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E. W. MacKie

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Archaeological tests on supposed prehistoric astronomical sites in Scotland

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[Plate 25]

CONTENTS

An astronomical interpretation of the British standing stone sites has been developed in great detail by A. Thom using methods and data which have hitherto rarely, if ever, been used by archaeologists. The unfamiliarity of these methods, and the revolutionary nature of the conclusions drawn from them, have no doubt contributed to the difficulties which the profession is evidently encountering in coming to terms with Thom's ideas. However, the raw data on which the theories are based are, like all other archaeological data, susceptible to checking and testing in traditional archaeological ways – by field-work and excavation. If one is to do this, one must isolate the hard evidence on which the theories are built and these are the many long alinements – from standing stone to a mark on the horizon – which are claimed to have astronomical significance. The plausibility or otherwise of these alinements is something that all can assess by visiting the sites. Moreover, at several of these sites it is possible to devise tests by excavation for the astronomical interpretation, and the results of two such tests are described.

Introduction

In two recent books (Thom 1967, 1971), and in a number of papers going back over many years (Thom 1954, 1955, 1961*a*, *b*, 1962, 1964, 1966*a*, *b*, 1968; Thom & Thom 1971, 1972*a*, *b*, 1973) Professor Alexander Thom has offered prehistorians a detailed new interpretation of the origin and function of the standing stones and stone circles and some new insights into the astronomical, mathematical and geometrical skills possessed by their builders. Although suggestions have not

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been lacking in the past that the Neolithic and Early Bronze Age inhabitants of Britain, or a few of them, practised quite sophisticated astronomy, such earlier views have usually been founded on a large number of assumptions based on individual sites such as Stonehenge and Callernish (Lockyer 1906; Somerville 1912, 1923; Hawkins 1966). Thom is the first to have systematically surveyed large numbers of standing stone sites, to have looked for possible astronomical alinements in them and to have founded his theories on a mass of data drawn from many sites instead of a few.

The Thom theories

Thom's hypotheses – based on new information mostly collected by him in the field – fall conveniently into three groups, only one of which concerns this paper. The first major theory is that the stone erectors practised sophisticated geometry in laying out their circles and rings – having knowledge, for example, of Pythagorean triangles – and used a precise and invariable unit of length in so doing. This is the 'megalithic yard', equal to 0.829 m (2.72 ft) and strikingly similar to the modern Iberian *vara* of between 0.843 and 0.838 m (2.766 and 2.7495 ft) (Thom 1967, p. 34). The second theory concerns the cup-and-ring rock carvings of southwest Scotland (and can presumably be extended to those of other regions); these were, Thom suggests, drawn out with the same elaborate geometry as in the circles and rings and were based on a unit of length independently inferred from the carvings to be 20.5 mm (0.808 in) or $\frac{1}{40}$th of the megalithic yard (Thom 1968).

The third major theory suggests that many standing stones and stone circles formed part of alinements to the horizon which were intended accurately to mark the rising and setting points of various celestial bodies at significant times (Thom 1967). The solar sites among these are particularly important and were presumably designed to make possible the keeping of an accurate calendar by pinpointing the days when the Sun was at its extreme (solstitial) and central (equinoctial) positions on the horizon. Another major part of this astronomical theory is that many other alinements were designed to record the much more complicated motions of the Moon, and that this was done in order to predict eclipses (Thom 1971). In this paper I shall consider only some aspects of the astronomical theory.

Methods of approach

When assessing the value of a new and controversial theory – the acceptance of which would require some drastic changes in long established ideas – it is important to be quite clear on the nature of the evidence on which the novel hypothesis is based. In the case of those of Thom it is evidently not proving easy for the archaeological profession to come to terms with Thom's ideas which would credit the prehistoric British population of the late Neolithic and early Bronze periods with skills in practical surveying, advanced geometry and observational astronomy which are far above any hinted at by the more traditional archaeological evidence (Childe 1955; Hawkes 1967; Hogg 1967). So unexpected indeed are the Thom interpretations when set against previous archaeological ideas that it is only fair to ask that the evidence on which they are based be subject to careful scrutiny and the theories themselves tested where possible. Obviously it would be wrong to reject these theories on the facile ground that they do not accord with the previously generally accepted picture of prehistoric Britain. Our failure to find evidence of sophisticated intellectual activity among the barrows, cairns, standing stones, stone circles and henge monuments of 4000 years ago cannot mean that such

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evidence does not exist. It need only mean that most of the archaeological profession was not equipped either by training or temperament to discover it.

Equally, however, the theories should not be accepted uncritically and it would be just as scientifically naïve to assume that they are correct simply because the data collected has been subjected to impeccably accurate and skilled mathematical analysis. It is of course axiomatic in science that such analyses can only be as reliable as the data they use. Therefore it is essential to isolate and test the factual basis of the Thom astronomical theories. What is this evidence? In essence it consists of the identification of a large number of long alinements from standing stones to prominent points on the horizon and of the discovery that these sight-lines cluster round significant prehistoric astronomical declinations such as those of the Sun at the solstices and equinoxes, the Moon at its four extreme positions, the rising and setting points of various stars and so on (Thom 1967, Fig. 8.1). If one assumes that the alinements are genuine the histogram of their declinations is by itself a highly significant body of evidence since these alinements only cluster in this way when converted into declinations. A histogram of their azimuths would show a more random distribution. However, it is clearly on the genuineness of these alinements on the ground – or in other words on the objectivity of the means by which they have been identified – that the whole theory depends.

Possible tests for the Thom theories

There are a variety of tests which can be applied to both the evidence that Thom has assembled and to the various theories which he has devised to explain it. They can best be identified as the answers to the following questions: (1) Have the alinements been identified objectively? (2) Are the horizon notches and mountain peaks, which have been chosen as the foresights visible from and used at any given stone, self-indicated or inferred? (3) Are they the most likely ones, and the only ones, to be seen from the sites concerned? (4) Have any of the alinements been chosen because they were expected in a particular place? (5) Does the archaeological dating of the structures inferred to be part of such alinements fit the fairly precise dates given to them on astronomical grounds? (6) Are there features at individual sites which the astronomical interpretation requires to be present which can be checked by fieldwork and excavation? (7) Can the astronomical inferences be correlated with the cultural groupings seen in the stone circles and henge monuments and made on the basis of site plans and associated pottery and artefacts? (8) Does the astronomical theory involve equipment and techniques which a Neolithic technology is unlikely to have been able to produce? (9) Does it involve the storing of knowledge of a type and in a manner for which there are no known parallels among recorded non-literate societies?

I propose to consider here tests for three of these problems, which involve the examination of three different sites. The first, Ballochroy in Kintyre, relates to the plausibility and completeness of the chosen alinements (questions 1 to 3). The second site, which may supply an answer for question 6, is Kintraw, also in Argyll. The third is Duntreath in Stirlingshire which, with other evidence, is relevant to question 5. Finally I add a short section dealing with question 9, though here the evidence naturally comes from comparative material rather than from deliberately organized tests.

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The importance of solstice sites

The first two sites mentioned are thought to be solar solstice observatories, and a few words are needed to explain why these are of crucial importance for the Thom astronomical theory as a whole. Because of the very small changes in the Sun's declination at these times the accurate detection of the summer and winter solstices is a formidable task for a people with a Neolithic technology even if one leaves aside the problems presented by refraction and temperature changes in the evening air near the horizon. In fact one may assume that, if they had mastered this, the *practical* problems of observing the Moon and stars for example would have been relatively simple by contrast. In the 24 h before and after the moment of the solstice the change

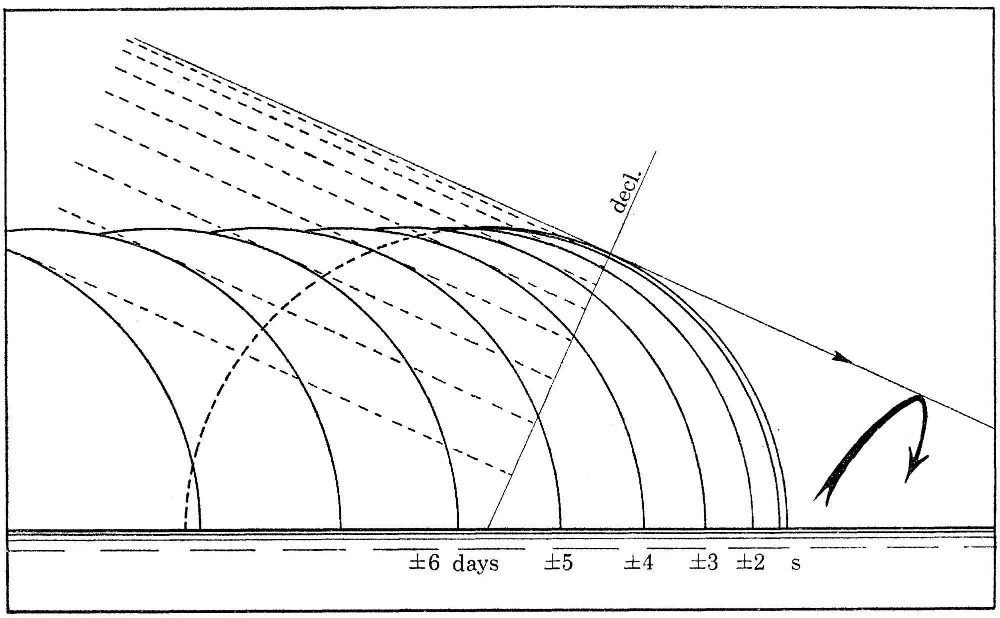

Figure 1. Representation of the changes in the solar declination during the 8 days before and after the summer solstice at about latitude 56° N. The Suns are shown half set on a sea horizon and the dotted lines and the black arrow mark the changes in its real position. The solar diameter is about 32′.

in the solar declination (which corresponds also with its position on the horizon at the equator) is 12″ and this daily movement increases with the square of the interval (figure 1). At the latitude of Scotland the actual movement of the Sun's disk that this represents along the horizon is greater, about 0.5′, because of the shallower angle that the path of the Sun's descent makes with the horizon in northerly latitudes: yet this still represents only about $\frac{1}{64}$th of the solar diameter. However, in the case of the most accurate kind of solar observatories, described below, the changes in the sun's declination are seen against a mark on the horizon which is about parallel to the diurnal path: here the declination change to be observed would be 12″, 0.2′, equivalent to $\frac{1}{160}$th of the solar diameter. Table 1 shows how the daily change in the Sun's real position decreases and increases before and after the solstices.

So if our hypothetical British Neolithic astronomer-priests did discover the exact length of the year, and were thereby able to construct an accurate calendar (an achievement which would have been essential if they carried out the more advanced observations of the Moon's movements), even up to the level of detecting cycles of eclipses suggested by Thom (1971) they must have had

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Table 1

time from solstice days	difference from solstitial declination
s	0′ 0″ (= ± 23° 27′)
$s \pm 1$	0′ 12″
$s \pm 2$	0′ 48″
$s \pm 3$	1′ 48″
$s \pm 4$	3′ 12″
$s \pm 5$	5′ 0″
$s \pm 6$	7′ 12″
$s \pm 7$	9′ 48″

(diameter of solar disk 32′)

some technique for detecting this tiny solar movement of less than half a minute. There appear to be three ways of doing this available to societies which lack the means to make small, accurate instruments – one involving the sun-dial or gnomon and the other two long sight-lines to points on the horizon.

Techniques for solstice detection

If sufficiently large gnomons could be constructed it might be possible to tell not only the time of day from the angle of the shadow but also the time of year from the length of the shadow at midday. Possibly some of the tall, pointed-topped, standing stones in Arran and Orkney may have served such a purpose, though presumably flat, level, plastered platforms marked with scales would have been an essential part of the instrument. Such platforms have not been discovered and, in any case, the distance represented on the ground by the 12″ change in solar declination as seen in the position of the midday shadow of a 6.1 m high stone in Orkney (lat. 59° N) at midsummer is far too small to be detectable. Presumably the great 18.3 m high masonry gnomon built at Delhi in the eighteenth century by the Emperor Jai Singh II might have been able to detect the solstice; here the shadow fell on carefully built, graduated masonry arcs at right angles to the edge of the triangular gnomon (Bergamini 1971). A similarly tall masonry sun tower was built in the thirteenth century in China (Needham, this volume, p. 67). Both these structures clearly involve a skill and accuracy in building in mortared masonry which was far beyond the technological capabilities of Neolithic and Early Bronze Age Britons (Atkinson, this volume, p. 123).

The difficulty with the gnomons highlights the main problem of detecting the tiny amount of solar movement at the solstice – or, to put it another way, of detecting when this very slow and diminishing movement has ceased to go north and has started south again (at midsummer). It is clear that if a shadow could be cast over a long enough distance even a movement of 0.2′ would be represented by a substantial distance on a flat surface. However, because of the increasing width of the penumbra the exact position of the edge of the Sun's shadow becomes indistinguishable after a relatively short distance and this method is clearly impracticable. Yet if one in effect reverses the operation and watches the rim of the Sun's disk against some distant smooth edge such as a mountain slope, the optical problems become much simpler. The edge of the penumbra of the mountain's shadow is itself invisible of course, but it is there and the eye can detect its precise location when it sees the first flash of the brilliant, clearly defined rim of the sun appear from behind the mountain.

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This is the basis of the method of solstice detection suggested by Thom (1967). If the observer arranges his position a few days before the solstice so that he sees the Sun set behind a mountain with a smooth, slightly convex right slope, and then manoeuvres himself so that the right edge of the disk momentarily reappears as a flash in the convexity as it sets, he will have exactly defined the solar position on the horizon for that evening. This will presumably be marked with a peg. On the following evening the Sun will set somewhat further to the right and the same procedure will find a peg a few metres to the *left* of the first one, the exact distance depending on the distance of the mountain. Even the tiny horizontal movement of 0.2′ in the 24 h before and after the solstice could be represented by a distance of a few metres on the ground if the line of sight is sufficiently long. At the peg farthest to the left would be set up a permanent marker, such as a standing stone, from which the day of the solstice could be checked in future years. Table 2 illustrates the distance on the ground subtended at the observer by an angular change of 0.2′ at various distances from him. It will be seen that an alinement at least 8 km long, and preferably 15 or 30 km, is needed for accurate solstice watching and, using these criteria, that it is improbable that any of the alinements so far detected at Stonehenge could have served as accurate solstitial instruments of this type.

Table 2. Base lengths of right-angled triangles whose angle at the apex is 12″

length of triangle (i.e. distance to foresight)	example	length of base (i.e. horizontal distance needed to distinguish solstice)
80 m (260 ft)	centre of Stonehenge to Heel stone	4.8 mm (0.19 in)
915 m (1000 yards)	—	55 mm (2.16 in)
1.6 km (1 mile)	Duntreath to Strathblane hills	96 mm (3.7 in)
16 km (10 miles)	—	0.975 m (3.2 ft)
30.7 km (19.1 miles)	Ballochroy to Jura	1.84 m (6.1 ft)
43.6 km (27.2 miles)	Kintraw to Jura	2.66 m (8.62 ft)
48.1 km (30 miles)	—	2.89 m (9.5 ft)

The second method of using alinements was suggested by Hoyle (1966) to resolve this difficulty over the short sight-lines at Stonehenge. If the foresight is aimed a degree or two *inside* the estimated solstice position, the point of sunset or sunrise will pass it while the daily change in declination is large enough to be seen even with a short sight-line. The sun will rise or set again over the foresight marker some time after the solstice and the date of the latter should be obtainable with some precision by halving the interval between the two observations.

Credibility of the alinements

A long alinement for observing the solstice could simply consist of a backsight of a standing stone, marking where the observer was to stand, and a foresight which was a distant mountain peak or a notch on the horizon. If the stone was isolated and irregular there would be no built-in indication of where the foresight was and the identifier of such sight-lines might be open to the charge that he was selecting mountains in the appropriate place for a particular theory. Alinements with some sort of built-in direction indicator would clearly be more reliable and such might include a view from a stone in which there were really distant peaks in only one or two directions, or a flat-sided stone alined towards the peak concerned, or a second outlying stone pointing the way to the foresight. On the whole it seems improbable that an outlying

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standing stone could act as a solar foresight by itself unless it was used in the Hoyle method described above: if it were far enough away to be moderately accurate it would be too small against the bright disk of the sun and if it were near enough to hide most of the disk it would be insufficiently precise. These and other considerations must be kept in mind when assessing the plausibility of claimed astronomical alinements in the field.

Orientations and alinements

The archaeological literature contains several examples of claims being made about structures being alined towards astronomically significant directions. Lockyer (1906) and Somerville (1923) surveyed numerous barrows, cairns, stone circles and alinements of standing stones in Britain and concluded that large numbers had been laid out with astronomical considerations in mind. Hawkins (1966) claimed numerous astronomically significant alinements between the various stones and stone-holes at Stonehenge and Somerville (1912) found the same at Callernish. The temples and pyramids of Egypt have also provided material for the 'astro-archaeologists' (Hawkins, this volume, p. 157). The whole field is being surveyed by Baity (1973). However, it seems that Thom (1967) was the first to show how distant horizon marks might actually have been used to make precise astronomical observations in prehistoric times in the manner explained above and the inherent inaccuracy for solar observation of short sight-lines, commented upon earlier, seems to make it necessary to distinguish between on the one hand potentially useful, practical instruments and, on the other, structures which are simply built with their axes or sides orientated in an astronomical direction.

It seems very doubtful whether any useful, accurate observations of the Sun could be made simply by looking along the straight side of a masonry building, no matter how precisely alined. Even an arrangement whereby the observer stood on the steps of a pyramid at the solstices and saw the sun rise at opposite ends of a range of masonry buildings 60 m away – as perhaps at the Maya site of Uaxactun, Guatemala (Morley & Brainerd 1956, p. 300) – seems incapable of giving much more accuracy than the Heel stone at Stonehenge (MacKie 1968). In fact there is evidence that the Maya practised similar kinds of long-distance observations that Thom has suggested for Neolithic and Early Bronze Age Britain. In the *Codex Nuttall* there is a drawing of a man looking out through a temple doorway through a pair of crossed sticks – a simple device to ensure that his eye is in exactly the correct position – and presumably observing some phenomenon on the horizon from this high vantage point. Another drawing in the *Codex Bodleian* shows the eye behind the crossed sticks – this time seen from the front – and nearby a star or planet descending into a distant notch (Morley & Brainerd 1956, p. 258). This must surely imply that long alinements to the horizon were used by the Maya in their astronomical work.

It thus seems useful to make a distinction between *orientations* and *alinements* in primitive structures. It is reasonable to suppose that many buildings and constructions were *orientated* towards a particular direction for magical, religious or traditional reasons: the consistent directing of the long axes of Christian churches towards the east is a classic example and many prehistoric and ancient structures could well have been orientated towards the solstices and equinoxes from equally non-scientific motives. The term *alinement* by contrast could well be reserved for long sight-lines which are capable of being used as observing *instruments*. If this terminology is adopted it might help to reduce misunderstandings over what is being claimed about ancient astronomical practices in Europe, and about the motives which lay behind them.

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Two solstice sites

An independent description and assessment of two sites in Argyllshire claimed as solstice observatories may help to answer the questions posed earlier (p. 171) about the credibility of the alinements. At Kintraw, at the head of Loch Craignish (grid ref. NM/831051) there is a standing stone from which the midwinter Sun could have been seen setting exactly behind Beinn Shiantaidh on Jura about 3800 years ago. At Ballochroy, on the west coat of Kintyre (grid ref. NM/730525) there are three standing stones from which the same phenomenon at midsummer would have been seen behind Corra Beinn, also on Jura. It is reasonable to found a preliminary assessment of the general plausibility of the Thom astronomical theories on these two sites, first because solstice alinements are both difficult to set up and essential as the basis for all other work by prehistoric astronomers (p. 172 above), and second because the author of the theories himself considers them important sites (Thom 1967, 1971).

Ballochroy

This site consists of three standing stones close together in a line running from northeast to southwest; there is a massive stone cist on the same line about 37 m to the southwest. The field in which the stones stand is behind a raised beach. Thirty km away across the sea in the northwest are the Paps of Jura, forming a series of four very striking peaks on the horizon (figure 2). Two of the stones have very flat right faces which are orientated unequivocally

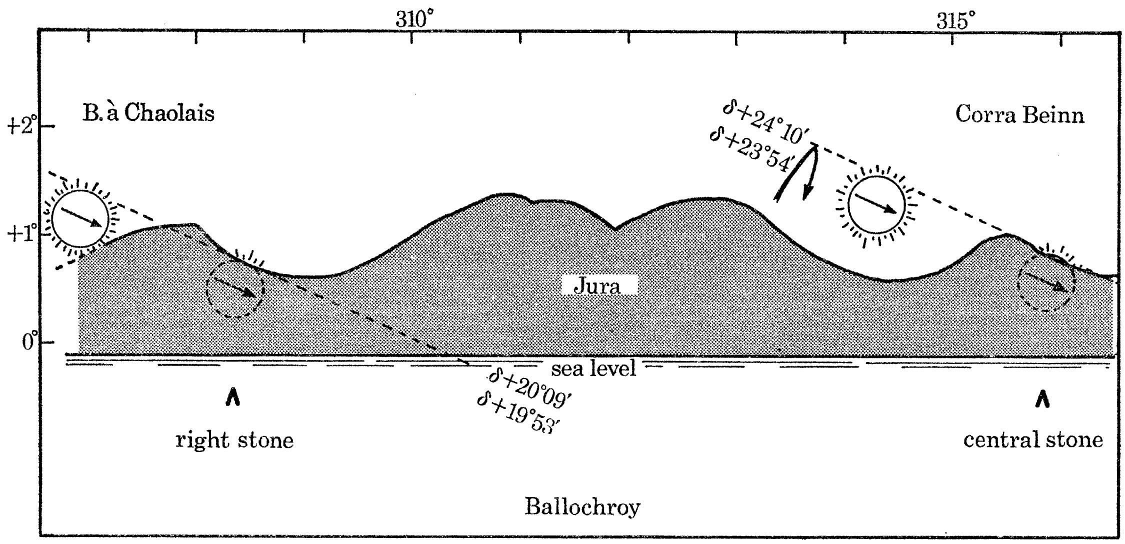

Figure 2. Scale drawing of the Paps of Jura as seen from the Ballochroy standing stones. The directions indicated by the flat sides of the two alined stones are shown with inverted V's and the declinations of the Sun setting behind the two hills concerned are given.

towards two of the Paps. The central stone, 3.3 m high, points at the right slope of Corra Beinn which has a declination of + 24° 10′: if the Sun was setting behind this peak with its upper rim just grazing the edge of the right slope the centre of the disk would have a declination of + 23° 54′, suitable, according to retrospective calculations, for a midsummer solstice of about 1800 B.C. The right-hand (northernmost) stone, however, is equally clearly alined towards the right slope of Beinn à Chaolais, the most southerly of the four Paps; the centre of the solar disk

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setting behind this mountain in the same way has a declination of about $+19° 53'$, well inside even the modern solstice.

The character and situation of the site do indeed make the astronomical interpretation of it most attractive. The Jura mountains conspicuous in the northwest (R.C.A.H.M.S. 1972, pp. 46–47, pl. 10*a*), the fact that two of the slabs are alined precisely towards two of these peaks and the general absence of any other distant markers (except Cara island, described below), all combine to suggest forcibly that stones and mountains are interconnected in some way. Yet simultaneously there are some odd aspects to the site which remind one of the need to assess the objectivity of the chosen sight-lines on the ground by careful examination.

At first sight it is not easy to understand why Corra Beinn was selected as the foresight for the solstice: its right slope is about parallel to the angle of the Sun's descent but somewhat uneven (Thom 1971, Fig. 4.1). There is in fact a difference of about 2.7′ in the declination of the edge of the solar disk according to whether one assumes that it grazed the top of the slope or the lower part (Thom 1971, Fig. 4.1). Both Beinn Shiantaidh, immediately to the left, and Beinn à Chaolais at the southern end of the row of peaks have smooth, concave right slopes which would be much more suitable as sunset markers: their declinations would be unambiguous and precise. To use these peaks the backsight markers would need to have been positioned further southwest down the coast.

As we have seen the right hand, shortest stone does in fact indicate the right slope of Beinn à Chaolais quite clearly but the declination of the centre of the convex slope, at $+20° 9'$, is difficult to interpret. The centre of the Sun's disk when it was just showing from behind this slope would be about $+19° 53'$. If one considers the site without foreknowledge or preconceived ideas there is no reason from its layout to prefer either of the indicated alinements as the primary solstitial one. That to Beinn à Chaolais uses a more suitably shaped foresight but is marked by a smaller, flanking stone: that to Corra Beinn is marked by the tall central stone but uses a less precise foresight. The declination of Beinn à Chaolais falls uneasily between peaks of alinements on Thom's histogram at about $\delta + 16.89°$ and $+\ 21.84°$ – which represent, he suggests, two points in the 16 'month' solar calendar (Thom 1967, Table 9.2) – and its significance remains obscure at the present.

It is possible, as Thom suggests, that the stones were sited in their present position in order that two alinements could be observed from the same spot, one for midsummer and one for midwinter. If one looks along the front edges of the stones, which are approximately in line, one sees Cara island 8 km away in the southwest and the western end of this gives a declination of $-23° 53'$ for the centre of the solar disk if its upper edge is just grazing the point. This of course is almost exactly the same as the declination of Corra Beinn and supports the view that the site was a dual purpose one. However, if one again looks at the alinement objectively one notices that the edges of the stones indicate a point some way east of the *eastern* end of the island; the chosen western end is not marked at all precisely. In addition, the small hump or peak on the eastern end is a much more conspicuous foresight marker than the featureless western end, These may be minor objections but they do illustrate that close analysis will often show that the astronomical interpretation of an archaeological site may not always be as simple as it seems at first sight. Moreover the megalithic cist (burial chamber), which is on the alinement to Cara island, was almost certainly once covered by a cairn and, if it is older than the standing stones – which is more than probable in view of the massiveness of its construction – then it would have completely blocked the view to the island. Nevertheless the plausibility of the claimed

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primary alinement at Ballochroy (to Corra Beinn) is greatly increased by its similarity to the second solstitial site to be described, at Kintraw.

Kintraw

This site consists of a single menhir and a large and a small cairn, the latter almost completely destroyed; they all stand in a level field on an otherwise steep slope rising from the head of Loch Craignish in Argyllshire, 19 km north of Lochgilphead (figure 3). The cairns were excavated in 1959 and 1960 (Simpson 1967) and a kerb of massive stones was found around the large one with a small, empty cist at this periphery. There was no central burial but part of the shaft-hole for an upright wooden post $7\frac{1}{2}$ cm in diameter, and resting on the old ground surface, was traced in the centre of the cairn material.

Thom discussed this site (1967, p. 154) and suggested that the menhir marked the spot from which one looked down Loch Craignish to Beinn Shiantaidh one of the Paps of Jura. At about 1800 B.C. the midwinter Sun should have set behind the mountain so that as it disappeared its right edge flashed momentarily in the col between it and Corra Beinn to the west (figure 4). The declination of this notch as seen from the site is $-23° 38'$ so that the declination of the centre of the Sun's disk when its upper edge was just showing in the col would be $-23° 54'$ (Thom 1971, p. 42). This position is almost identical to that of Corra Beinn as seen from the Ballochroy stones ($+23° 54'$, p. 176 above) and it is hard to believe that this is the result of mere coincidence. One must recall too that these two declinations for hill slopes are not themselves identical ($+24° 10'$ as opposed to $-23° 38'$): they only become identical if one assumes that the real measurement is that of the centre of the Sun's disk when the edge is just showing. At the midwinter solstice the centre of the solar disk will be *further away* from δ 0° than the mountain slope of the foresight: hence one will add 16′ (the Sun's semidiameter) to the measured figure. At the summer solstice, however, the centre of the disk is *nearer* δ 0° than the slope of the foresight: in this case 16′ would be subtracted from the measured figure. In my view this is sufficient evidence by itself that the almost exact coincidence of the declinations of the centre of the Sun's disk at the two sites is a result of the sites having been laid out as complementary solstice observatories.

However, a problem was posed by the presence of a tree-covered ridge 1.6 km in front of the stones which hides the foresight mountain from the surface of the field (figure 4). How could the sunset phenomenon have been seen from the stone and how indeed could the position of the stone have been fixed originally if the claimed foresight is invisible from it? Thom suggested that the cairn had once been higher (there are sheep fanks nearby which could have been built from its material) and that it could have served as an observation platform from which one could see over the ridge. However this would not solve the problem of how the position of the site was first established. (In fact it is possible to see the Jura mountains from the ground beside the standing stone but as soon as one moves to the left or southeast – that is in the direction in which the essential sightings of the Sun setting on the col before and after the midwinter solstice would be taken – the col is obscured.)

Thom discussed the site again (1971, p. 37), mentioning Simpson's excavations and the discovery of the post-socket in the centre of the large cairn. The problem of how the cairn's position was fixed initially could have been solved by first locating the solstitial alinement with a series of sunset observations taken on the higher ground to the north of the field – a steep slope falling into a gorge with a stream. On exploring this slope Thom found a long narrow ledge at

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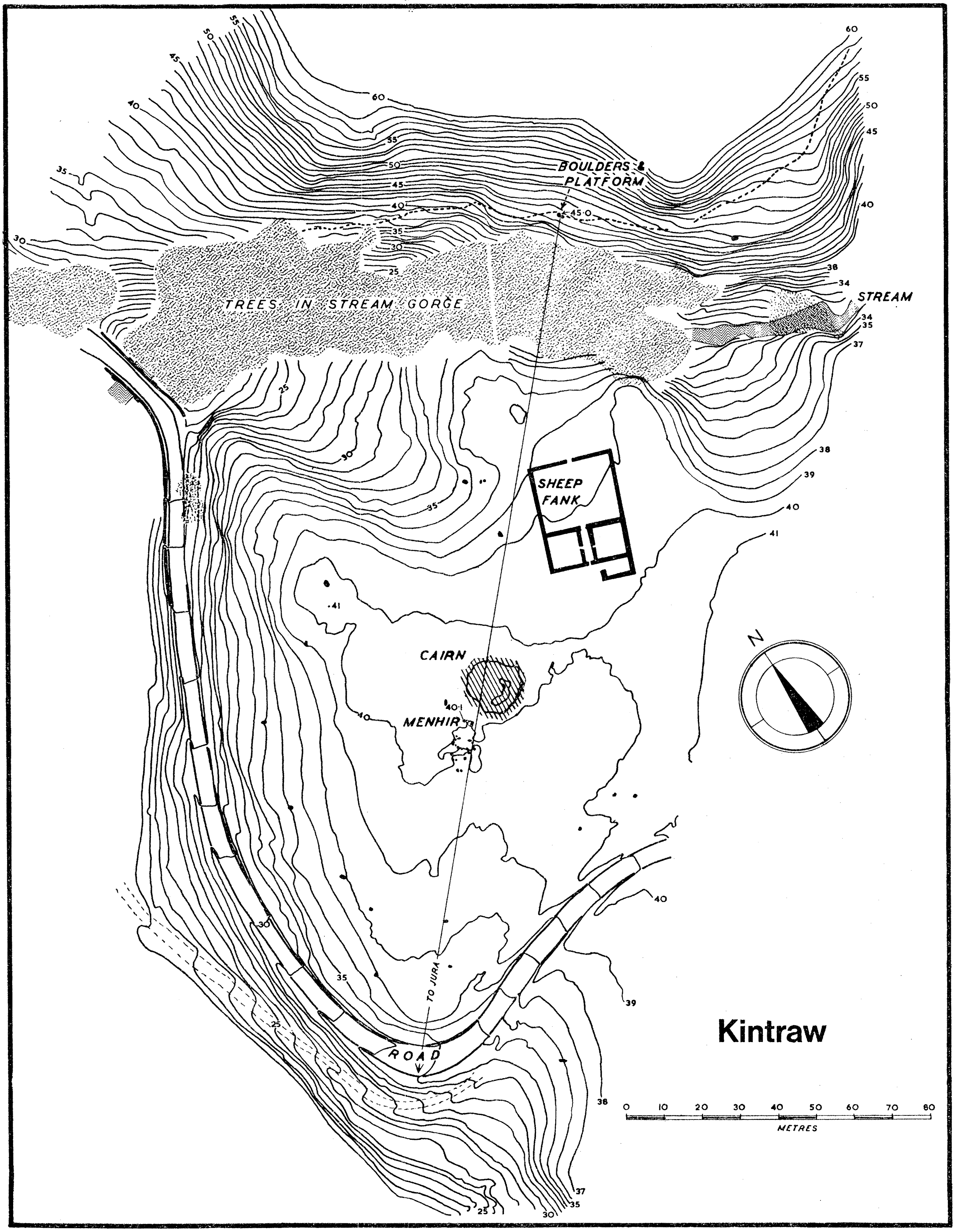

FIGURE 3. Photogrammetric contour plan of the Kintraw site showing the field with the cairns and standing stone ('menhir'), the stream gorge and the platform discovered beyond on the hillside. The contours are at 1 m intervals above mean sea level and spot heights at the stone and boulder platform are marked.

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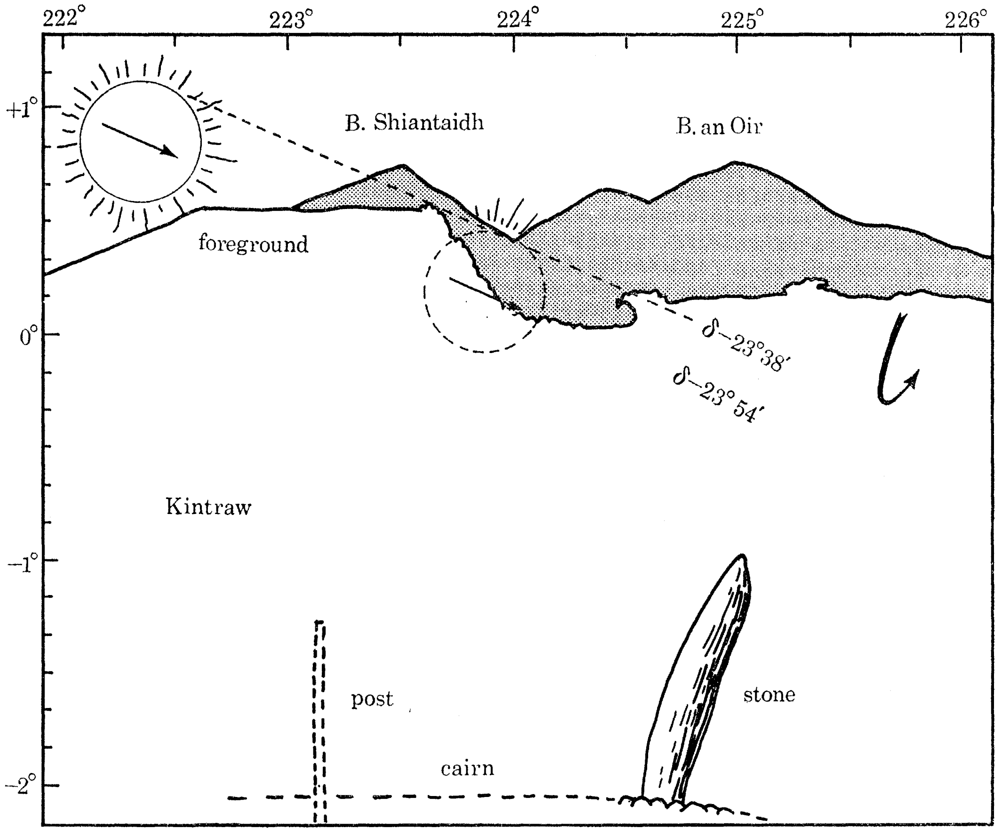

Figure 4. Scale drawing of the Paps of Jura as seen from the boulder platform on the hillside northeast of the standing stone at Kintraw, which is shown in the foreground. The Sun is shown as it should have appeared setting on midwinter's day about 3800 years ago, the direction of the change in its declination being marked by the black arrow.

the appropriate height from which Beinn Shiantaidh can be seen clearly over the ridge (in good weather). At the spot on this ledge cut by the alinement from the western slope of Beinn Shiantaidh through the Kintraw menhir was a large prostrate boulder (figure 3). He surmised that the menhir and the cairn/platform were positioned from this ledge or terrace – which he thought might be artificial – with the aid of a ranging post, traces of which were found in the cairn. The reasons for needing an observation platform in the flat field instead of on the steep slope were partly convenience of access and partly the suggested existence of a lunar alinement pointing to the north-northwest, which runs through the field. The cairn would serve for both but the hill ledge only for the solstice.

I discussed Kintraw with Professor Thom and Dr A. E. Roy in the autumn of 1969 and the former was kind enough to let me read the manuscript of his new book (1971) in which the above discussion of the site occurs and in which he first described the hill terrace and its possibilities. It quickly became clear that the site presented what might be a unique opportunity for an archaeologist to throw light on the astronomical theory by excavation. For the theory in effect predicts that traces of human activity ought to be found on the steep slope north of the field, and moreover at the exact spot from which the solstice should have been seen from behind the menhir (or perhaps from behind the cairn post, slightly to the left). If signs of such activity – in the form of an artificial platform, post-holes, potsherds and so on – were found this would be as near to proof for the astronomical theory as one could hope to obtain in archaeology since

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there is no other obvious reason why prehistoric activity of this nature should have occurred in just that spot on a steep slope and above a steeper gorge.

A preliminary reconnaissance of the site in June 1970 suggested to me that the terrace above the gorge was primarily a natural feature. It varies in width and runs for many metres along the slope, gradually descending towards the road bridge 130 m downstream; it extends for a much greater distance than was necessary or convenient for a cut platform to fix the time of the solstice. In any case the preliminary sightings for the winter solstice would have been taken to the left, or *upstream*, from the final alinement (see below). The ledge does run upstream and after a few metres it widens to a sloping platform several metres broad (figure 3); there is another large boulder at the lower edge which has apparently fallen down the slope to this point. A third large rock is on the ledge where it is much narrower, about 20 m downstream from the 'solstice' boulder. Thus there was no reason to select the central of the three boulders for investigation rather than one of the other two except that it is on the hypothetical line with the standing stone and Beinn Shiantaidh, 42 km away.

Excavations were carried out at the boulder for a week each in August of 1970 and of 1971. It was also intended to investigate the socket of the standing stone, and perhaps obtain a carbon-14 date for its erection, but it is a scheduled monument and the then Ministry of Public Building and Works in Edinburgh was unable to give permission. One long trench, extending up the slope from the ledge, was dug just to the west of the boulder and three more squares were opened behind the boulder and extended upstream from it and along the ledge (figure 5). The front face of the boulder was also exposed.

These trenches showed that the terrace was composed of a great thickness of bright red earth, containing many randomly scattered stones, which continued up the steep slope above the boulder: no trace of stratification was observed in it. So deep was this soil that bedrock was not reached anywhere, although a depth of a metre was achieved in places on the upper slope. The long trench running up this slope was designed to reveal any stone socket at the western end of the boulder and thereby to test whether this rock had once been standing upright. There was no socket but some stones were found jammed against its western end which might have been packing. The cutting also revealed the rounded end of what proved to be an extensive, nearly level layer of small stones which lay behind the boulder and ran further upstream.

The stone layer

Making a sharp contrast with the random scatters of stones and small boulders found in the soil farther up the slope was a compact layer of angular stones, some 15 cm thick and resting on the same red soil, which lay immediately behind the boulders (figure 6). The marker boulder was in fact found to be two adjacent stones set upright in the red earth and with pointed ends which met to form a large notch (below p. 183): into this notch the stone layer ran. As noted the layer appeared to end just to the west (downstream) of the boulders but was traced for more than 6 m upstream. The depth of the layer below the turf varied from less than 5 cm behind the boulders to 73 cm at the farthest point east exposed. The longitudinal section (figure 5) shows that the layer was almost exactly level along the slope and the cross-section shows a slope of about 10°, substantially less than that of the turf (figure 5). Thus in both directions the surface of the stone layer was much more level than the turf of the terrace above it.

The question of whether this stone layer was a standard feature below the turf on this terrace was considered. Two other nearby boulders were investigated, both of similar size to

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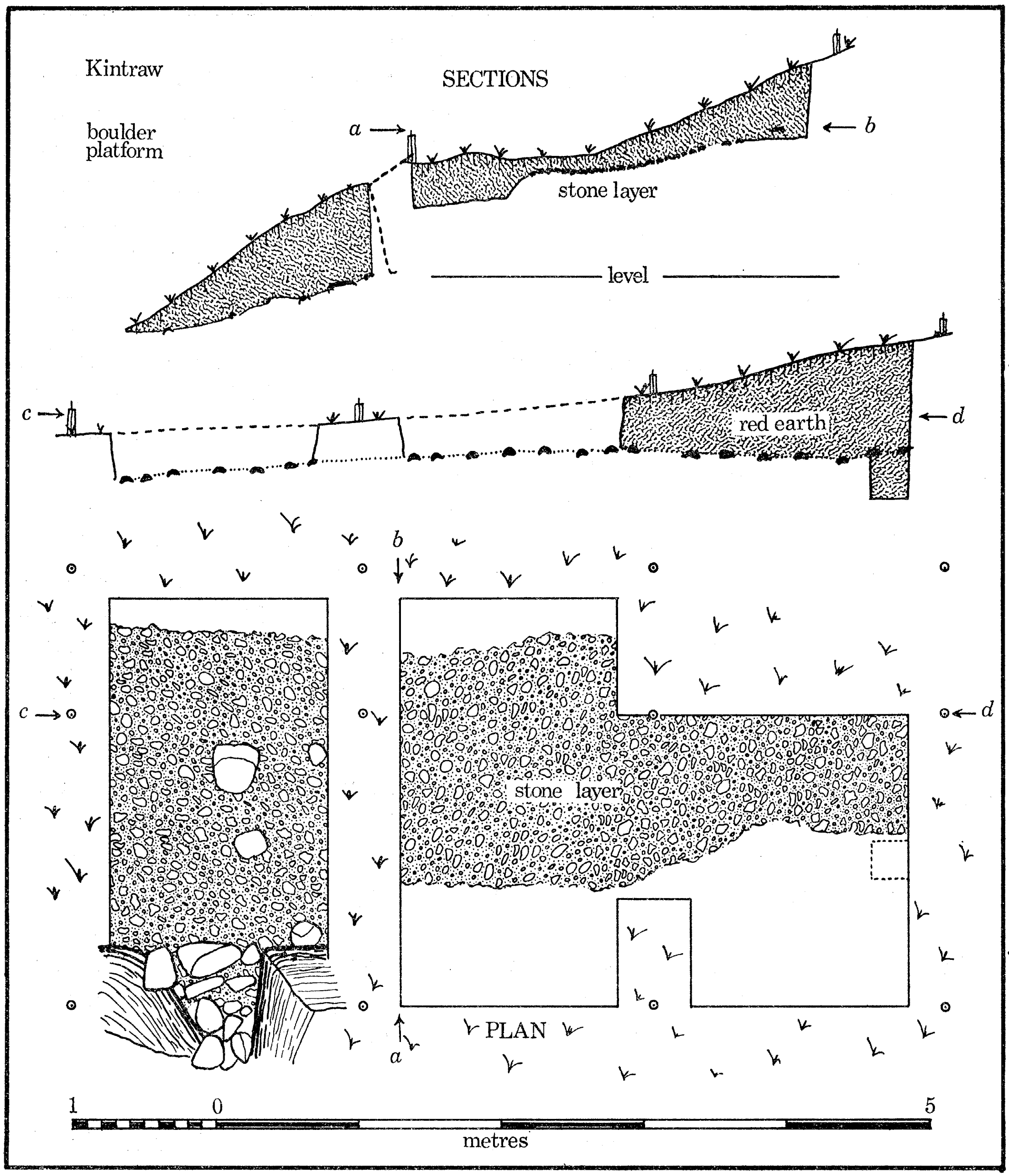

Figure 5. Plan and sections of the trenches cut at the boulder platform at Kintraw in 1970 and 1971. The long trench running up the hillside, seen in figure 6, plate 25, is not shown: it was 0.5 m to the left of the others.

the two forming the notch and in similar positions at the downhill edge of the terrace, poised above the steep slope down to the stream. The first rock was about 20 m downstream, at a point where the terrace narrowed to the width of the sheep path: it proved to have an accumulation of small stones in the small space between its vertical uphill side and the steeply sloping rock face of the hill immediately behind it. No firm conclusions can be drawn about this boulder because any small stones falling down and striking the rock would be certain to fall back into the narrow space behind it and form an accumulation there. The conditions are not the same as at the boulder notch where there is a relatively broad area of terrace behind the boulders and where the ground is almost flat immediately next to them.

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FIGURE 6. View of the boulder notch, and the stone layer behind it, at an early stage in the excavations (1970). The stone layer can be seen coming to an end at the right of the boulders; it was subsequently traced for another 4.0 m to the left (upstream) and may go further.

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The other rock is 46 m upstream, again at the downhill edge of the sloping terrace at a point where it has widened to about 13 m (figure 3). An excavation 1.5 m deep behind this boulder revealed the same deep deposit of red earth containing a random scatter of stones and small boulders throughout. Bedrock was not reached, not even by probing a further 0.5 m into the base of the trench. Nowhere in the deposit was there any stratum of stones of any kind, nothing comparable to the stone layer found behind the boulder notch. Two probes out of three went into the ground from the surface for the full length of the instrument (0.8 m) without striking any stones at all. Since small boulders and stones have become incorporated into the soil deposit here at all depths, it would appear that these were able to roll down the slope above as far as the large boulder. Hence if the stone layer behind the boulder notch is a deposit of scree there would seem to be no obvious reason why a similar layer did not accumulate behind the southeastern boulder; yet one did not.

That the stone layer behind the boulder notch is not in any case an accumulation of scree is implied by its angle of rest down the slope – about 10° (figure 5) – and demonstrated by the petrofabric analysis (appendix). Observation of any pile of scree at the foot of a slope shows that its surface comes to rest at an angle of about 30° to the horizontal. There appear in fact to be only two plausible explanations for the stone layer: it could either be a man-made deposit or it could be a natural platform formed under periglacial conditions. Such natural platforms are known and have been studied in Scotland (appendix). The diagnosis of the layer as man-made would, for reasons given earlier, obviously have profound significance for the astronomical interpretation of the site advanced by Thom and, by implication, for his astronomical theories in general. However, such a diagnosis is handicapped by the complete lack of what one might call the normal archaeological signs of human activity – no potsherds or artefacts of any kind were found during the excavations, nor any fragments of charcoal such as might have come from fires. Neither were there any signs of post-holes, kerb-stones or any other obvious structural remains. Only the stone layer itself, and the two adjacent boulders up against which it runs, are there to be considered.

The boulder-notch

As noted earlier, excavation showed that what originally appeared to be a single large stone, possibly fallen from the upright position, was in fact two boulders which had clearly remained in the position in which they were when the stone layer was formed. This layer ran up against them, and into the notch formed by their pointed ends, and a cutting through the layer showed that it rested on red earth which itself rested against the lower part of the boulders (figure 6, plate 25). Excavation down in front of the boulders showed that these were standing more or less upright in the soil, though at different depths, and with their front faces vertical and more or less parallel. Stones at the base of the smaller, upstream boulder could have been set there to wedge its base in position; a similar cluster of possible packing stones were found at the end of the right hand, larger boulder. If these boulders were a natural formation it must be assumed that they rolled down the hill and by chance came to rest together in the red soil – touching, more or less upright and in line. Their appearance suits the interpretation that they are a man-made formation but the evidence is perhaps not conclusive.

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The petrofabric analysis

The absence of all but circumstantial evidence relevant to the problem of whether the boulders and stone layer at Kintraw were man made or natural led to the opinion of a soil scientist being sought. Mr J. S. Bibby, of the Macaulay Institute for Soil Research, came to the site and performed two analyses of the orientation and dip of the long axes of the stones of the platform layer. As he describes in his appendix (p. 191 below) the pattern taken up by stones varies according to the origin of the layer, the angle of the slope and so on. The orientations and dips of a hundred adjacent stones are plotted on a Schmidt net (figure 8*a*). The easiest way to visualize this net is by thinking that the circle represents a view of half the hollow interior of the earth, with the north pole at the centre. The stones are plotted so that their dips are represented by latitudes as they would thus appear in two dimensions – vertical at the 'pole' in the centre, horizontal at the rim or equator – and their orientations appear on the lines of longitude, due north being at the top of the circle. The diagrams are contoured to show the relative frequency of these orientations and dips.

The two contoured diagrams from the Kintraw platform are shown (figure 8*b*, *c*) together with one of a known solifluction platform on Broad Law in Peebles-shire (figure 8*f*), one from a scree on Broad Law (figure 8*e*) and with another taken from a rubble floor layer of known human origin in the Sheep Hill vitrified fort in Dunbartonshire (figure 8*d*) (MacKie 1974*a*, forthcoming). Comparison of the five diagrams will show how closely the Kintraw patterns resemble that obtained from the Sheep Hill fort and how different they are from the two Broad Law diagrams. The slope of the Kintraw platform, about 10°, and the much steeper slope of the hillside above mean that the analogy with the 17° slope at Broad Law is close. The similarities between Kintraw and Sheep Hill are rendered more striking, as Bibby points out, by the fact that the conditions are in many ways quite different at the two sites (appendix).

Conclusions

The relatively clear results from this analysis agree well with the circumstantial evidence obtained from the excavations and described earlier, and also with the implications of the coincidence of the declinations of three of the foresights seen from Kintraw and Ballochroy. The combined effects of all this evidence is surely to leave very little room for doubt that the boulder notch and platform at Kintraw together form an artificial construction. Since the existence of an artificial platform of some kind at this spot was in effect predicted by Thom's astronomical interpretation of Kintraw – which held that observations *must* have been taken from this particular point on the hillside – this interpretation would appear to have been verified and also, by implication, that of Ballochroy. There can now be little doubt that these two sites were laid out as solstice observatories at some time in the past when the Earth's axis was tilted 23° 54′ away from the vertical.

The massiveness and permanence of this observation point seem to carry another implication. It looks like something more than a temporary flat surface from which the preliminary sightings were made in one year on a succession of evenings before midwinter simply to establish the correct line to Jura which was to be projected on to the field below (Thom 1971, p. 37). The structure could well be the permanent observing point from which the day of the midwinter solstice was regularly checked. If the site is interpreted in this way its various features seem to become more straightforward. The boulder notch is in fact easy to reach by the path along the

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side of the stream valley from where the road bridge now is. The view of Jura is unobstructed from the platform, whereas it is only just visible from beside the standing stone. If the cairn beside the stone was, as suggested, once higher and served as a viewing platform there would be little room for manoeuvre on top of it, in contrast to the hill platform. From the boulder notch the standing stone serves the useful function of directing the eye towards the foresight on Jura; the alinement would then be an indicated rather than an inferred one (figure 4). Altogether the Kintraw site would surely have been a more convenient and efficient observatory if the hill platform was the primary viewing point.

Dating the standing stone sites

As far as the solstitial sites are concerned the assumption is that the date of the construction of these can be discovered by retrospective calculation. It is claimed that the formula of Newcomb and others can project the present variations in the obliquity of the ecliptic – detected with the most advanced instruments – backwards into the past (Newton, this volume p. 99). According to this formula the obliquity (equivalent to the angle between the Earth's axis and a line vertical to the plane of its orbit) was about 23° 54′ in 1800 B.C., and this should be the date of the two solstitial sites at Ballochroy and Kintraw. Unfortunately no charcoal was found during the excavations at Kintraw and so it was not possible to date the construction of the boulder notch platform by radiocarbon. No isolated standing stones (as opposed to stone circles, discussed below) have yet been dated by radiocarbon except, tentatively, those at Duntreath in Stirlingshire (MacKie 1973). It seems reasonable to suppose that the standing stones and stone circles are of similar age and that the archaeological and radiocarbon dating for the latter apply also to the former.

Stone circles

Two well excavated sites – Cairnpapple Hill in West Lothian (Piggott 1948) and Stonehenge in Wiltshire (Atkinson 1956) – have produced information about the cultural context in which the stone circles there were erected. At both sites the building of the circle was not the first activity which was traceable: late Neolithic structures were also found. The stone circle at Cairnpapple and the first stone circle at Stonehenge (the bluestones) were associated with sherds of Beaker pottery, a characteristic ware almost certainly brought to Britain by immigrants at the beginning of the Bronze Age. The earliest radiocarbon dates for Beaker sites indicate a date of around 1900 to 1800 B.C. (Lavell 1970), which would be two or three centuries earlier in real years according to the tree-ring calibration (Libby 1970). Indeed the bluestone circle at Stonehenge received a carbon-14 date of 1620 ± 110 B.C. (I–2384) while charcoal below the bank surrounding the circle at Cefn Coch, Penmaenmawr, Caernarvonshire, was dated at 1520 ± 145 B.C. (NPL–11) and 1405 ± 155 B.C. (NPL–10) (Lavell 1970). The equivalent in real years of these three dates mentioned is probably two or three centuries older.

Thus, the limited amount of direct archaeological and radiocarbon evidence for the date of the stone circles suggests that they belong to the Early Bronze Age, early in the second millennium B.C. Yet there can be no guarantee that the period during which stone circles were built was not a long one, which extended back into the Neolithic period or forward into the Middle Bronze Age. For example, there is a stone circle surrounding the New Grange passage grave in Co. Meath which is unlikely to have been erected later than the massive cairn it encloses. The construction of the cairn has been well dated by two radiocarbon measurements; these

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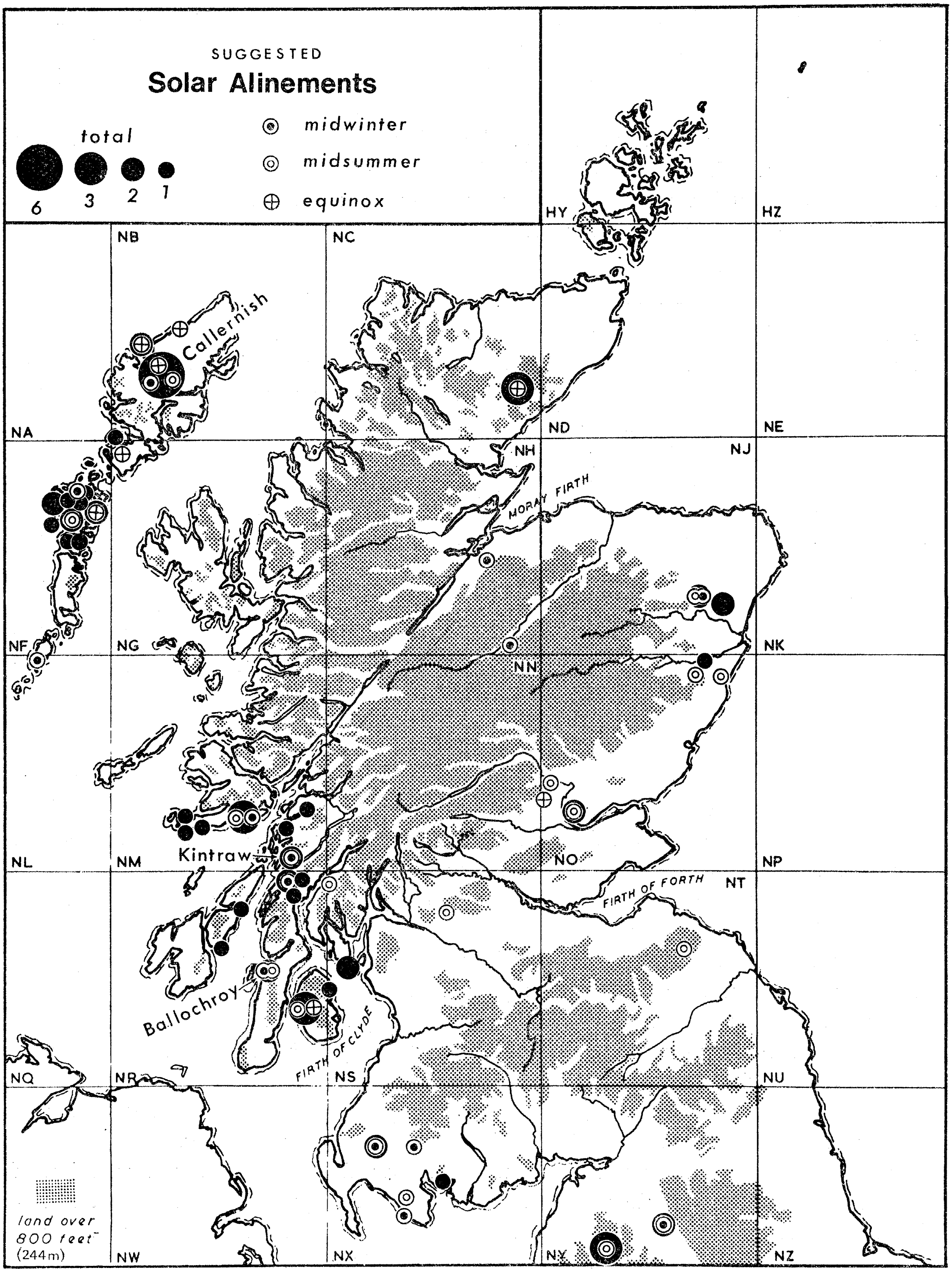

Figure 7. Map of Scotland showing standing stone and stone circle sites which are claimed by Thom to have solar alinements. Midwinter, midsummer and equinox lines are distinguished and the total of solar lines at each site is indicated by the size of the black disk. Information about the three line site on the isle of Arran was supplied by Dr A. E. Roy.

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were 2465 ± 40 B.C. (GrN–5463) and 2550 ± 45 B.C. (GrN–5462), indicating a date in real years of perhaps nearer 3000 B.C. (Libby 1970; Lavell 1970).

Standing stones, either isolated or in groups, are notoriously difficult to date precisely. It seems reasonable to suppose that they belong to the same period of building activity as the stone circles, that is probably to the early second millennium B.C., and this is supported by a few examples of such stones with cup-and-ring marks on them. Such rock-carving are also found occasionally on graves of Early Bronze Age type (Childe 1935, pp. 116–117). Thus what little direct evidence there is seems to support a date for the standing stones which fits well with the date assigned to their alinements by the Newcomb formula for calculating the obliquity of the ecliptic in the past.

Duntreath

Yet here again the lack of evidence that standing stones were erected later than the Early Bronze Age does not mean that such evidence will not be found. Equally it is possible that some were much earlier, as the dates from New Grange imply. In the summer of 1972 excavations were carried out at the Duntreath standing stones in Stirlingshire (MacKie 1973). This is a group of six stones, five of which are now prone, and which may once have stood in a row. From the stones a notch in the nearby Strathblane hills to the east gives a declination of $+24^\circ\ 0'$, and is claimed by Thom as a midsummer sunrise alinement (Thom 1967). The single upright stone has an extremely flat northern face which is precisely alined on a notch in the east. This notch (not measured by Thom) has a declination of $+1^\circ\ 37'$: thus if the upper edge of the rising sun was just showing in this notch the centre of its disk would have a declination of about $+1^\circ\ 21'$ which is close to, but certainly not at, the equinoctial position. (It marks the sunrise 2 days before the autumnal equinox and 2 days after the spring one). This is curious if the site is indeed an astronomical one, as the alinement to the notch is exactly indicated. The suggested summer solstice alinement – even though, being about $1\frac{1}{2}$ km long, it is rather short for accuracy – ought, if genuine, to be indicating a similar age for the stones as those at Ballochroy and Kintraw which have similar declinations.

The excavations revealed a sequence of four distinct layers in the soil around the stones and a study of the base of the standing stone suggested that the monoliths were inserted into layer 3 (layer 1 being the topsoil) and that the upper two strata accumulated later. Elsewhere on top of layer 3, a spread of whitish ash and charcoal fragments was found and the charcoal – presumably the remains of fires lit near the stones – gave a radiocarbon date of 2860 ± 270 B.C. (GX–2781). This would be equivalent to perhaps 3200 or 3300 B.C. according to the tree-ring calibration graph (Libby 1970). It is possible of course that the fires could have been lit on layer 3 (when it was the ground surface) at some time before the standing stones were put up, but the site is an exposed one which seems an unsuitable place for a camp or settlement. Although there are certain unsolved problems about the site, it seems reasonably probable at present that the fires were associated with the stones, and that this particular group was erected and used some 1500 years before the time inferred for the solstice sites at Ballochroy and Kintraw. No firm conclusions can be drawn on the basis of a single date, but Duntreath does illustrate the dangers of assuming that all problems are solved simply because none are apparent in the small quantity of hard evidence available.

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Astronomer priests in Iron Age Britain

The concept that advanced geometrical and astronomical work – albeit of an empirical, practical kind – was undertaken in Neolithic and Bronze Age Britain inevitably raised the question of what the type of society was which could produce and support the specialists needed to do this work and how indeed the masses of knowledge which these activities must have accumulated was stored and passed on to new recruits to what was presumably a priestly caste. It must be more than a coincidence that we have plenty of historical evidence for the existence of such a priestly class, well versed in astronomy and other knowledge, in Iron Age Britain. Indeed, such intellectual classes are not uncommon in non-literate, barbarian societies as the studies of the Polynesian navigators have shown in a spectacular manner (Lewis, this volume, p. 133). Piggott (1968) and Burn (1969) have recently reviewed the evidence for this élite intellectual class consisting of jurists, poets and holy men – which was flourishing in Gaul and Britain in the first century B.C. Burn (1969, p. 5) concludes, for example, that 'Celtic Christian monasticism, with its frequent choice of islands for settlement, . . . was continuing a practice well known to religious men of pre-Christian times'. The British and Gaulish élites are of course known to us as the Druids, a term which has had so many fanciful connotations added to it in post-Roman times that it might be thought of dubious value to the present discussion. Yet this name, Burn suggests, probably simply means 'wise' – derived from the root *id* or *wid* – with the intensifying prefix *dri* or *tri* added to it to give 'thrice wise'. The *Drus* or 'oak tree' origin of the name is, he thinks, a Graeco-Roman guess with little to recommend it.

Piggott cites the evidence of classical authors such as Strabo who said that the Druids were well versed in astronomy and calendrical computation; Strabo called this *Physiologia* or natural science. Julius Caesar wrote that the Druids have 'much knowledge of the stars and their motion, of the size of the world and the Earth, of natural philosophy'. Hippolytus attributed the status of the Druids as prophets to the fact that 'they can foretell certain events by the Pythagorean reckoning and calculations' (Piggott 1968, p. 122). There seems little reason to doubt from these contemporary descriptions that the Druids included competent practical astronomers in their orders. There may also be evidence of the survival of an astronomical temple in Britain as late as the fourth century B.C. in the well known and oft-quoted (Hawkes 1967, pp. 129–130; Atkinson 1960, pp. 183–184; Piggott 1968) passage from the lost *History of the Hyperboreans* of Hecataeus of Abdera (*ca.* 300 B.C.), preserved in the writings of Diodorus Siculus. The passage describes a spherical temple and a sacred enclosure dedicated to Apollo (the Sun) in the island of the Hyperboreans. It is probable, though by no means certain, that this island is Britain in which case the temples mentioned could either be Stonehenge or Avebury, or both. Diodorus also describes the legend that Apollo visited the island every 19 years, a circumstance which is usually taken to be a reference to the Metonic cycle of the same length of time, at the end of which the solar and lunar calendars coincide (235 lunar months total one day less than 19 solar years). If this story really refers to Britain, it would seem to imply the practice here of a fairly advanced form of observational astronomy of the Sun and the Moon at about 300 B.C. Druidical knowledge of the Metonic cycle seems also to be implied by the evidence of the Coligny bronze calendar (Piggott 1968, p. 123).

A considerable span of time, perhaps as much as 1500 years, lies between these Iron Age priest-astronomers and wise men and the comparable class of people which, Thom's researches

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suggest, existed in Britain in the late Neolithic and early Bronze periods. Yet it would be wrong to assume that there could be no continuity of traditional learning between even such chronologically widely separated and culturally distinct epochs: indeed quite independent evidence is now emerging that the geometry and metrology of the stone circles re-appeared in the Iron Age brochs of Scotland (MacKie 1974*b*). The Druids' expertise in *physiologia* is usually assumed to have been acquired from Greek science by way of the Greek trading colony at Massilia (Marseilles) from about 600 B.C. onwards (Piggott 1968, p. 125) but the existence of an advanced and presumably indigenous astronomy and metrology in Britain and Brittany at least as early as the Early Bronze Age would strongly suggest that the Druids were the inheritors of this ancient tradition, far older than Pythagoras.

In this context Caesar's descriptions of the Druids in *De Bello Gallico* are interesting. The reliability of his information has often been questioned because it was supposed to have been derived from the work of Poseidonios of Rhodes. However, Burn argues that this is unlikely, first, because the general theme of Caesar's writings is that he was doing what no Roman had done before and he is unlikely to have detracted from this impression with an obvious crib from a well-known book when on the subject of the Druids, and secondly, because he had a first class source of information to hand in the person of the great chief and Druid Divitiācus of the Aedui whom he had taken prisoner (Burn 1969, pp. 4–5). Caesar says of the Druidical learning, or *disciplina*, that it 'is believed to have been developed first in Britain, and thence introduced to Gaul: and to this day those who wish to pursue their studies of it more deeply usually go to Britain for the purpose'. The origin and more advanced development of the *disciplina* in Britain is harder to understand if much of the calendrical and cosmological knowledge is assumed to have diffused among the learned hierarchies of the northwest European Iron Age cultures outwards from Greece by way of Massilia, but the description exactly fits the state of affairs suggested by Thom's researches. The henge monuments, stone circles and standing stones of the period down to about 1500 B.C. (real years) are a phenomenon almost entirely restricted to the British Isles: Brittany alone elsewhere has a comparable concentration of standing stones and claimed astronomical alinements (Thom 1970, 1971, 1972) (though similar activities have been claimed for Germany – Müller 1970). The spread of the Neolithic or Early Bronze Age *disciplina* from Britain to Brittany now seems more than likely.

Lastly, the study of the Druids and allied non-literate intellectual classes helps to explain how a relatively sophisticated astronomical (and geometrical) knowledge could be acquired and transmitted without the use of writing. It has been pointed out that 'elaborate computations do not necessarily involve apparatus, or even the writing of figures. Among the Tamil calendar makers of South India in the last century the calculation of eclipses was done by arranging shells or pebbles on the ground in such a way as to recall to the mind of the operator the necessary algorithm, or steps in the process. One man, "who did not understand a word of the theories of Hindu mathematics, but was endowed with a retentive memory which enabled him to arrange very distinctly his operations in his mind and on the ground", predicted by such methods a lunar eclipse in 1825 within four minutes of its true time' (Piggott 1968, 124–125; Neugebauer 1952). It is easy to see how the presence of an intellectual class including men with such abilities in prehistoric Britain – abilities doubtless encouraged genetically by selective breeding and culturally by the appropriately favourable social environment – could have led to most of the achievements that Thom has inferred.

In a non-literate society specialized intellectual knowledge is likely to be transmitted by

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means of ballads and verse. Caesar also said of the Druids that 'Many are sent to join it (the learned order) by their parents and families. In it they are said to learn by heart huge quantities of verse. Some spend twenty years in this *disciplina*. They consider it impious to commit this matter to writing.' (Burn 1969, p. 4). No doubt this verse contained all the Druids accumulated knowledge and beliefs, including data on astronomy and cosmology. The oral transmissions of quantities of practical astronomical data for navigating canoes during long voyages in the Pacific by a Polynesian class of navigators has been described by Lewis (this volume, p. 133), and again seems to shed light on the practical problems of the storage and transmission of knowledge raised by Thom's interpretations.

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Appendix:
Petrofabric analysis

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Petrofabric analysis is the study of the spatial relations of the units that comprise a rock, including a study of the movements that produced these elements (Glossary of geology 1966). The fact that particles in a moving medium tend to orientate themselves with their longest (or *a*) axes parallel to the direction of flow and their shortest (or *c*) axes transverse to it has long been utilized in studies concerning the depositional history of particular rocks. In the last 40 years the technique has been used increasingly to deal with problems concerning superficial deposits such as glacial till, outwash sands and gravels and solifluction deposits. In Scotland, Kirby (1968), in a study of the stratigraphy of drift deposits in the Esk basin, Midlothian, utilized the technique to elucidate the direction of flow of ice depositing different boulder clays: a distinction was drawn between raised beach deposits and glacial outwash materials in the western Highlands (McCann 1961); and the orientation of stones in solifluction deposits with increasing slope has been described from the Southern Uplands (Ragg & Bibby 1966).

During archaeological investigations on a site at Kintraw, Argyll, a stone pavement was uncovered. It was important to determine whether the pavement had been formed by geomorphological agencies or by the activities of man. Natural stone pavements are known from the hill areas of the British Isles, and during the Pleistocene period they were of far greater extent. Their remnants are encountered frequently during the investigations of the Soil Survey

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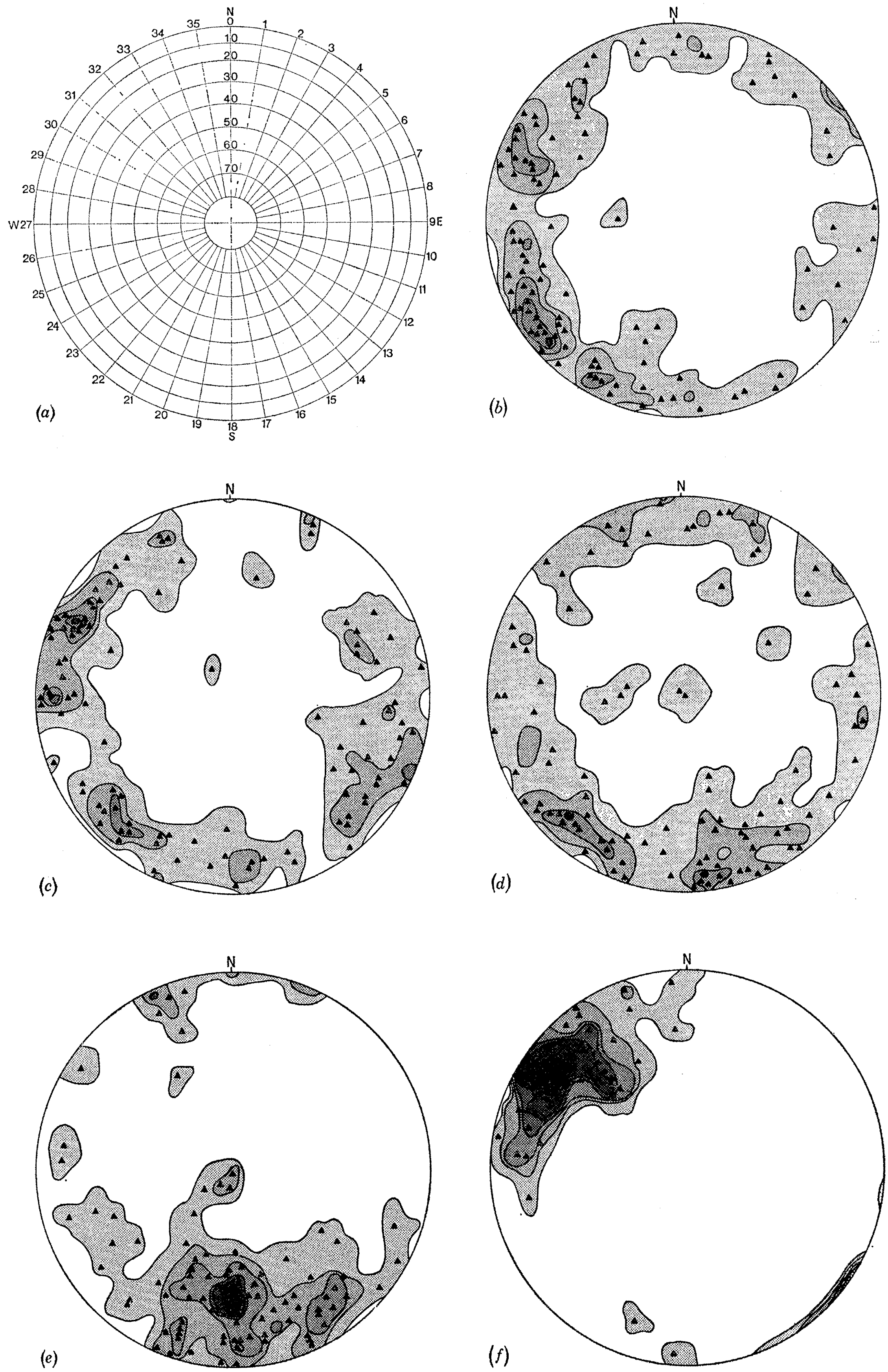

FIGURE 8. (*a*) The Lambert polar equal-area net. (*b*)–(*f*) Contoured petrofabric diagrams (contour interval 2 %) (*b*) Kintraw no. 1 (Argyll): direction of slope, 240° (mag.); angle of slope, 21°. (*c*) Kintraw no. 2 (Argyll): direction of slope, 240° (mag.); angle of slope, 21°. (*d*) Man-made pavement (Sheep Hill Fort, Dunbartonshire): direction of slope, 163° (mag.); angle of slope, 5°. (*e*) Scree (Broad Law, Peebles-shire): direction of slope, 175° (mag.); angle of slope, 37°. (*f*) Soliflucted stone horizon (Broad Law, Peebles-shire): direction of slope, 305° (mag.); angle of slope, 16°.

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of Scotland (see, for example, Mitchell & Jarvis 1956, p. 71). The accumulation of stones on the surface of a deposit can be caused by frost heave of coarse particles with concomitant downward movement of fine material (Corte 1962). In the situation at Kintraw it could also have been formed as a scree accumulation. Other considerations were ruled out by the particular site factors obtaining, and the nature of the underlying deposits.

It is well established that the orientation diagrams produced during petrofabric studies of deposits of markedly different origin show characteristic patterns that can be associated with the different modes of origin. An investigation was therefore undertaken to determine the pattern within the deposit at Kintraw, and whether this pattern had any characteristics which would enable statements to be made concerning its mode of origin.

Methods

Two areas were selected on the exposed pavement, each measuring 50 cm × 50 cm. At each site the *a* axis of each of 100 stones was determined by inspection, while the inclination from the horizontal was measured by Abney level and its azimuth determined with the aid of a prismatic compass. Only stones measuring over 3 cm in length were selected (smaller stones proved difficult to measure and handle effectively). They were derived mainly from schist and were dominantly tabular or wedge-shaped, forms which would normally react strongly to the stress forces responsible for orientation. The results were plotted on a polar-equiarea net (Lambert projection, figure 8*a*), which has a central point representing a pole at 90° to the plane of projection, with concentric circles representing angular declinations from this pole at 10° intervals, and radial rays the azimuths. Stereographic methods of data-presentation are described by Philips (1960). The inclination and orientation of the *a* axis of any stone can therefore be represented as a point on the stereogram; a horizontal stone would lie on the periphery of the circle and could be represented as either of two points 180° apart. The method of contouring (described by Philips 1960, p. 59) using a circle of 1 cm radius takes this anomaly into account.

Results

Two contoured petrofabric diagrams produced from the Kintraw data are reproduced in figure 8*b* and *c*. The salient features are the wide variation in the direction of dip of the *a* axis, and the relatively low angles of inclination. There is a concentration associated with the slope of the ground surface but it is not a strong one. By contrast, figure 8*e* is derived from an area of scree and figure 8*f* from a stone pavement produced by frost action and since modified by solifluction processes. In the diagram derived from scree there is a marked association both with direction of slope and with its inclination; this trend is even more apparent in the diagram representing the structure within the soliflucted stone pavement. It appears that the process of solifluction, involving mass creep lubricated by melt water, imposes a strong degree of orientation on the constituent particles. The strong degrees of orientation shown by figure 8*e* and *f* are in obvious contrast to the weak orientations shown in figure 8*b* and *c*.

No information was available concerning patterns produced on fabric diagrams by data drawn from man-made stone pavements. In order to obtain some check, however tentative, a visit was made to the Sheep Hill vitrified fort, Milton, Dunbartonshire, where a pavement exists that has been identified as man-made by independent evidence (MacKie, in the press). The resulting diagram is shown as figure 8*d* which, allowing for the different direction of

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ground slope, is closely similar to figure 8*b* and *c*. This resemblance is all the more remarkable because of the contrast in parent materials and stone shape between Kintraw and Sheep Hill, the former being dominantly tabular schists and the latter wedge-shaped basalt.

The evidence from petrofabric analysis indicates that the stone horizon discovered at Kintraw bears little resemblance in structure to superficially similar horizons known to have been formed by the action of frost heave or by scree accumulation. Other forms of genesis are rendered unlikely by the particular combination of lithological and site conditions obtaining. The available evidence supports the hypothesis that the Kintraw pavement was man-made.

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FIGURE 6. View of the boulder notch, and the stone layer behind it, at an early stage in the excavations (1970). The stone layer can be seen coming to an end at the right of the boulders; it was subsequently traced for another 4.0 m to the left (upstream) and may go further.

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