6)	NS	–	None	CN
9	IV: To plateau	14° 50′	Sun (May Day)	NS	–	None	CN
7	I: E av to S	−29°·3 (XG)	Moon $-(\epsilon+i+s)$	EL	–	None	OL
7	I: W av to S	−29°·4 (XG)	Moon $-(\epsilon+i+s)$	EL	–	None	OL
7	I: S line to S	−29°·0 or −29°·5 (XGJ)	Moon $-(\epsilon+i+s)$	EL	–	None	OL,M(0°·3 or 0°·2)
7	I: W line to E	−0°·6 (X)	Sun (equinox)	EH	–	None	LC,M(0°·3)
7	I: E line to W	−6°·6 (XG)	Moon $-(i+s)$	EM	–	None	LR,M(1°·2)
7	I: Stone 9–20	22°·3 (X)	Sun $+(\epsilon-s)$	Cl	–	None	E?,M(1°·4)
7	I: Stone 9–34	28°·3 (XG)	Moon $+(\epsilon+i-s)$	Cl	–	None	E,M(0°·5)
7	I: Stone 29–34	23°·5 (X)	Sun $+(\epsilon-s)$	Cl	–	None	E?
7	I: Stone 29–35	29°·4 (XG)	Moon $-(\epsilon+i+s)$	Cl	–	None	E?
7	I: Stone 35–30	27°·4 (XG)	Moon $+(\epsilon+i-s)$	Cl	–	None	E?,M(1°·4)
7	I: Stone 35–33	18°·5 (XG)	Moon $+(\epsilon-i-s)$	Cl	–	None	E?
10	I: E av to N	32°·5	Capella 1790BC	1	Wider	None	LST
10	I: W av to N	32°·5	Capella 1790BC	2	Wider	None	LST
43	I: E av to S	−30°·2	Moon $-(\epsilon+i+s)$	EL	–	None	LOZ
43	I: W av to S	−30°·2	Moon $-(\epsilon+i+s)$	EL	–	None	LOZ
10	I: W line to W	0°·3	Sun (equinox)	4	Difft	None	LCD
10	I: E line to E	6°·9	Altair 1760BC	5	Difft	None	LSH
3	I: Ellipse axis	24°·3	Sun $+(\epsilon+s)$	NC	–	None	
10	I: Line to V	−24°·5	Sun $-(\epsilon+s)$	EV	–	None	M(0°·3)
10	II: Line to VI	−19°·7	Moon $-(\epsilon-i+s)$	26	Difft	Moon	*K
10	III: Line to I	5°·4	Sun (calendar)	27	Wider	None	YC
10	III: Line to II	−10°·2	Antares 1880BC	28	Wider	None	S
10	IV: Line to V	−22°·8	Sun (calendar)	31	Difft	None	CK
10	IV: Line to VI	1°·0	Sun (equinox)	32	Wider	None	C
43	V: *dcb*	−29°·6	Moon $-(\epsilon+i-s)$	19	Narwr	Moon	*QZ
43	V: *dcb*	−28° 35′ (G)	Moon $-(\epsilon+i-s-\Delta)$	NN	Same	Moon	*Z
10	V: Line to I	23°·8	Sun $+(\epsilon-s)$	33	Wider	Sun	*
10	V: Line to II	27°·8	Moon $+(\epsilon+i-s)$	34	Same	Moon	*
10	V: Line to VI	13°·6	Sun (calendar)	37	Difft	None	CK
10	VI: Line to I	16°·9	Sun (calendar)	38	Wider	None	C
10	VI: Line to IV	0°·0	Sun (equinox)	40	Difft	None	CK
10	VI: Line to V	−12°·9	Sun (calendar)	41	Wider	None	C

KEY TO REMARKS IN COLUMN THREE

X: The declinations presented in his Table 1 are not those indicated, but those of the centre of the object considered to be indicated, which can lead to confusions in the interpretation. We have taken this into account in calculating the declinations assumed to be indicated.

TABLE 6: Continued

J: No sign is given for the "error", hence the two possible values.
G: This is a corrected (geocentric) declination.

KEY TO COLUMN FIVE

Lines considered by us:

Number: The number of our corresponding line in Table 4.
NN: This is the declination of a notch: see our Table 5.

Lines excluded by us:

Cl: Lines of higher class exist at the site (Section 3.1).
EL: We excluded this line for reason (L) (similarly (M), (H) or (V)) in Section 3.2 or 3.3.
NC: This line is not catered for in our classification.
NS: We do not consider the indicator to be a *bona fide* site.

KEY TO COLUMN SIX:

Our declination range is:
Difft (different)
Wider
Narwr (narrower) or the
Same
as that obtained by the author.

KEY TO OUR COMMENTS

*: Agreed.
A: Accuracy greater than 1′ not justified by instrumental errors.
B: Somerville could not see the hill behind Site VI because of bad conditions; hence the declination discrepancy.
C: We do not consider calendar declinations (Section 7.2).
D: Both Somerville and Thom obtain declinations about a degree higher than ours. The west line curves slightly northwards, and if only the western two stones are considered, a notch to the north of our profile is indicated. It seems that the other authors considered this notch rather than the profile indicated by all four stones.
E: This line would be excluded in any case by an (L), (M), (H) or (V) condition (Section 3.2).
F: These are not even amongst the brightest stars: extinction will cause them to be invisible when rising or setting.
H: Both Somerville and Thom obtain declinations about a degree higher than ours. The east line contains three menhirs (30–32) in a good line and a fourth (33) at the east end to the north of this line. We took the indication along the first three stones; it seems that the other authors took an average line along the four.
K: The way Thom describes his results[45]—"Somewhat rough surveys . . . all [of which] ought to be very carefully measured and examined before any of the . . . declinations can be accepted as final"—may explain the discrepancy between his results and ours.
L: Stones not accurately in a straight line: accuracy unjustified.
M: Misses the claimed indication by the stated amount.
N: No notches: accuracy greater than 0°·1 not justified.
O: The distant horizon is obscured by local outcrops.
Q: All but one end of the range claimed to be indicated is obscured by local ground.
R: The setting Moon halfway between its monthly limits cannot be detected. At this time the Moon's setting path is moving along the horizon at a rate of about 12°/day, and there is no way of knowing whether the Moon happens to set just as its setting path crosses the midway point.
S: We do not consider stellar lines (Section 7.2).
T: All lines within 10° of true north will give declinations of roughly the colatitude 32° (depending on horizon altitude) (Section 7.2).
Y: Site I subtends a large angle from Site III, so the accuracy is much less than 0°·1.
Z: Thom's table,[44] which is used to obtain the best fit for ϵ, i, s and Δ from his lunar lines, contains 6 lines from Callanish calculated from the Ordnance Survey. Of these, the two avenues to the south at Site I and 3 of the 4 notches indicated by the line to the south at Site V are obscured by local horizons, leaving only the one included in our Table 5.

Site VI as seen from Site II $-(\epsilon-i-s+\Delta)$, $-(\epsilon-i-s)$, $-(\epsilon-i-s-\Delta)$ and $-(\epsilon-i-\Delta)$;

Site II as seen from Site V $+(\epsilon+i-s-\Delta)$.

Two lines miss indicating standstills by 0°·1: line *ea* at Site II just misses $+(\epsilon+i+s+\Delta)$, and Site I as seen from Site XI just misses $-(\epsilon+i+s+\Delta)$.

Thus a total of six lines out of 46 may have been astronomical, with a further three just failing to satisfy our criteria. It is notable that all six lines indicate a limb, rather than the centre, of the Sun or Moon. Calendar declinations[42] have not been considered; in a survey independent of that of Thom these should not be included until evidence for them has accumulated in our histogram. We note with interest that none of the astronomical indications found was at or from Site I.

Stellar lines are not considered at all. Their large variation in declination over the centuries due to the precession of the equinoxes means that the utility of a site as a stellar indicator would be only temporary, certainly less than a century. In addition it is very easy to fit a given declination to a bright star by choosing an appropriate date. By allowing all first magnitude stars and a range of five centuries, about a third of the total horizon can be construed as astronomically significant. However, we note that, in his early work, Thom[23] attempted a statistical analysis of stellar alignments. His interpretation, and that of others, is compared with ours in Table 6.

7.3 *Accurate Indications at Callanish*

Horizons can be used as accurate indicators if they contain features that enable very small changes in setting points to be detected. Such features are taken to be either notches which accurately define rising or setting points, or else changes in the slope in a concave sense such that certain lines of constant declination reappear in the dip. We consider the possibility that such features were used whenever they occur in the indicated horizon.

An attempt has been made to divide features into three classes according to their quality with respect to other nearby features that might equally well have been used. This allows the possibility of statistical weighting in favour of the more convincing features. This has been done by considering the two horizons

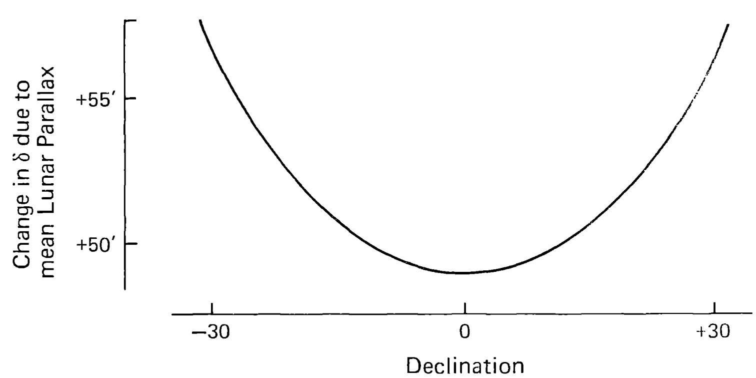

FIG. 6. Lunar parallax correction curve for Callanish.

adjacent to the indicated horizon and of equal length to it in azimuth. The classes are:

Class 1: The indicated horizon contains features of greater prominence than the adjacent horizons;
Class 2: The indicated horizon contains features of roughly equal prominence to the adjacent horizons;
Class 3: The indicated horizon contains features of lesser prominence than the adjacent horizons.

Prominence is a subjective concept, but in practice there is usually little doubt about the classing. Adjacent horizons have not always been shown in full in the profile diagrams (see Section 5) when they are featureless.

Eighteen features were obtained from the Callanish profiles, and the Great Menhir (29) at Site I as seen from Site II has also been included. Their declinations are listed in Table 5. The declination taken is that of the lowest point in the case of notches and the lowest declination reappearing in the case of concave changes in slope. In this latter case if the upper limb of the Sun or Moon were at this declination it would twinkle in the dip. The declinations obtained by previous authors are listed in Table 6 for comparison.

Only line *dcb* at Site V can be considered significant. The lunar geocentric declination calculated for this line is 3′ from $-(\epsilon+i-s-\Delta)$ and so this standstill declination is indicated for a possible value of the lunar parallax. The total range of significant declinations consists of the lunar standstills, which cover 8′ allowing for parallax variation, and the solstitial positions 2′ wide. The equivalent total significant range of azimuth is 12° wide, calculated using the compression factor (Figure 4). So there is a probability of 0·03 of a line of random orientation indicating a significant declination. With 19 lines the probability of one or more being significant is 0·44. We conclude that the one accurate astronomical indication at Callanish could easily have occurred by chance.

7.4 *Epilogue*

The large diversity of methods in the literature for using sites and foresights increases the chances of being able to fit a theory at any particular site and decreases the willingness of outsiders to believe the claims being made. In this paper we have illustrated a proposed procedure for considering only a fixed range of possibilities, in an attempt to produce statistically analysable results. We should very much welcome comments from archaeologists, statisticians or astronomers as to its faults and possible improvements, and express the hope that as a result a generally recognised procedure could be implemented by different groups at a large number of sites. This would be a fitting sequel to the early work of Thom and could cast new light upon his later, more complex, theories.

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