PART I PAST DIRECTIONS

1

Sun, Moon and Stones

Some 'Classic' Astronomical Sites

> From a country home of mine near Florence I plainly observed the Sun's arrival at, and departure from, the summer solstice, while one evening at the time of its setting it vanished behind the top of a rock on the mountains of Pietrapana, about 60 miles away, leaving uncovered a small streak of filament of itself towards the north, whose breadth was not the hundredth part of its diameter. And the following evening, at the similar setting, it showed another such part of it, but noticeably smaller, a necessary argument that it had begun to recede from the tropic.
>
> Galileo Galilei, 1632[1]

> Now when it is recalled that 24 hours before and 24 hours after the actual solstice the Sun's declination is only about 0′·2 less than its maximum, it seems wellnigh impossible to develop any observing technique which will differentiate the actual day of the solstice itself. If any arrangement will make this possible it is that at Ballochroy.
>
> Alexander Thom, 1954[2]

> It must be remembered that Lockyer's observations [of midsummer sunrise at Stonehenge] were made with instruments of the highest precision, whereas the instruments used by the original builders were confined to their own naked eyes and, at the most, a number of straight sticks cut from the nearest hazel-thicket.
>
> Richard Atkinson, 1956[3]

NEWGRANGE: SYMBOLIC ORIENTATION ON THE SUN?

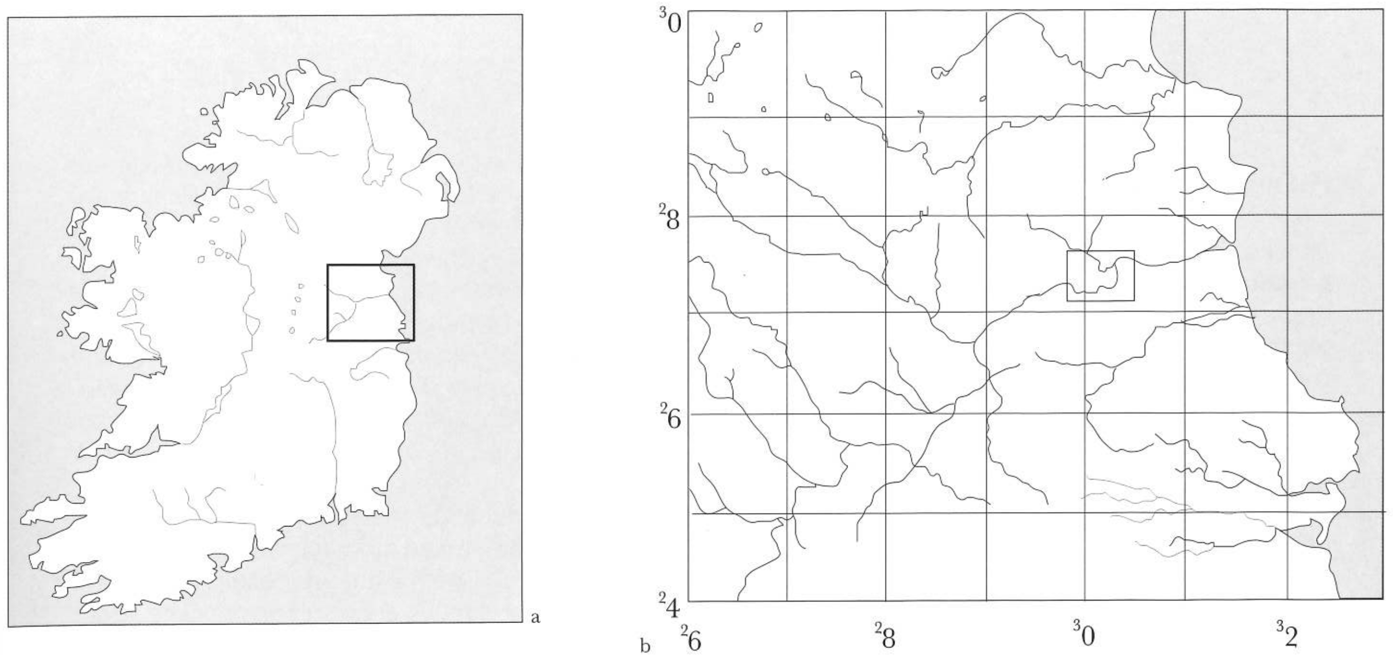
There is no better place to begin a discussion of astronomy in prehistoric Britain and Ireland than the magnificent passage tomb at Newgrange (O 007727). It represents a relatively uncontentious example of an imposing prehistoric monument incorporating a simple, yet elegant and spectacular, solstitial alignment. Both archaeologists and their colleagues in other disciplines have played a part in the discovery and detailed investigation of the phenomenon of midwinter sunrise at the site.

Situated some 14 km west of Drogheda in Co. Meath, Ireland, Newgrange forms part of the Boyne Valley passage tomb cemetery, a rich complex of prehistoric monuments built in the fourth and third millennia BC amidst fertile agricultural land along the northern banks of the River Boyne (Fig. 1.1; see also Archaeology Box 2). The tomb itself is situated on a long, low ridge with a commanding view over the valley. Around it is a scattering of what appear to be 'satellite' structures: three smaller passage tombs along the ridge to the east, and various barrows, standing stones and enclosures down towards the river. Upstream and downstream respectively are Knowth and Dowth, companion great tombs each with their own cluster of satellites.[4]

Newgrange has been described as a *tour de force* in megalithic tomb architecture.[5] The mound, carefully constructed of layer after layer of pebbles and turf, is over 80 m across. The fine façade that confronts the visitor today, with its high walls gleaming with white quartz (Fig. 1.1d), is the product of restoration following excavations by Michael O'Kelly between 1962 and 1975.[6] This frames an entrance on the south-east side from which a 19 m-long passage, with walls of large upright stones and ample headroom for the modern visitor, leads to a large central chamber. The chamber itself is remarkable for its fine corbelled vault some 6 m high. Three recesses open out from it, two at the sides and one at the end, and each of these originally housed a stone basin in which cremated bone and grave goods seem to have been placed. Cunningly conceived drainage channels, carved into the tops of the roof slabs, divert rainwater away from the tomb's interior. Radiocarbon dates suggest a date of construction somewhat before 3000 BC.[7]

The stones in most chamber tombs are rough, with non-planar surfaces and edges far from straight. Inside Newgrange, the majority of the stones are carefully dressed. There is also a profusion of artwork decorating the walls and roof of the chamber, the recesses, the passage and the kerbstones on the outside: intricate and beautiful designs made up of spirals and cup marks, triangles and lozenges, zig-zags and lattices. Across the tomb entrance is the finest carved stone of all, its outward side completely covered by a pattern containing five interlocking spirals surrounded by curves and lozenges (Fig. 1.3b).[8]

The entire passage tomb is surrounded by a so-called 'Great Circle' of large standing stones a little over 100 m in diameter. These are large, rough blocks of stone, providing a considerable contrast to the dressed stones in the tomb. In fact, only



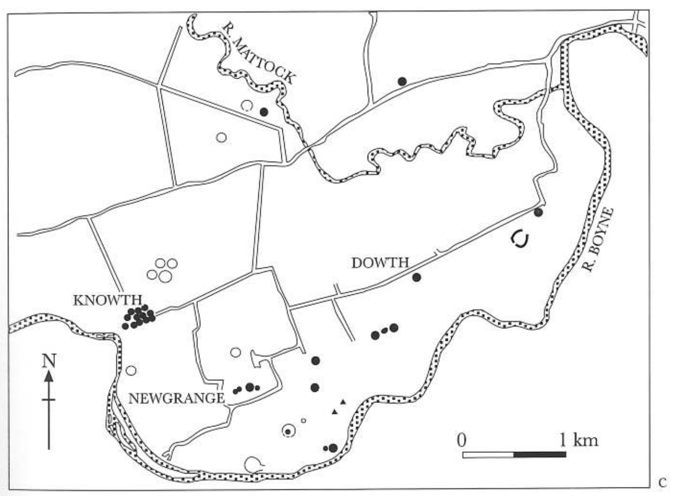
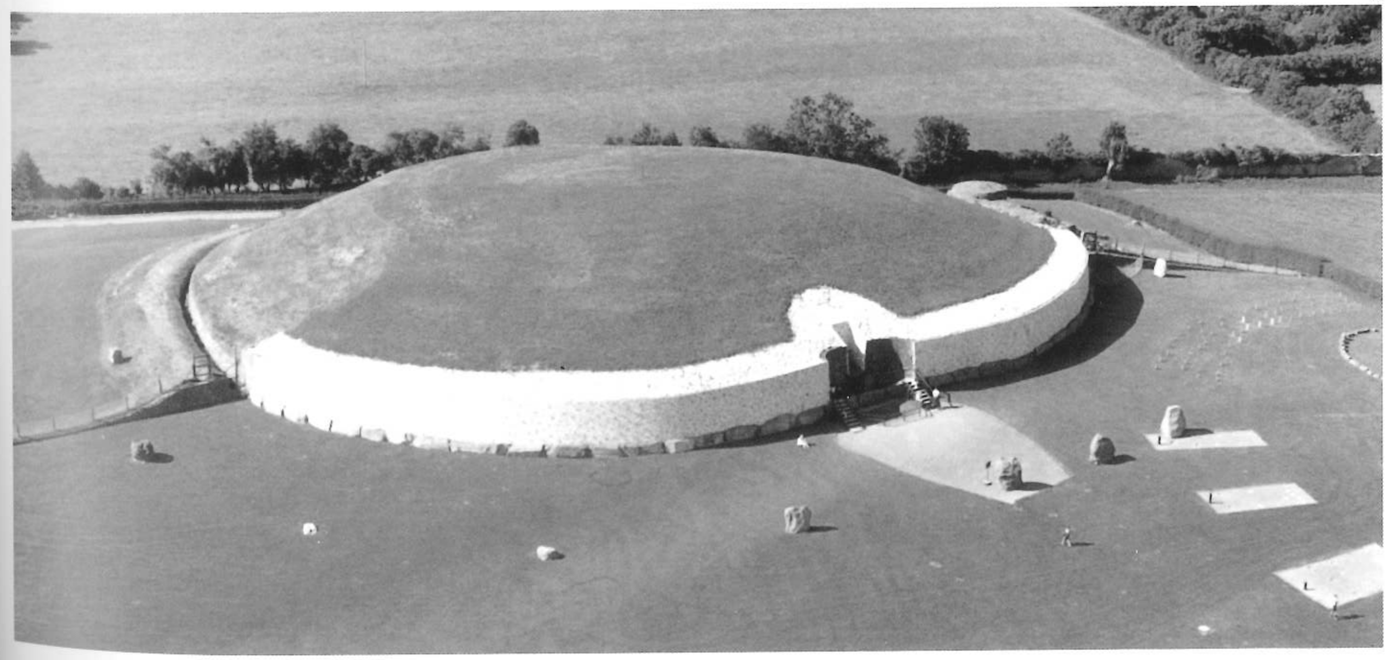


Fig. 1.1 Newgrange, Co. Meath.
a,b. Location of the Boyne valley monuments.
c. Situation of Newgrange with respect to the other Boyne Valley monuments. Filled circles mark tombs and cairns and open circles denote enclosures. After O'Kelly 1982, fig. 2.
d. Newgrange passage tomb, as reconstructed, viewed from the south-east.



ARCHAEOLOGY BOX 2

CONSPICUOUS PREHISTORIC MONUMENTS IN BRITAIN AND IRELAND

This box describes some of the main types of conspicuous Neolithic and Early Bronze Age monuments, often characterised as 'ritual' monuments, encountered in Britain and Ireland and gives an idea of their chronology.

LONG BARROWS AND CHAMBERED TOMBS

Chambered tombs are amongst the earliest stone monuments erected by agricultural communities in Britain and Ireland. They were mostly collective burial places, and were erected in considerable numbers in England, Wales, Scotland, and Ireland between about 4250 and 2750 BC:[1] over 1500 examples remain in Ireland alone.[2] There is a broad dichotomy in design between 'long tombs' whose central chambers open straight to the outside and 'passage tombs' (formerly known as passage graves) containing an entrance passage, although there are a great many variations on these themes and the boundary between the two main categories is far from clear-cut. The long tombs represent the earlier development, paralleling that of the long barrows of earth, turf, timber and chalk, constructed in lowland England and Scotland between about 4250 and 3250 BC.[3]

Major typological groupings of long tombs include the Cotswold–Severn tombs in central southern England and south Wales, the Clyde tombs of western Scotland, and the court tombs in Ireland. Passage tombs are found around Ireland but in particular concentrations at the famous cemeteries in the Boyne Valley and Loughcrew, Co. Meath, and Carrowkeel and Carrowmore, Co. Sligo. They are also found in the Hebridean islands, northern Scotland and the islands of Orkney.[4] The dating of all these monuments is hampered by the fact that they were often used and reused over a considerable period, some being built on top of smaller, simpler tombs from earlier times and many being used for later interments.[5]

Two variants of passage tomb, the Clava cairns in the area around Inverness, Scotland[6] and the wedge tombs of south-west Ireland, may represent the last vestiges of this tradition. The wedge tombs were still being erected late in the third millennium BC, and their use may have extended well into the second millennium.[7] Recent radiocarbon dates from four Clava cairns centre on about 2200–2000 BC.[8]

ROUND ENCLOSURES AND CIRCLES OF TIMBER AND STONE

Round enclosures are found throughout Britain and Ireland and date from the early fourth millennium BC onwards. The earliest are the causewayed enclosures, large irregular earthwork rings with many entrances built in southern England up to about 3000 BC. These possibly served a range of functions, related to settlement, defence, ceremonial activity, and even the exposure of dead bodies prior to burial (cf. Archaeology Box 4). Amongst the best known examples are Hambledon Hill in Dorset and Windmill Hill in Wiltshire.[9]

Henge monuments are later than the causewayed enclosures, smaller, and more regular. They consist of a roughly circular ditch with outer bank, usually with a single entrance or two entrances on opposite sides.[10] Henges are found all over Britain and Ireland, but in greatest concentration in the east of Britain. Their construction appears to span the period from about 3250 to 2250 BC.[11] On the other hand, timber and stone circles (more correctly termed rings, since many are nowhere near exactly circular) are found mainly in the north and west of Britain and in Ireland. Around forty examples of timber circles—which do not remain as conspicuous monuments in the modern landscape—are now known.[12] They appear to span a period from about 3000 to 1500 BC.[13] Many hundreds of stone circles have been documented, of various sizes and forms,[14] and Fig. 1.2 gives an idea of their geographical distribution within Britain and Ireland. Stone circles are notoriously difficult to date, but it has been suggested that they began to appear not long after the first henges, and indeed that the great stone circles of western Britain, such as Castlerigg in Cumbria, may well have been 'the counterparts of henges in those highland areas where it was hard to dig but where building stone was plentiful'.[15]

Sometimes these monuments are found in association with each other. Settings of wood or stone, and particularly rings of upright wooden posts or standing stones, are found inside some henges,[16] and there is evidence that some timber circles were later replaced by henges, or reconstructed in stone.[17] Some of the best known henges with associated stone circles are the Ring of Brodgar and the Stones of Stenness in Orkney, Balfarg in Fife, Arbor Low in Derbyshire, and Avebury in Wiltshire.

Amongst the latest stone circles may be some of those in south-west Ireland, which appear to have been constructed well into the second millennium, and often consisted of only five stones.[18] Examples of a type of monument consisting of just four standing

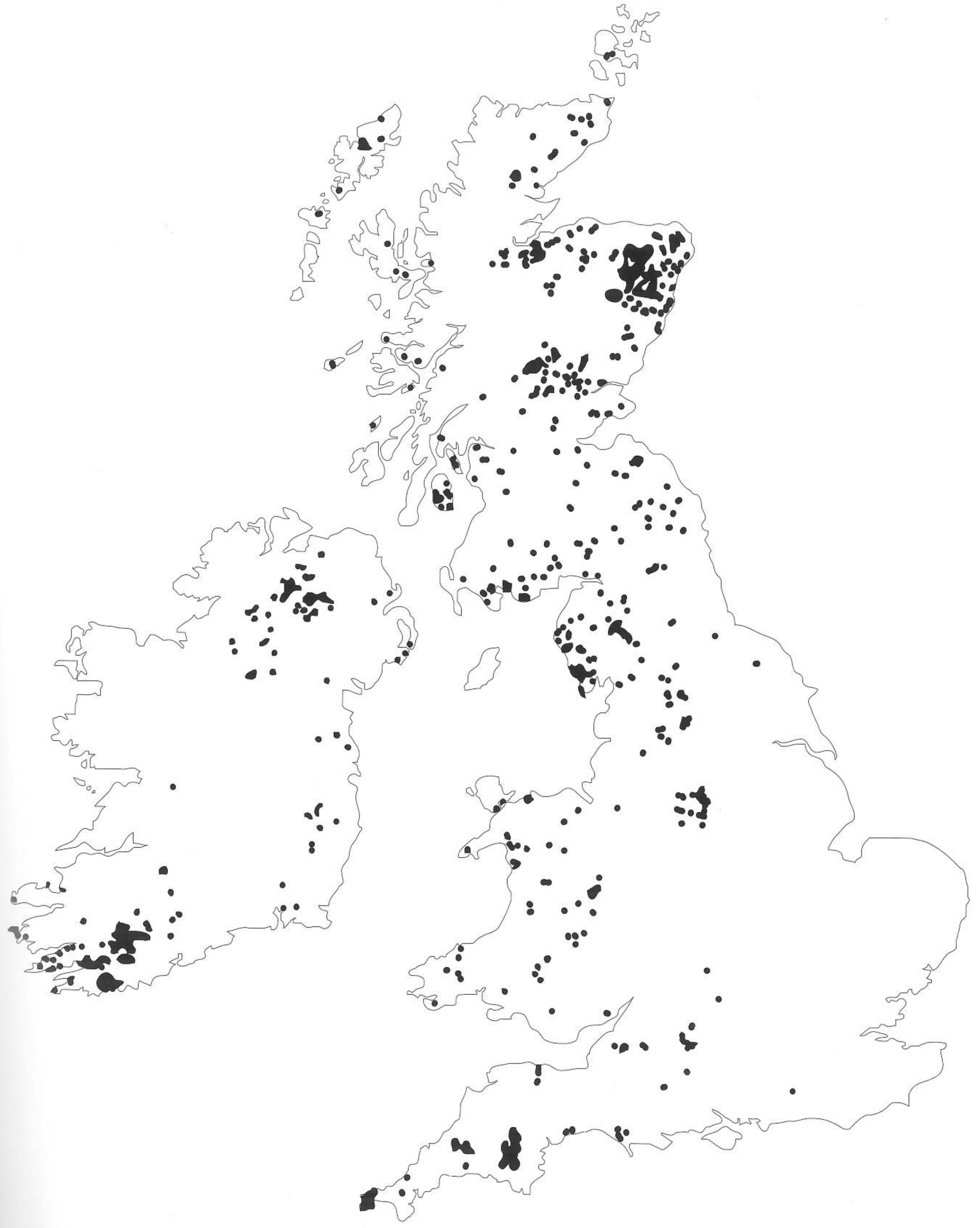


Fig. 1.2 The geographical distribution of stone circles in Britain and Ireland (after Burl 1976, fig. 1).

stones in a rectangular formation, known as a 'four-poster', are found throughout Britain and Ireland and may be a diminutive form of stone circle.[19]

LINEAR MONUMENTS

Linear constructions appeared throughout much of lowland Britain in the mid-fourth millennium BC in the form of cursuses (or cursūs), linear earthworks comprising two widely separated ditches and banks running parallel. The longest of these, the Dorset cursus, is some 10 km long.[20] Bank barrows, over-long long mounds with ditches close to their edge, appear at about the same time and seem to be part of the same tradition.

Early in the third millennium avenues and rows of standing stones began to be attached to circles, famous examples being the 2 km-long West Kennet Avenue at Avebury and the radial avenue and rows at Callanish on Lewis in the Outer Hebrides. The existence of detached avenues, especially in northern Ireland, and double rows, especially in south-west England, suggests a transition towards the construction of linear stone monuments in their own right. Certainly, by around 2000 BC long, single rows of stones were being constructed in south-west England, south-west Wales and northern Ireland. Short rows of up to six stones also appeared at around this time, and were subsequently erected in their hundreds, with particular concentrations in western Scotland, northern Ireland, and south-west Ireland, possibly until late in the second millennium BC.[21]

ROUND CAIRNS AND BARROWS

During the third millennium BC there was a gradual transition towards individual rather than collective burial, and towards small round cairns and barrows instead of large chambered tombs.[22] There was considerable regional variation in the type of burial (e.g. cremation or inhumation). In northern Britain and in Ireland especially, crouched inhumations were often placed in stone cists, accompanied by special pots called Beakers and by food vessels. Round cairns and barrows started to appear in a great variety of forms,[23] including the ostentatious Wessex bell barrows and disc barrows, and (by the mid-second millennium) the ring cairns and kerb cairns that are so widespread in Scotland. They were often constructed in groups (cemeteries). Some round barrows are complex in internal structure while others are simple mounds covering a single burial; superficially similar structures may turn out to be very different upon excavation. Round cairns and barrows continued to be erected until around the middle of the second millennium BC.[24]

STANDING STONES

Large standing stones are often found in association with cairns (e.g. Strontoiller in Argyll), as well as with henge monuments (e.g. the Heel Stone at Stonehenge) and stone circles (e.g. Long Meg and her Daughters in Cumbria). Single standing stones are widespread in Britain and Ireland, but while many undoubtedly date to the later Neolithic and Early Bronze Age, they have also been erected throughout later prehistoric, historic and modern times as boundary markers, route markers, cattle rubbing posts, and for a variety of other purposes. On the other hand, a single standing stone may be the only visible remnant of a more complex prehistoric structure such as a stone row or stone circle. Of all types of prehistoric monument, single standing stones are perhaps the most difficult to date (often within extremely wide margins) and the most difficult to interpret.[25]

DECORATED STONES

Many of the passage tombs of Ireland are highly decorated with abstract motifs such as concentric circles, spirals, zig-zags, and a variety of other abstract forms.[26] These may be related to the patterns on a type of Late Neolithic pottery known as Grooved Ware, often found in henges. While forms such as lozenges, chevrons and triangles are also found in Scotland, the dominant type of decoration consists of simple cup marks or cup-and-ring marks, sometimes in large groups. Such marks are found on standing stones, cist slabs, and natural outcrops.[27]

twelve circle stones survive, and they are concentrated on the southern side of the tomb and irregularly spaced, as can be seen in Fig. 1.3a. However, there is no evidence that the 'missing' stones ever existed and it seems probable that the circle, if intended as such, was never completed.[9] Other evidence indicates that the incomplete circle was erected many centuries after the tomb.[10]

Lockyer had noted in the 1900s that the passage at Newgrange was approximately aligned upon the rising sun at winter solstice.[11] However, the true nature of the interplay between the light from the rising solstitial sun and the architecture of the tomb (see Fig. 0.1) was only realised more than sixty years later, when it was witnessed at first hand by Michael O'Kelly on 21 December 1969 and again in 1970:

> At exactly 8.54 hours GMT the top edge of the ball of the sun appeared above the local horizon and at 8.58 hours, the first pencil of direct sunlight shone through the roof-box and along the passage to reach across the tomb chamber floor as far as the front edge of the basin stone in the end recess. As the thin line of light widened to a 17 cm-band and swung across the chamber floor, the tomb was dramatically illuminated and various details of the side and end recesses could be clearly seen in the light reflected from the floor. At 9.09 hours, the 17 cm-band of light began to narrow again and at exactly 9.15 hours, the direct beam was cut off from the tomb. For 17 minutes, therefore, at sunrise on the shortest day of the year, direct sunlight can enter Newgrange, not through the doorway, but through the specially contrived slit which lies under the roof-box at the outer end of the passage roof.[12]

The 'roof-box' referred to by O'Kelly is a feature uncovered in the excavations, which appeared at first to have no obvious function. It is situated above the long roof slab at the front of the passage, its floor being the top of the roof slab itself, while its own roof is formed by a lintel jutting clear at the front (only the tip of which was visible before excavation) and a corbel slab sloping down to meet the passage roof at the back (see Fig. 1.3c). The corbel slab was richly decorated with dot-in-circle and rayed dot and circle motifs.[13] It is this box, and not the entrance below, that admits the midwinter sun's light into the interior.

We immediately encounter a question that will recur time and time again throughout the investigation of prehistoric

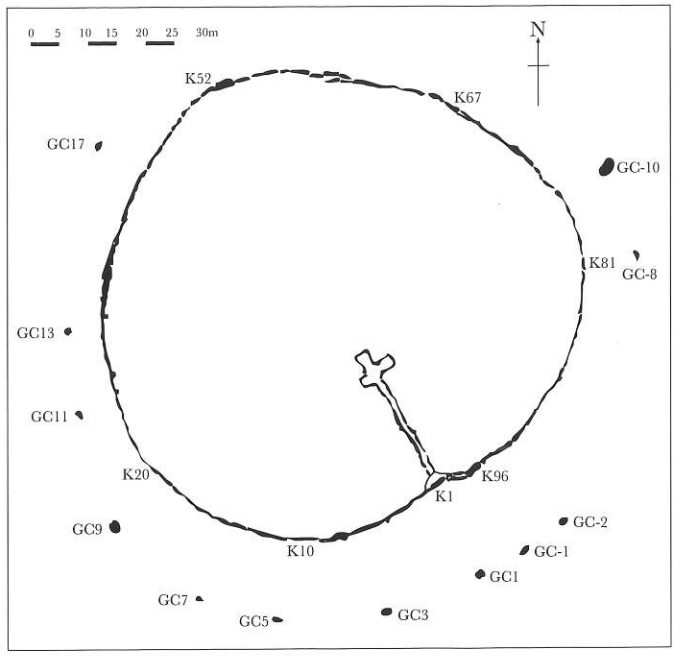
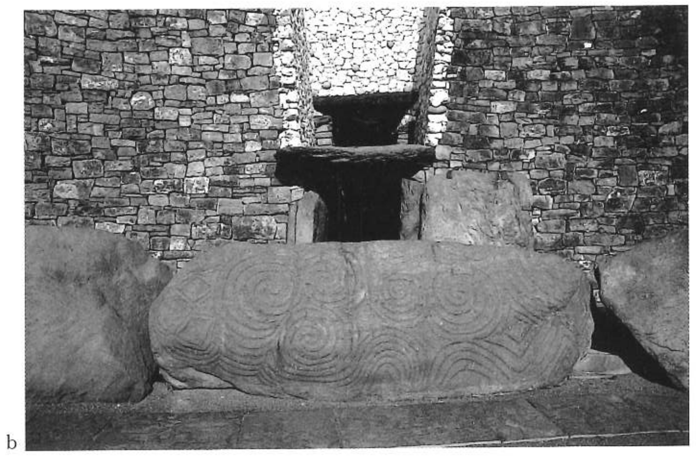
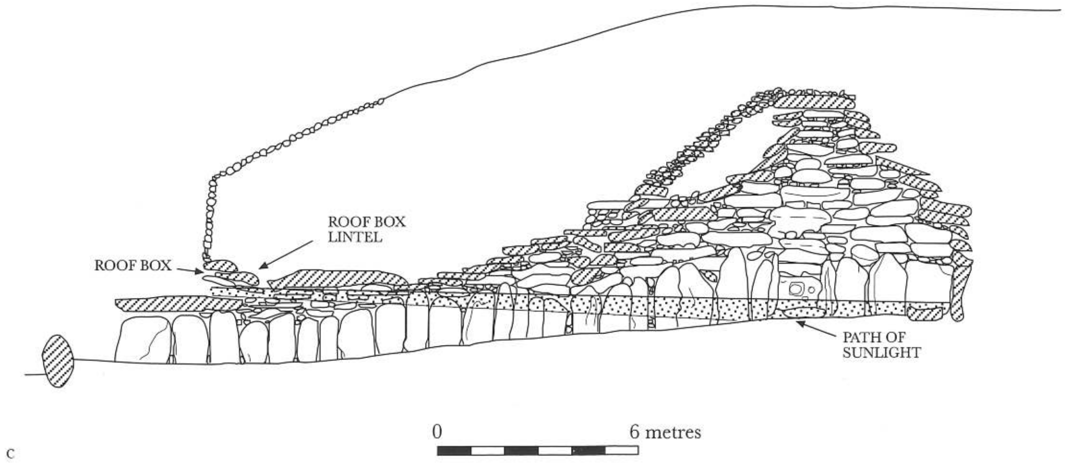


Fig. 1.3 The solstitial alignment at Newgrange.
a. Plan of Newgrange, showing the passage and surrounding stone circle. After O'Kelly 1982, fig. 3.
b. The entrance viewed from the exterior, showing the carved entrance stone (K1).
c. Cross-section of the passage at Newgrange, showing the path of the light from the rising midwinter sun. After Patrick 1974, fig. 1 and O'Kelly 1982, fig. 22.





ASTRONOMY BOX 1

THE CONCEPT OF DECLINATION

In order to understand the arguments about which celestial phenomena may have concerned people in prehistoric Britain, it is necessary to have a basic understanding of the apparent movements of the heavenly bodies as seen from the earth's surface, in other words of what is known as positional astronomy. It is not generally necessary to know why these motions appear as they do, except insofar as this helps to understand the apparent motions themselves.

For our purposes, declination is the single most important concept in positional astronomy. It allows us to encapsulate, in a single number, certain key astronomical properties of any point in an observer's sky, and in particular of any point on their horizon. The main text will refer to the concept time and again.[1]

THE CELESTIAL SPHERE

A cloudless sky, whether viewed on a clear evening, during a sunny day, or on a dark starlit night, appears to be a great hemispherical dome. Positioned upon it, moving around, are the discs of the sun and moon and the points of light forming the stars. This optical illusion is mimicked exactly by a planetarium, which projects images of the sun, moon, planets and stars onto a physical dome. If one were to stand for several hours at night in one spot, monitoring the slow collective movement of the stars, each rising behind the eastern horizon, progressing across the sky and setting behind the western horizon, one would soon gain the feeling of being at the centre of an entire celestial sphere that was slowly rotating.

This concept of a 'celestial sphere' in fact provides a remarkably convenient, as well as natural, way of describing the apparent motions of the heavenly bodies. All observers, at a particular position on the earth and at a particular time, see part of the sphere above their heads with the remainder being hidden below their horizon (exactly half and half, if the horizon is completely level and flat).[2]

From the point of view of an observer on the earth, the celestial sphere rotates once daily with all the heavenly bodies affixed to it. Thus we can identify its north and south poles (the celestial poles) as the points around which it pivots. From central parts of Scotland the celestial north pole is located at an altitude of about 57° above the north point of the horizon, whereas the celestial south pole is equally far below the south point and is never seen. Having defined the poles on the celestial sphere we can go on to identify its equator (the celestial equator) and its lines of latitude and longitude, just as on the earth.

Declination is simply a synonym for latitude on the celestial sphere.[3] The celestial equator, then, is the line where declination = 0°. By convention, declinations north of the celestial equator are positive and those to the south negative. The declination of the north celestial pole is +90° and that of the south celestial pole is −90° (Fig. 1.4).[4]

The significance of declination is that all the heavenly bodies move daily around lines of constant latitude on the celestial sphere, i.e. around lines of constant declination. Thus the Pleiades have a declination of about +24°, and Polaris, which is very near to the north celestial pole, has a declination of +89°. Hence, by determining the declination of a horizon point and referring to sources of astronomical information such as star lists or atlases, one knows at a stroke all the heavenly bodies that will rise or set there at some time during the daily cycle.

LONGER TIMESCALES

On timescales longer than a single day, the simplification that each heavenly body can be associated with a single declination line begins to break down. The sun, moon and planets in fact move slowly about on the celestial sphere as it rotates, with the result that their declinations vary cyclically. The declination of the sun, for example, varies over an annual cycle between approximately +23°·4 at the summer solstice on 21 June and −23°·4 at the winter solstice on 21 December. The declinations of the stars vary over a much longer timescale owing to a phenomenon known as precession. These and other longer-term variations will be discussed in later boxes.

The important point for the moment is that all the relevant changes with time are well documented, so that the declination of a horizon point can tell us not only what will rise or set there at different times nowadays, but also what would have done so at any specified epoch in the past.[5]

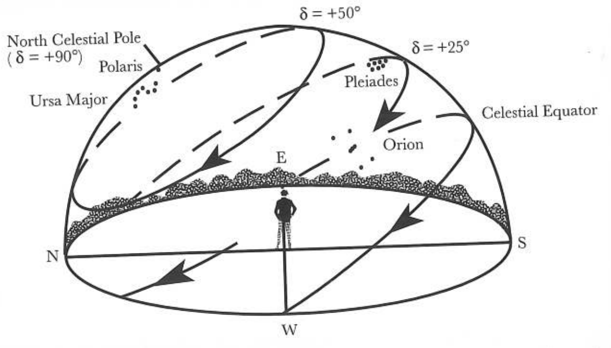


Fig. 1.4 The celestial sphere and lines of declination, as seen from the latitude of central Scotland.

astronomy. Was it deliberate? After all, any construction with a small opening will admit sunlight if and when the sun reaches the relevant part of the sky; is it possible that the Newgrange phenomenon could have arisen fortuitously rather than being an integral part of the design? The fortuitous occurrence of an alignment involving the sun at a special time of year (the solstice) and a special time of day (at sunrise) is more unlikely, but the question must still be asked.[14]

Claire O'Kelly herself was certainly convinced that the alignment was intentional:

> It is difficult . . . to remain sceptical once one has actually seen the thin thread of sunlight striking in along the passage at the winter solstice, this most dismal of all times of the year, until the dark of the chamber begins to disperse and more and more of it becomes visible as the sun rises and the light strengthens. Upon looking outward towards the entrance, one sees the ball of the sun dramatically framed in the slit of the roof-box and one realises that in the whole course of the year this brief spell is the only period when daylight has sway over the darkness of the tomb.[15]

Actually the last remark is a little misleading since 'direct sunlight penetrates to the chamber for about a week before and a week after the solstice but not as fully as on the few days centring on the 21st'.[16]

The sun's path through the sky is related to its declination, or latitude on the celestial sphere (see Astronomy Box 1). Over the year this varies between a maximum (most northerly path) of +23°·4 at the June solstice and −23°·4 at the December solstice. In prehistoric times the limits of the annual variation were somewhat greater: about ±24°·0 around 3000 BC. Following O'Kelly's discoveries, a survey of Newgrange was undertaken by Jon Patrick.[17] He calculated that the sun's rays would enter the roof-box, penetrate the entire length of the passage and illuminate the chamber just after sunrise whenever its declination lay between about −23°·0 and −25°·9. A resurvey by Tom Ray[18] has since raised the lower limit to about −25°·2. Even in 3000 BC the sun could never reach below −24°·0, but the range between −23°·0 and −24°·0 was sufficient to ensure that direct sunlight reached the centre of the tomb every morning for about two weeks on either side of the winter solstice. Nowadays the declination of the solstitial sun has increased to −23°·4 and the period of days during which dawn sunlight enters the tomb is shorter. At the time of construction, the rising solstitial sun would have cast a narrow beam down to the floor of the chamber immediately as it rose, rather than some four to five minutes later as at present.

But these are the details. More important at the outset is to avoid the purely subjective conclusion that a light-and-shadow phenomenon must have been deliberate simply because it is spectacular. The evidence at Newgrange does seem to weigh in favour of the deliberate rather than the fortuitous. First, the roof-box is an anomalous feature without any obvious function in utilitarian terms (as it seems to us). Second, if the gap in the roof-box were merely 20 cm lower or higher, or the passage a few metres shorter or longer, then sunlight would never have entered the chamber.[19] Third, at some time after its original construction, when the bones of a number of people had been placed within the tomb,[20] the entrance was permanently blocked with a large stone weighing about a tonne.[21] The roof-box, however, was only covered with two small quartz blocks which could be, and evidently were, moved to and fro to permit the roof-box to be opened and closed.[22] In other words, the design was such that although the living could no longer enter, by moving aside the quartz blocks at the relevant time the light of the midwinter sun could be allowed to continue to do so.

Nevertheless, the evidence is not conclusive. It could be that the roof-box had a function that seems obscure to us, yet was of great importance to people at the time: perhaps as an opening through which people could communicate with their ancestors,[23] or 'a soul-hole through which the spirits of the dead could come and go'.[24] We must also bear in mind that we are dealing with a reconstruction; the sides of the passage beneath the roof-box needed a good deal of rebuilding and some question must remain about the degree to which the stones and corbels of the reconstructed roof-box were replaced in their original positions, and to what extent this would effect the passage of sunlight.[25]

If astronomy really was involved we need to explore the possible reasons why it was important that the dawn sunlight around midwinter should light up the interior of the tomb. What *is* certain is that Newgrange was not an observatory, at least in any sense that would be meaningful to a modern astronomer. Its chief function was as a tomb for the dead (although see p. 89). Yet few people—archaeologists or astronomers—have doubted that a powerful astronomical symbolism was deliberately incorporated into the monument,[26] demonstrating a connection between astronomy and funerary ritual that, at the very least, merits further investigation.[27]

BALLOCHROY: PRECISE SOLSTITIAL FORESIGHTS?

No such consensus developed for many years with regard to the possible astronomical significance of Ballochroy (NR 731524) (see Fig. 1.5),[28] which for many people became the very embodiment of Alexander Thom's 'megalithic astronomy'. Unlike Newgrange, it is not a large, spectacular monument extensively visited by the general public, but merely a small group of megalithic structures situated on private ground, one of dozens of relatively unimposing sites to be found in the Argyll district of western Scotland alone. The Ballochroy site is located in the northern part of the Kintyre peninsula, close to the main A83 Tarbert–Campbeltown road, about 24 km beyond Tarbert. It can be accessed by walking up a steep, winding farm track which leaves the road about 400 m north of Ballochroy farmhouse.

From this vantage-point—a level area of high ground close to the west coast—one overlooks a broad stretch of the Sound of Jura including the small island of Gigha. Further away on a clear day can be seen the Isle of Jura itself, with the Paps of Jura, the group of peaks in its centre, being particularly impressive. Only some modern features (a nearby corrugated iron hay barn roof and some telegraph wires) serve to mar the view. The most conspicuous feature of the site itself is a 5 m-long row of three standing stones. The two southernmost stones (*a* and *b*) are a little over 3 m tall; the northernmost (*c*) is shorter but appears to have been broken off at the top. Stone *a* is roughly square at the base, tapering irregularly to a pointed top, but the

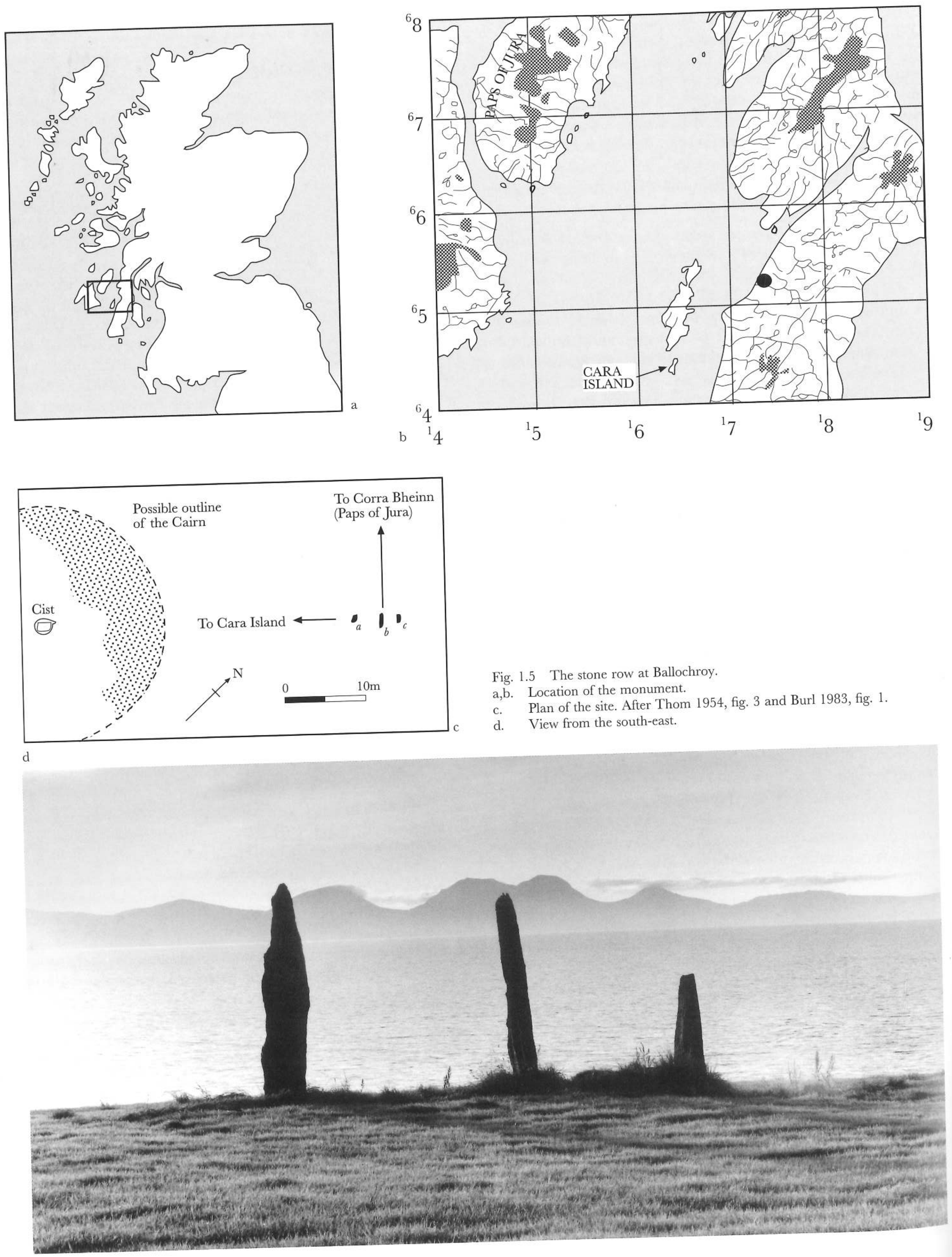


Fig. 1.5 The stone row at Ballochroy.
a,b. Location of the monument.
c. Plan of the site. After Thom 1954, fig. 3 and Burl 1983, fig. 1.
d. View from the south-east.

other two are thin slabs oriented across the alignment. Some 35 m away to the south-west, and protruding by about a metre above present ground level, is a rectangular burial cist with a large cap-stone. The cist is located in the same alignment as the stones, and its longer sides are also oriented in the direction of the alignment.[29] From the wider archaeological evidence, it is likely that megalithic constructions at Ballochroy commenced in the late third millennium BC at the earliest (see Archaeology Box 2), that is at least a thousand years after the construction of the tomb at Newgrange.

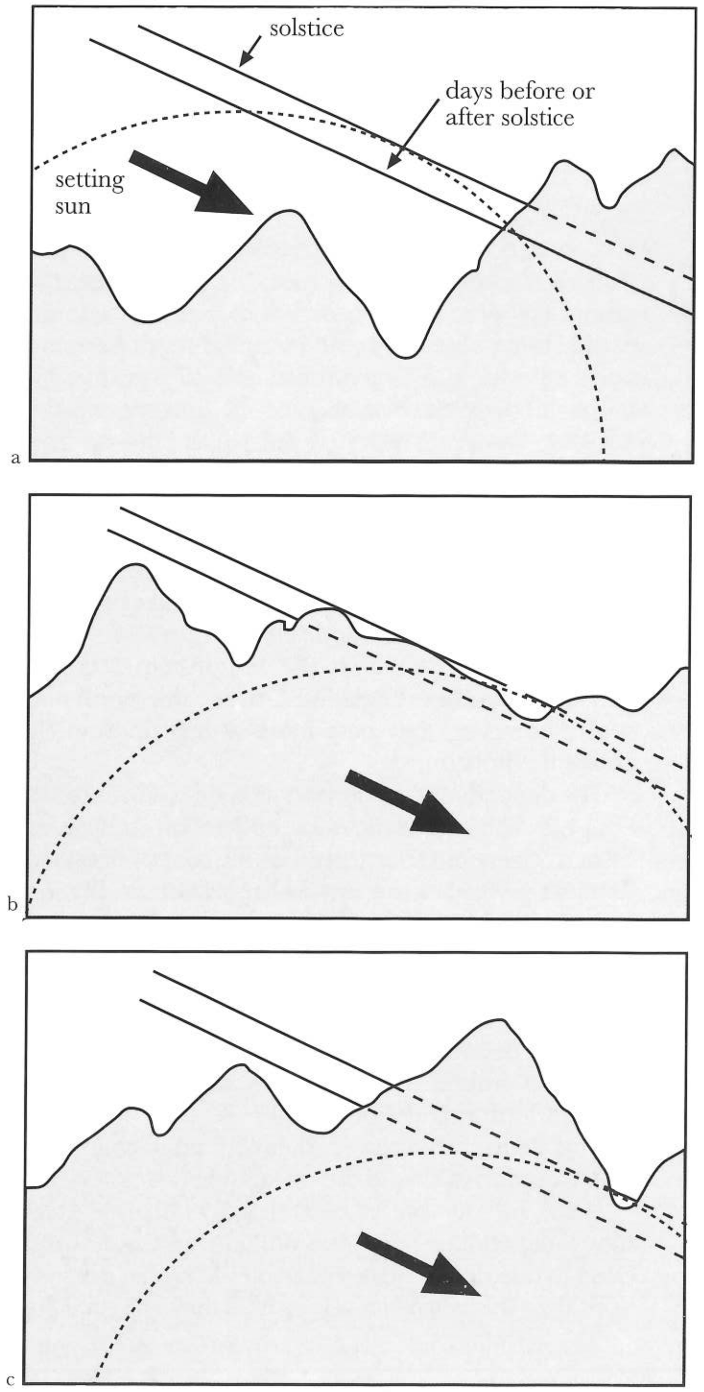
Thom, who had mentioned Ballochroy in his first published paper on megalithic astronomy,[30] came to regard it as one of the most important solar sites known to him.[31] Having carried out careful theodolite surveys to determine the declinations of conspicuous points on the horizon (see Astronomy Box 2), he suggested that the function of the monument was to pinpoint the longest and shortest days of the year by marking the exact setting position of the sun on both. This is by no means trivial to achieve. At Newgrange, as we have seen, sunlight entered the tomb not just on the solstice itself but for a period of several days before and after; this was inevitable because, close to the solstices, the daily change in the sun's path through the sky only alters by a very small amount (see Astronomy Box 3). At Ballochroy, however, the solstices could be discriminated by a subtle method using only natural features on the distant horizon.

The method is best appreciated by considering a hypothetical observer who stands at the same spot each evening in order to watch the sun setting. Suppose that from the chosen spot there is a clear view to a distant, hilly horizon in the west, containing plenty of fixed, identifiable landmarks such as hill summits and valleys. Given a run of clear evenings it would be easy to monitor the nightly progression of the sun's setting position along the horizon; at least for most of the year. It moves steadily northwards between late January and late May, and southwards between late July and late November, the daily change in the sun's sloping path when it is changing fastest—around March and September—being almost as great as its own diameter. By standing at a given spot, the daily change soon shows up against any distant fixed features such as hill-tops, valleys or trees.

However, within a week or two of the solstices the movement of the setting position becomes much smaller as it approaches its northern (June) or southern (December) limit. During a period of a week on either side of the solstices the sun's setting path changes by only about a third of its own diameter. In most circumstances it would be impossible to detect any difference in the sun's setting position throughout this period, even behind a mountainous horizon (Fig. 1.6a). How, then, could this have been achieved at Ballochroy?

The answer, according to Thom, was to use a distant, natural horizon feature as a foresight. Suppose that, as the sun sets on the day of the June solstice, there comes a moment where all that shows of it is the very tip of its upper limb, the point on the sun that traces out the top of its setting path. Because of the brightness of the sun even a tiny part of its surface can be clearly visible. The tip of the sun might be seen to twinkle down a hill slope parallel to its setting path, or else to gleam briefly in a horizon notch some while after the sun had set behind a hill to the left. In these special circumstances, even the very small lowering in the sun's setting path two or three days on either side of the solstice would be sufficient to ensure that the twinkle or reappearance would not take place (Fig. 1.6b, c). The December solstice could be marked in a similar way by noting the *non*-appearance of the tip of the sun behind a hill slope or notch, since on days adjacent to the solstice the sun's setting path would be higher up than on the solstice itself.

Fig. 1.6 Pinpointing the solstice, according to Thom. Generally, the minuscule difference between the sun's setting position on the summer solstice and two or three days earlier or later will be undetectable, even behind a mountainous horizon (*a*). However, by using a suitable hill slope (*b*) or notch (*c*), the last twinkle of the sun's upper limb will be seen on the solstice but not on the other days (after Ruggles, *New Scientist* 90 (1981), p. 751).



ASTRONOMY BOX 2

DETERMINING THE DECLINATION OF A HORIZON POINT

The *azimuth* of a horizon point is defined as its bearing from the observer measured clockwise round from true north, so that due east corresponds to an azimuth of 90°, south to 180°, west to 270°, and north to 0° and 360°. Its *altitude* is defined as the angle it subtends above the horizontal.

By surveying the azimuth A and altitude h of a point on the horizon from some fixed position (see Fig. 1.7),[1] and knowing the latitude λ of that position, one can calculate the declination δ of the horizon point approximately (say, to the nearest degree) using the formula

$$\sin\delta = \sin\lambda\,\sin h + \cos\lambda\,\cos h\,\cos A \quad \ldots \text{(A2.1)}$$

The dependence on (terrestrial) latitude in this formula comes about because the whole celestial sphere tips over as the observer changes latitude on earth. For an observer at the terrestrial north pole, the north celestial pole is overhead and all the stars go round in horizontal circles. For an observer at the equator, the north celestial pole is on the horizon at the north point, the south celestial pole is on the horizon at the south point, and all the stars rise vertically in the east and set vertically in the west (see Fig. 1.8).

At the latitude of Britain and Ireland, heavenly bodies rising in the east and setting in the west do so at a shallow angle (about 30° in northern Scotland and 40° in southern England). Close to due north and south, however, they pass more or less horizontally above the horizon.

The dependence on horizon altitude is illustrated in Fig. 1.9. This shows lines of declination as viewed from a given observing position in central Scotland (latitude 57°). Given a low horizon (altitude 0°), an azimuth of 91° would yield a declination of about −1°, corresponding to the modern-day rising of ε Ori (the middle star of Orion's belt). On the other hand, if the horizon were higher, with an altitude of, say, 4°, then the declination corresponding to azimuth 91° would be around +3° and ε Ori would rise several degrees to the right (south).

The highest horizon declination attainable at a given location is around the co-latitude (i.e. 90° − 57° = +33° for our site in central Scotland), the exact figure depending upon the altitude of the horizon close to due north. Heavenly bodies at higher declinations than this will never set; instead they will circulate around the celestial pole in the sky. Similarly, the minimum possible declination is around minus the co-latitude; heavenly bodies at lower declinations than this will remain below the horizon and never be seen.

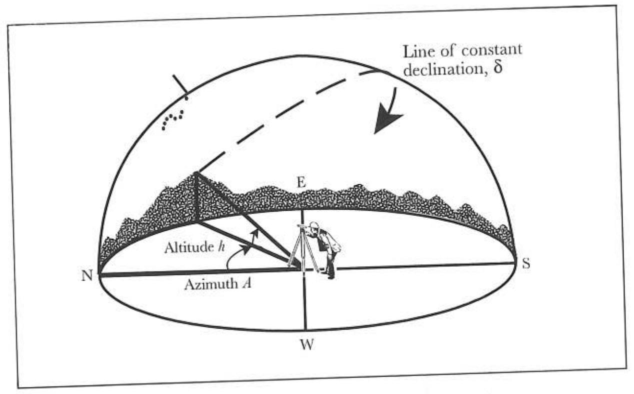


Fig. 1.7 Determining the declination of a horizon point.

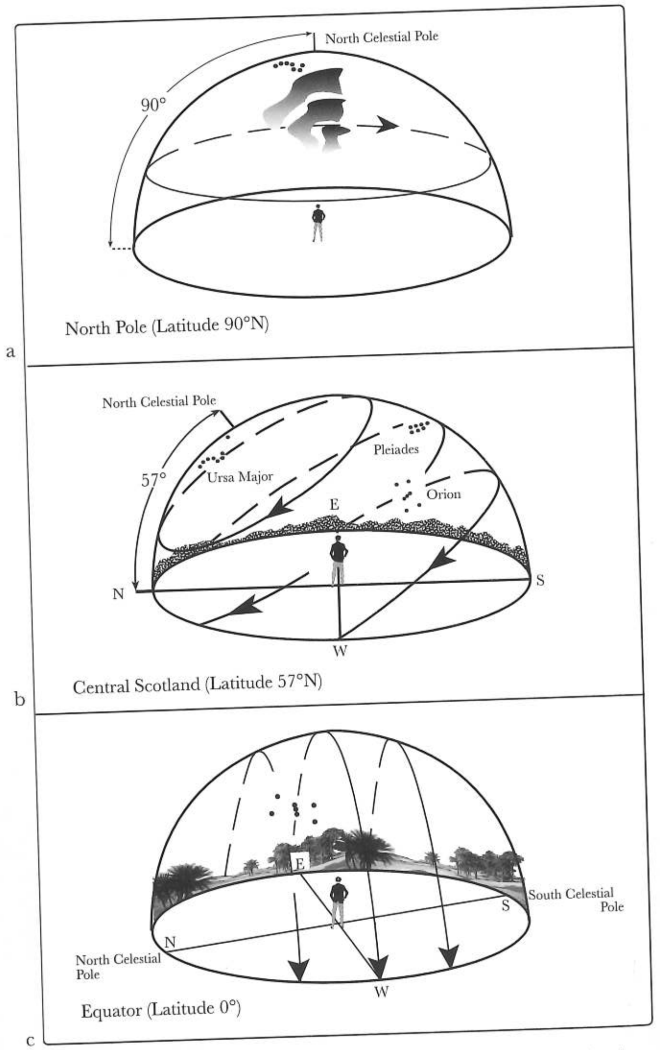


Fig. 1.8 The appearance of the celestial sphere at different latitudes. Inspired by Aveni 1980, fig. 20.

REFRACTION AND PARALLAX

For more accurate work, other factors need to be taken into account before formula (A2.1) can be applied. The most serious of these is atmospheric refraction, which bends downwards rays of light reaching an observer from a distant object. This means, for example, that the rising or setting sun can be seen when it is in fact below the horizon. If it were not for refraction, the sun rising with declination 0° over a level horizon (altitude 0°) would appear exactly due east (i.e. at azimuth 90°).[2] In fact, as is evident in Fig. 1.9, the rising sun will be seen due east over a level horizon when its declination is somewhat less than 0°.

In order to take account of this effect, a correction must be applied to the measured ('observed') altitude, which is often denoted by h_0, in order to arrive at the appropriate value h to be inserted in formula (A2.1). For many purposes it is adequate to apply a 'mean refraction' correction which is simply dependent upon h_0 itself, the correction being smaller for higher altitudes.[3] For more accurate work still, it may be necessary to take account of variations about the mean resulting from different atmospheric conditions (see also Astronomy Box 3).

A further effect, which is of concern (only) in the case of the moon, is parallax.[4] The problem arises because formula (A2.1) assumes that we stand at the earth's centre, whereas we actually stand on its surface. Allowance can be made for this in two different ways. For work of the highest accuracy it is necessary to apply an additional 'lunar parallax' correction to the measured altitude if the moon is of interest as a possible target. Formula (A2.1) then produces a 'geocentric lunar declination' for a given point on the horizon, distinct from the declination calculated for other purposes, and this is used exclusively in analyses concerning the moon.[5] This approach is necessary in discussing high-precision lunar phenomena (see Astronomy Box 7). Fortunately for all other needs it is sufficient to make a 'mean parallax' correction when calculating the expected declination of the moon at a given stage in its motions. This, which is the approach taken in Astronomy Box 4 and used throughout the book except in a small part of chapter two, is much simpler because it enables us to treat declination as a universal concept applying to all astronomical bodies.

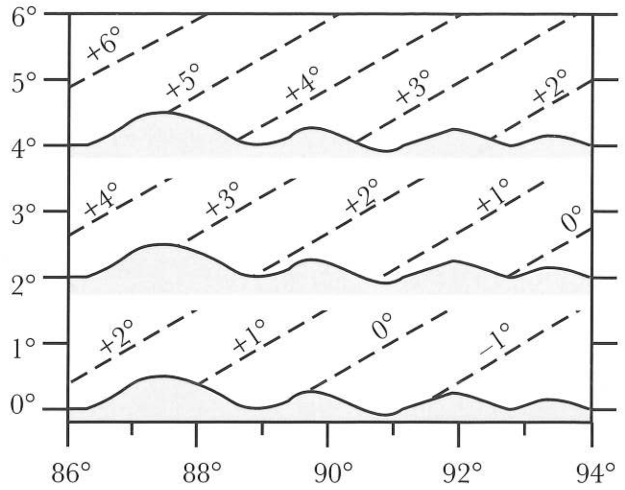


Fig. 1.9 The dependence of declination on horizon altitude. The figure shows fictitious horizon profiles for a location in the vicinity of Callanish, Isle of Lewis.

A widespread misconception is that Thom's method of using distant horizon foresights allows the solstice to be pinpointed to the very day. Thom himself certainly believed this, and it is inherent in his own scenario for how the sightlines were set up, involving setting out stakes at the position where the last gleam of the sun could be seen on successive nights.[32] However, the maximum possible difference between the sun's declination at the sunset nearest the solstice and that two days earlier or later is less than a minute of arc, or one thirtieth of the sun's own diameter.[33] Such a minuscule variation is almost certainly swamped by daily changes in atmospheric conditions (see Astronomy Box 3).[34] This rider notwithstanding, the use of distant natural foresights to observe and mark horizon astronomical events is unquestionably the most far-reaching single idea about preliterate astronomy propounded by Thom. This technique could have enabled the prehistoric inhabitants of Britain, with no instruments apart from the horizon available to them, to observe and mark particular astronomical events to a precision that is still remarkable.

Ballochroy attracted particular attention because of the presence of not just one but two high-precision solstitial foresights, one marking midsummer sunset and one marking midwinter sunset, both of which are 'indicated' by the standing stones themselves. The flat faces of the wide central slab *b* are oriented upon the right-hand slope of Corra Bheinn on Jura (NR 526755) at a distance of 31 km (Fig. 1.12a). According to Thom, in prehistoric times the tip of the setting midsummer sun would have twinkled down this slope (Fig. 1.12b). The alignment of the three stones points in the south-west to Cara Island (NR 638438), a small island some 12 km distant (Fig. 1.12c). The tip of the setting midwinter sun just clipped the right-hand end of the island, which could have acted as a foresight (Fig. 1.12d).

At first sight, the simultaneous presence of these two indicated foresights seems difficult to put down to chance. The implication that the site of Ballochroy was specially and carefully chosen for this reason seems reinforced by the fact that the declinations obtained correspond to a similar date, within

ASTRONOMY BOX 3

THE ANNUAL MOTIONS OF THE SUN

The declination of the centre of the sun varies annually between limits of ±ε, where ε is the obliquity of the ecliptic.[1] This has a value of about 23°·4 in the present day but was slightly greater in prehistoric times: about 24°·0 around 3000 BC.

THE SUN'S DECLINATION OVER THE YEAR

To a first approximation, the sun's declination δ at any time in the year is given by

$$\sin\delta = \sin\varepsilon\cos(0{\cdot}9856n) \qquad \ldots\text{(A3.1)}$$

where n is the number of days that have elapsed since the June solstice[2] and all angles are expressed in degrees. The annual variation in the sun's declination calculated from this formula is shown in Fig. 1.10: it corresponds quite closely to a sine wave.[3] The magnitude of the daily change in the sun's declination is given by

$$\Delta\delta = 0{\cdot}9856\sin\varepsilon|\sin(0{\cdot}9856n)|/\cos\delta \qquad \ldots\text{(A3.2)}$$

where once again all angles are expressed in degrees.

Around the equinoxes ($n = 91$ and $n = 274$) the daily change reaches 24′, so that the sun's setting path is displaced from that on the previous day by three-quarters of the solar diameter.[4] However, near to the solstices the value is much smaller. By seven days from the solstice the daily change reaches just 3′, or one tenth of the solar diameter (Fig. 1.11).

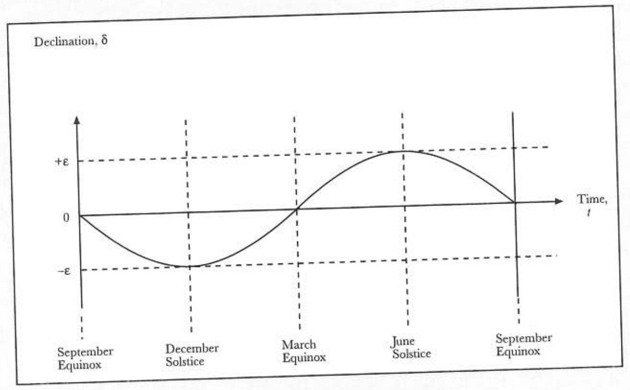


Fig. 1.10 The sun's annual variation in declination.

THE SUN'S SEMIDIAMETER

In any observations of high precision, it is not the centre of the solar disc that is likely to be important but its edges. If the declination of the centre of the sun at some moment is δ, then the declination of its 'upper limb'—that part of the sun that traces the upper (northerly) limit of its path through the sky—will be (δ + s), where s is the sun's semidiameter, approximately 16′. Similarly, the declination of its lower (southerly) limb will be (δ − s).[5]

In particular, the declinations of the sun's limbs at the solstices will be as given in the following table:

	Upper limb	Centre	Lower limb
Summer Solstice	$+(\varepsilon + s)$	$+\varepsilon$	$+(\varepsilon - s)$
Winter Solstice	$-(\varepsilon - s)$	$-\varepsilon$	$-(\varepsilon + s)$

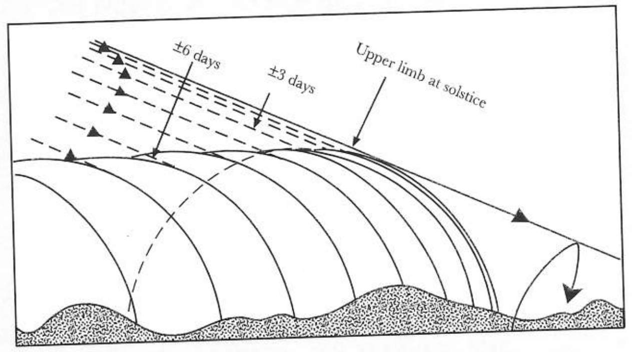


Fig. 1.11 A pictorial representation of the variation in the sun's declination on days close to the solstices, based on MacKie 1974, 172. Note that while the sun is shown each day with its centre on the horizon, sunset actually occurs when the upper limb disappears. The diagram shows the theoretical situation. In practice, the precise daily variation will depend upon factors such as the time of day at which the moment of solstice occurs. The apparent setting position may also vary from day to day by several arc minutes owing to variations in atmospheric conditions.

It is the upper limb that is involved when the tip of the sun just gleams behind the distant horizon, as is suggested by Thom at Ballochroy and Kintraw. Thus, for example, the bottom of the col between Beinn Shiantaidh and Beinn a'Chaolais as seen from the platform at Kintraw has a declination of −23°38′, corresponding to the upper limb of the setting sun when the declination of its centre is 16′ lower, i.e. −23°54′ (Fig. 1.14c).

THE SUN'S MOTIONS CLOSE TO A SOLSTICE AND THEIR DETECTABILITY

The difference between the sun's limiting declination at the exact solstice and at times t_1 and t_2, twenty-four hours before and after, is minuscule: only about 0′·2. If the sun sets just as it reaches its limiting declination then this value will represent the difference between

the declination at sunset on the solstice and that on the preceding and following days. In general, however, two sunsets will occur between t_1 and t_2. In this case the declination difference between the sunset nearest the solstice and the other that occurs within this period will be even less.

The maximum possible difference in declination between the sunset nearest the solstice and that two days earlier or later is still less than a single arc minute. Three days before and after the solstice the sun's declination still differs from its solstitial limit by at most 2′; by seven days this has risen to 11′. Only by twelve days before and after the solstice does the difference approach a whole solar diameter, although by five further days before and after the solstice the sun is two full diameters away from its solstitial position.

The extent of atmospheric refraction is dependent upon air temperature and pressure. From his own measurements Thom calculated that daily and seasonal variations in atmospheric conditions would lead to an uncertainty in apparent declination of at most one minute of arc.[6] Others, however, warned that the uncertainty could be rather greater.[7] More recent work indicates that variations in atmospheric conditions can alter the apparent declination of an observed low-altitude object in Britain or Ireland by several arc minutes, and possibly by as much as half a degree.[8]

The evidence available today suggests strongly that the effects of variable refraction make it impracticable to detect the small differences in the sun's motions for at least two or three days on either side of the solstice, and possibly for a considerably longer period.

about one hundred years of 1600 BC,[35] a date comfortably within the bounds of archaeological possibility for the row of standing stones.[36] But there are a number of problems.

One difficulty is that the line along the stone row is not well defined, because two of the stones are slabs oriented across it. The alignment might be taken to point anywhere within an azimuth range of some 10° or more, depending upon whether one lines up the left- or right-hand sides of the stones, the centroids, the tops, and so on. Certainly the mean alignment is well to the left of Thom's foresight,[37] much closer in fact to the prominent bump on the left-hand end of Cara Island. The right-hand end of this bump would form a suitable foresight—indeed, arguably a better one than that proposed by Thom, since it is at higher altitude and is more prominent—except for the fact that it is not close to the setting path of the solstitial sun. We have no *a priori* reason for supposing the stone row to have been indicating one potential foresight rather than the other; only the *a posteriori* argument that one is astronomically significant whereas the other is not.

Similar criticisms apply to the Corra Bheinn foresight. While stone *b* indicates the hill slope in question, stone *c*, whose faces are equally flat, indicates a different hill slope that is without solar significance.[38] The wide face of stone *b* is not perfectly flat, and the stone may well have shifted somewhat since prehistoric times, so that it is impossible to say exactly which part of the slope of Corra Bheinn (if any) was intended; the slope is not quite parallel to the setting sun's path, so that the exact declination obtained depends upon which part is selected.[39]

There are also difficulties on archaeological grounds. It was pointed out in 1974 that the cist, which is on the line of sight to midwinter sunset, would almost certainly have been covered by a large cairn, and this would have obscured the view of Cara Island.[40] While we have no direct evidence on the relative chronology of the cairn and standing stones at Ballochroy, we can rule out archaeologically the possibility that such a cairn would have been constructed much later than the mid-second millennium BC; if anything, it is more likely that it predated by several centuries the astronomical date obtained for the standing stones on the assumption that the high-precision foresights were intentional.[41] Perhaps inevitably, the suggestion was then made that the cairn might have been destroyed in prehistoric times in order to permit the observations.[42] However, this idea is ruled out by a sketch of the site made by Edward Lhuyd around 1699[43] which clearly shows an alignment consisting not only of the three stones and the cairn (still erect) but also of two further, smaller cairns and a fourth standing stone. In summary, the Cara Island foresight appears to have been obscured throughout the assumed period of use, and furthermore the original monument was more extensive than what remains for us to see today, which casts further doubt upon interpretations based upon currently obvious features alone.

Taken as a whole, then, the evidence weighs overwhelmingly against the idea of there being intentional solstitial alignments of the high precision envisaged by Thom. Not that such a debate is ever finally settled: an astronomical enthusiast could, for example, always suggest that an observer in prehistoric times might have stood to one side of, or even on top of, the cairn to make midwinter sunset observations.[44] However, it is more plausible to suggest that the solstitial orientation, if deliberate, was of a much lower level of precision: an alignment of symbolic significance associated with the rituals of death and burial,[45] similar, in that respect, to Newgrange. The approximately solstitial orientation of one of the slabs set roughly at right angles to the alignment might well have arisen simply because the azimuths of midsummer and midwinter sunset happen to be roughly 90° apart at this latitude.[46]

Nonetheless the example of Ballochroy is a salutary one, serving to expose some of the dangers of embracing astronomical interpretations of orthostatic monuments too enthusiastically and uncritically.

KINTRAW: A SOLAR OBSERVATION PLATFORM?

An obvious response to the dangers just mentioned is to try to derive ways of testing astronomical hypotheses concerning prehistoric monuments. And an obvious way of attempting this is by archaeological means. The classic site in this context is

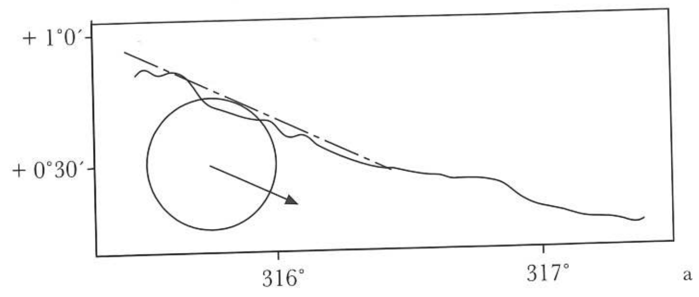
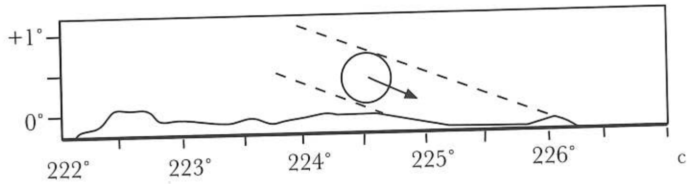
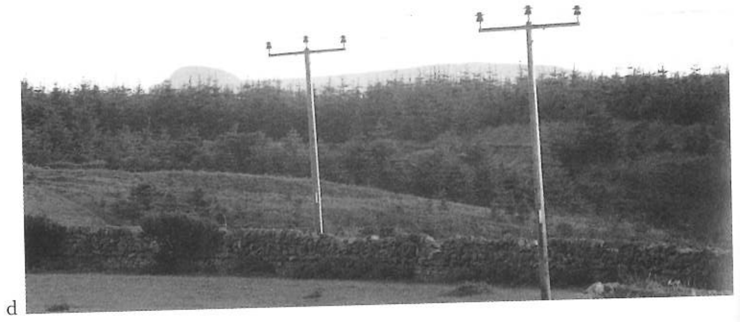


Fig. 1.12 The solar foresights at Ballochroy.
a. Corra Bheinn, Jura. The mountain is seen to the right of the two highest Paps in Fig. 1.5d. The drawing here shows midsummer sunset at around 1600 BC, after Bailey *et al.* 1975, fig. 2.
b–d. Cara Island. In photograph (b), note the remains of the cairn Carn Mor in the alignment. (c) shows midwinter sunset at around 1600 BC, after Bailey *et al.* 1975, fig. 1.





Kintraw (NM 831050).[47] Situated on a level terrace overlooking the head of Loch Craignish on the west coast of Argyll (Fig. 1.13), the most conspicuous feature here is a single, 4m-high standing stone, which can be clearly seen from the main A816 road as it winds steeply inland on its way south from Oban to Lochgilphead. Until 1978 this stone leaned at a noticeable angle; then, during the following spring, it finally fell over, and was subsequently re-erected in its original position as determined by excavation of the socket hole.[48] Flanking the standing stone are the remains of two cairns, excavated in 1959 and 1960.[49] To the north-west is an enclosure, possibly also prehistoric.[50]

The story of Kintraw is one of the best-known in the entire debate about 'megalithic astronomy'. The flat faces of the standing stone are roughly oriented upon the deep col between Beinn Shiantaidh and Beinn a'Chaolais on Jura, some 45km distant, which from this direction appears as a prominent V-shaped notch. The mountains form part of the Paps of Jura, the cluster of high mountains in the centre of the island that were also visible from Ballochroy, some 50km further south along the coast.

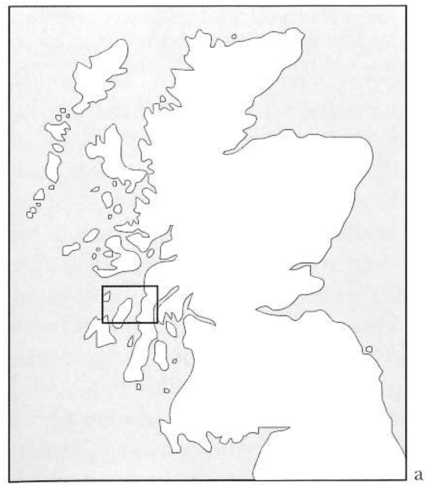
Unlike at Ballochroy, there is no question that this distant notch is the most prominent horizon feature in the direction concerned. The south-westerly orientation of the local topography draws the eye to the left along the Craignish peninsula on the opposite side of the Loch, out to where the Paps of Jura suddenly appear. Nor is there much doubt that the stone was closely aligned upon this notch, whether intentionally or not, since its current position and orientation are as close to the original as can be determined from the available archaeological evidence.

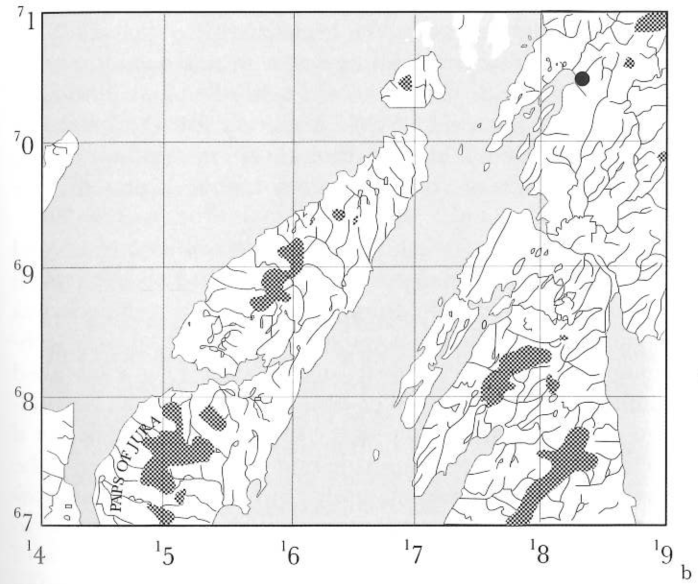
Thom obtained a declination of $-23°54'$ for the setting sun whose upper limb would briefly reappear in the col.[51] This value is exactly the same in magnitude as those obtained at Ballochroy, and corresponds to winter solstice within the first half of the second millennium BC.

There is just one problem. As viewed from the standing stone, the bottom of the col is obscured by an intervening ridge less than 2km away. In order to see it an observer would have to be raised off the ground by about 2m. Thom initially suggested that observers stood on one of the nearby cairns, which he assumed to have been level-topped.[52] But this left the problem of how they knew where to place the cairn, when they could not see the col from ground level.[53] Clearly it was more satisfactory to postulate a different observing position. If the standing stone was acting not as an indicator but as a 'backsight', to be lined up with the distant foresight, then possible observing positions might be found to the north-east. Unfortunately, the ground to the north-east of the standing stone runs level for about 80m and then falls steeply into a deep gorge.

The far side can best be reached by crossing the valley by the road bridge and then approaching from the north-west. This side of the valley is generally steep but it rises well above the level of the standing stone and cairns. When Thom first explored it he (actually, his granddaughter)[54] discovered a narrow ledge with a boulder at its edge at exactly the point where the standing stone and foresight were in line. Further up the hillside was another small stone that could have marked a position from which someone might have given an 'early warning' of the sun's reappearance in the col.[55]

The ledge, Thom now suggested,[56] was the intended observing position (Fig. 1.14), and he surmised that it represented the





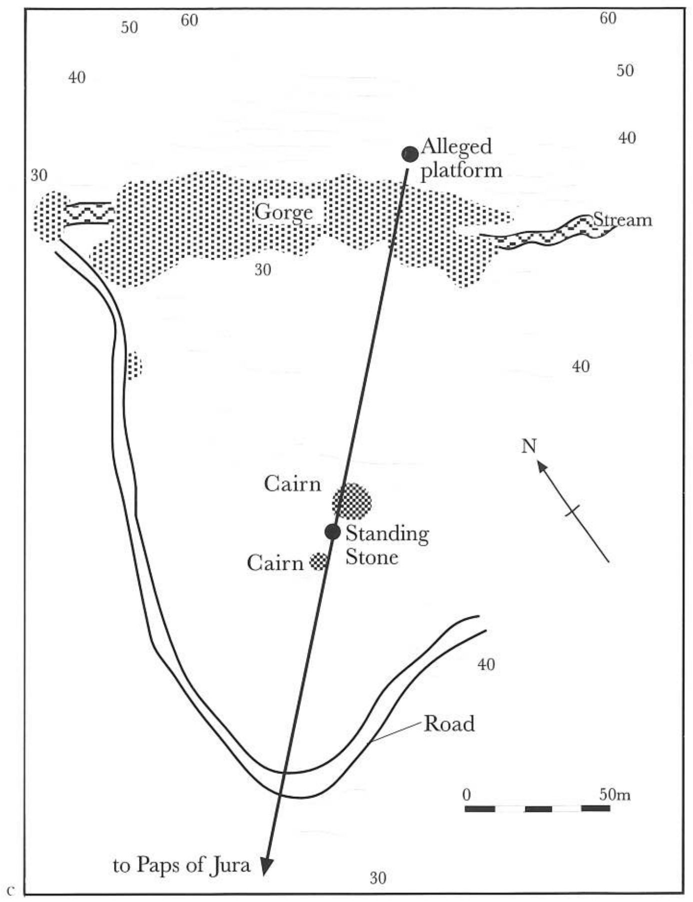
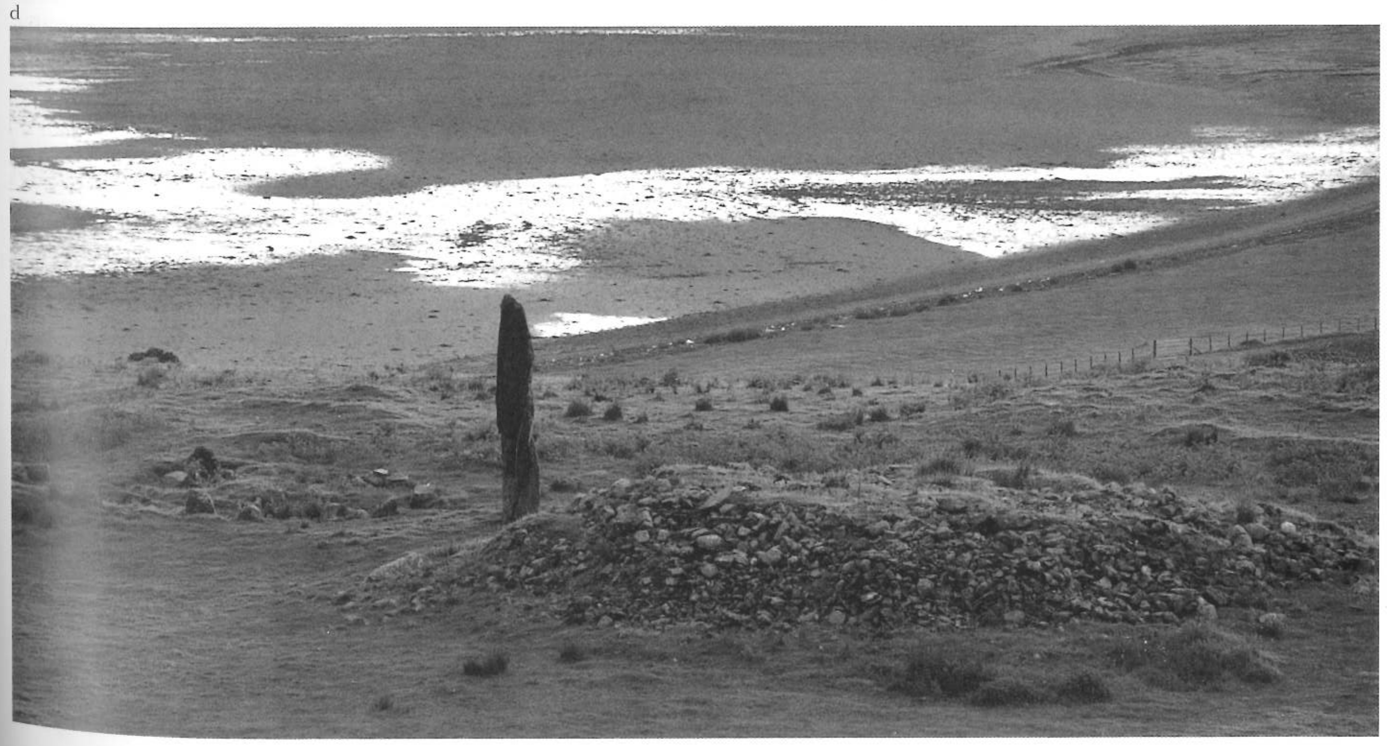


Fig. 1.13 Kintraw, Argyll.
a,b. Location of the monument.
c. Plan of the features near to the standing stone, based on MacKie 1974, 179 and RCAHMS 1988, 64. The road has subsequently been widened.
d. The standing stone and cairns from the east.



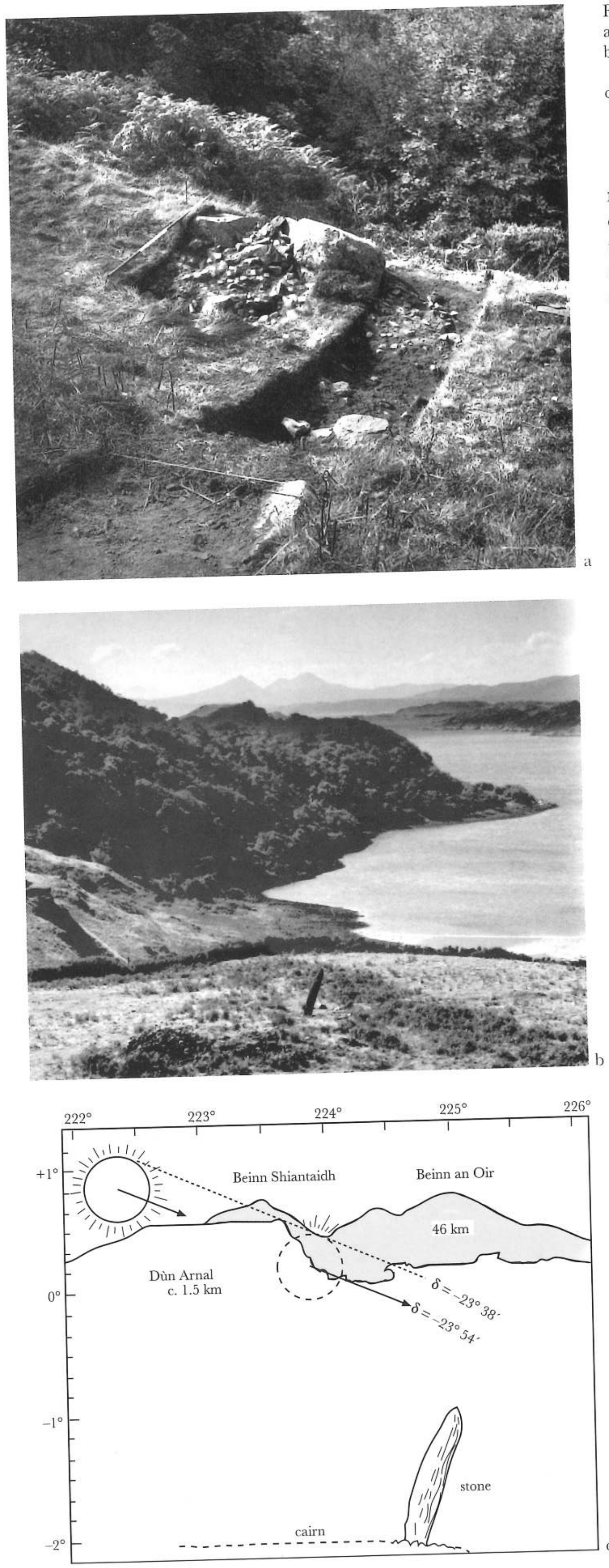


Fig. 1.14 The solstitial alignment at Kintraw.
a. The boulders and platform at Kintraw, during excavation.
b. The view from the platform at Kintraw (taken before 1978, when the standing stone was leaning).
c. Midsummer sunset at around 1800 BC as viewed from platform. The standing stone in the foreground is shown leaning, as it did prior to 1978. After MacKie 1974, 180.

remains of an artificially levelled platform. Euan MacKie recognised this as a unique opportunity to test, using standard techniques of archaeological excavation, a prediction following directly from the general idea of astronomical alignments upon distant natural foresights.[57] He duly excavated the platform in 1970 and 1971.[58]

Evidence that the platform was artificial would have given strong support to the astronomical interpretation of Kintraw.[59] Unfortunately, no direct trace of human activity was found there, whether in the form of flints, potsherds, postholes or charcoal. The boulder at the leading edge of the platform, however, was found to comprise two rocks lying end to end, their pointed ends just touching each other and forming a notch on the inner side. While it was possible that they had rolled down the hill and chanced to come to rest in contact, MacKie felt it more likely that they had been placed there deliberately.[60]

Covering the ledge behind these rocks was a compact and fairly level layer of small stones several centimetres thick. Such a layer could well have arisen naturally, so a technique was required to test whether it could be artificial. A suitable technique, known as petrofabric analysis, was long established within geomorphology.[61] The idea is that the overall distribution of orientation and dip of the stones would be different if such a platform were man-made from what would occur if the layer of stones had arisen naturally. By comparing the Kintraw distribution with various 'controls', it should be possible to decide whether the platform is artificial or not. An analysis of the orientation and dip of the long axes of the stones in the Kintraw platform was duly carried out.[62] On the basis of a visual examination of the results obtained, MacKie[63] argued that the distribution pattern of stones in the Kintraw stone layer appeared to resemble those found in other known artificial layers and not those found in natural ones. He concluded that this left 'little room for doubt that the stone layer behind the "boulder-notch" at Kintraw was made by man' and that Thom's interpretation was 'decisively vindicated'.[64]

Others disagreed. A major difficulty is the complete lack of human debris found during the excavation, which is very surprising if the platform was used as the astronomical theory supposes. A number of criticisms were also made of the way in which the petrofabric analysis had been carried out.[65] While MacKie responded forcefully to these criticisms,[66] he later conceded that, since no material was found to allow the platform to be dated, the evidence from Kintraw was inconclusive.[67]

Another doubt was cast upon the interpretation of the Kintraw ledge by the assertion[68] that the bottom of the distant col could not, in fact, quite be seen from the platform because the intervening ridge just obscures it. MacKie flatly denied this,[69] and indeed the present author has seen the notch from the platform; however a movement of less than 0·5 m from the centre of the platform made a crucial difference.[70] The disagreement may be accounted for by differences in eye height of different investigators, by differences in vegetation levels on the intervening ridge at different times of year, and perhaps most importantly by differences in weather conditions altering atmospheric refraction.[71]

This discussion leads one to ask why the solstice observations were not made from further back up the hillside in the first place,[72] either from the vicinity of Thom's 'early warning' stone or, even better, from higher up still, where 'the steep slope flattens out to a much more gentle crest where it is possible to walk or even run freely . . . without the risk of falling into the gorge, unlike the perilous situation on the "platform". More significantly there is a very scenic panoramic view of Loch Craignish and its islands with a *totally* unobscured view of the Paps of Jura.'[73] The answer is that as the observer's elevation rises, so the observed altitude of the distant notch decreases, necessitating a movement to the south-east in order to compensate. The hill-crest drops away sharply in this direction, and it is simply not possible to gain enough height to bring the foresight back into view beyond the intervening ridge.[74]

There would also have been severe difficulties in setting up the sightline in the first place. One method suggested by Thom is that an observer 'would seek by rapid movement across the line of sight to reduce the brilliant light to a point while the limb slid past the bottom of the notch',[75] but this would involve stepping rapidly sideways along a narrow path above a steep gorge. Another suggested method uses a row of observers:

> To those at the left the Sun would not reappear at all. The first man along the line to see the twinkle of light would be in the correct position, which would immediately be marked by a stake. If this process were repeated on several evenings around the time of the solstice the stake position would move first towards the right and then towards the left. The extreme right position would mark the day of the solstice.[76]

The problem here is that moving away from the platform along the ridge to the south-east (that is, to the left) causes the bottom of the col to disappear from view completely behind the intervening ridge.[77] As we have already noted, this difficulty can not be resolved by placing the row of observers further back up the hillside.

It is clear, then, that there are severe difficulties for the theory that Kintraw represented a high-precision solstitial sightline using the deep col in the Paps of Jura as a foresight. It is also clear that what promised to be an elegant and satisfying procedure—the archaeological verification of an astronomical hypothesis—has turned out in practice to be messy and inconclusive. This is not to say that the idea of such a verification is necessarily a bad thing, but rather that it has to be handled carefully within the context of many related questions such as how the astronomical hypothesis was arrived at, whether it was necessarily the best one to suggest on the evidence available before the test,[78] what other evidence bears upon the interpretation, and the extent to which that evidence is supportive or contradictory. In short, the integration of astronomical and archaeological evidence is a more complex process than it may seem at first.

BRAINPORT BAY: A CALENDRICAL COMPLEX?

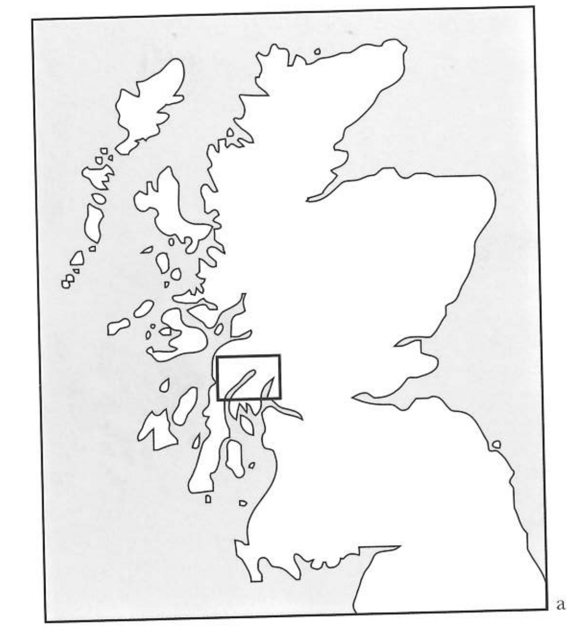
It is instructive to elaborate upon this theme in the context of another site that has attracted a good deal of astronomical attention: Brainport Bay, near Minard in Argyll (NR 976951).[79] Here, on the western shores of Loch Fyne, are man-made platforms, standing stones, cup-marked stones and several other features, most of which were discovered and investigated between the mid-1970s and mid-1980s (see Fig. 1.15).

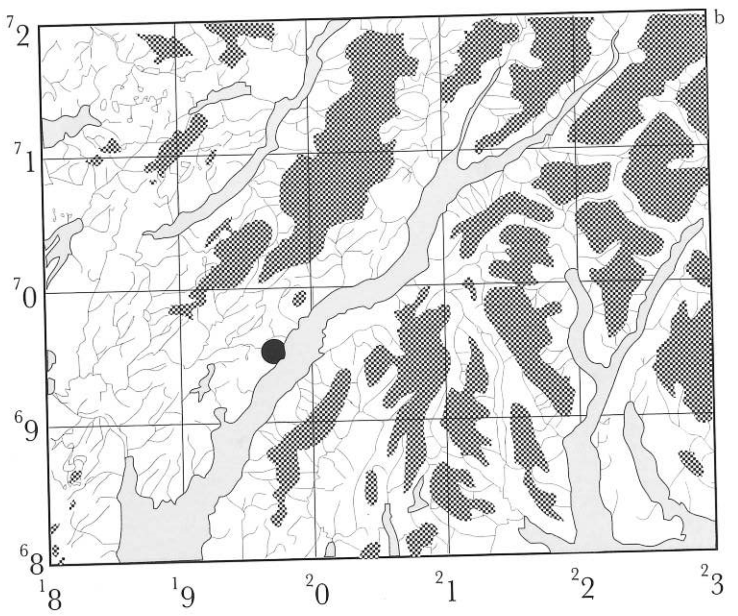
What is most striking about Brainport Bay is that a number of stone structures occur in a single NE–SW alignment. These were explored from 1976 onwards by Colonel P. Fane Gladwin and members of the mid-Argyll Archaeological Society.[80] At the south-west end, at an elevation of some 15 m, is the so-called *back platform and projection* (*A*), an area of natural outcrops that have apparently been converted into a platform by shaping and by infilling using small boulders and slabs of schist. Surface scatters of quartz chippings were found here. Some 60 m downhill to the north-east are two large boulders (*B*) oriented across the alignment, separated by a flat rubble surface about 0·5 m wide. The so-called *main platform* (*C*) starts some 10 m further again to the north-east, and extends for some 30 m to the north-east. It is a rocky outcrop up to 12 m in width (NW–SE), that has been modified and added to with paving and revetted platforms.[81]

At first, these features were thought to represent the remains of some kind of ancient settlement. However, there was a troublesome lack of any clear evidence of dwellings or midden deposits. Furthermore, a number of other features seemed without explanation. These included two socket holes—one (C_2) at the north-east end of the central, highest area of the platform, and the other (C_3) in a V-shaped cleft between two boulders at its south-west end—together with three small stone slabs between 1·1 m and 1·3 m long lying nearby on the surface, two of which appeared to fit well into the sockets.[82]

The idea that they were related to the distant horizon seems to provide a promising explanation of a number of otherwise anomalous features. The alignment (see *a* in Fig. 1.15e) is oriented to the north-east towards the only distant horizon visible from the site, at the far end of Loch Fyne. The rubble surface between the two large boulders at *B* provides an ideal position from which to view along the alignment to the north-east, the front stone being at a convenient height (1·6 m) to look over. From this vantage-point the rock outcrops of the main platform are silhouetted beneath the distant skyline, and the two small standing stones (as re-erected) appear, one behind the other, in the V-shaped cleft formed by the rocks on either side of the nearer stone (Fig. 1.16). Above the standing stones is a horizon notch formed by the junction between Beinn Dubhchraig and Beinn Oss, some 45 km distant. The dramatic effect of the two stones lining up upon the distant notch through a nearby cleft has been likened by Euan MacKie to the sights of a rifle barrel.[83]

MacKie, whose attention had been drawn to the site in 1976,[84] viewed midsummer sunrise from Brainport Bay in the following year, and the horizon was subsequently surveyed by Alexander Thom's son Archie. He determined that the upper limb of the sun rising with a declination of +23° 6′ would just





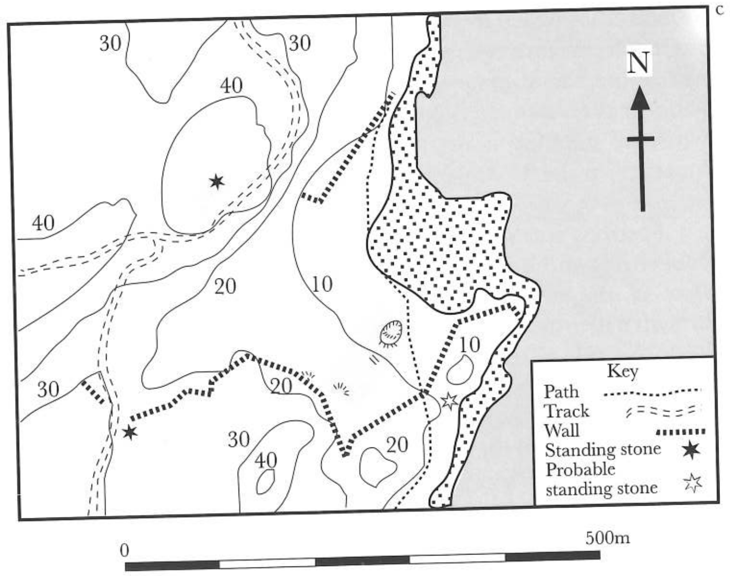


Fig. 1.15 Brainport Bay, Minard, Argyll.
a,b. Location of the site.
c. Overall plan of the site. After Fane Gladwin 1985, fig. 1. The shaded rectangles indicate the areas shown in more detail in Figs 1.15e and 1.17a.
d. The main alignment at Brainport Bay, viewed from the 'back platform'.
e. The main alignment at Brainport Bay, and features in the vicinity. Based on Fane Gladwin 1985, fig. 2; cf. RCAHMS 1988, 209. Scales and orientation are approximate.

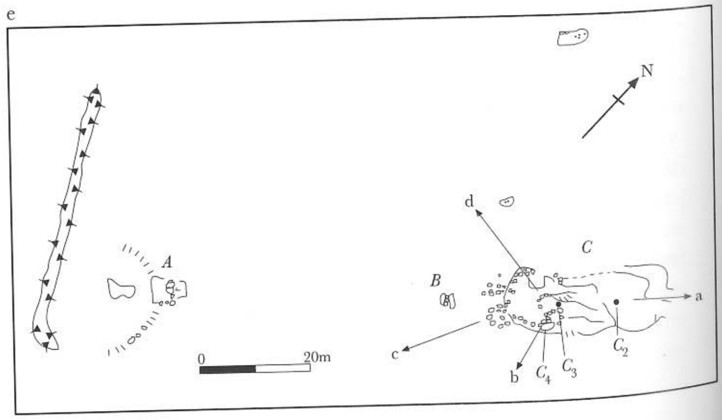
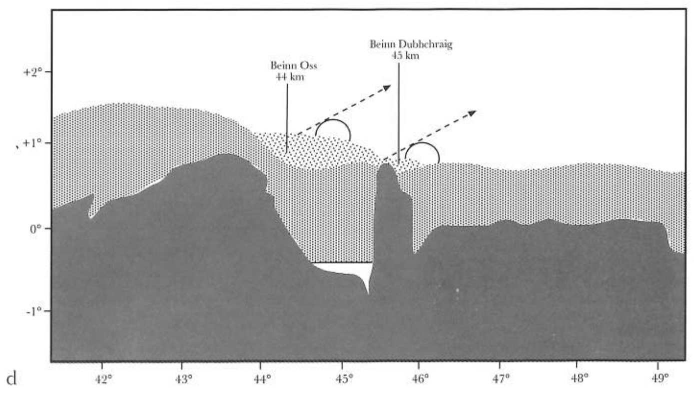


Fig. 1.16 The 'main platform' and solstitial alignment at Brainport Bay.
a. The 'observation boulders' viewed across the alignment from the south-east.
b. The 'main platform', with the two pointer stones as reconstructed, and the alignment to the north-east, as viewed from the 'observation boulders'.
c. Midsummer sunrise between Beinn Dubhchraig and Beinn Oss, as viewed today.
d. Sunrise at Brainport Bay in *c.* 1800 BC, at the solstice (left sun) and approximately fifteen days before and after (right sun). Based on Fane Gladwin 1985, fig. 4, cf. MacKie 1981, fig. 3.8.



appear in the notch. Unlike at Ballochroy and Kintraw, this does not correspond to the exact time of solstice, but some days before and after (about fifteen days in 1800 BC).[85]

As a candidate for an astronomical alignment, the linear features at Brainport Bay seem to compare very favourably with the ledge and standing stone at Kintraw. Unlike at Kintraw, the platforms here (although basically formed by natural outcrops) were indisputably paved, terraced and modified by man; in addition, flint flakes and artefacts and shattered quartz fragments were found on various parts of the site. Excavations in 1982 established a ^{14}C date from the back platform corresponding to the fourteenth century BC.[86] Furthermore the linear structures have no obvious function apart from indicating an alignment. Unlike any of the three sites so far discussed, there does not seem to be a funerary association: there are no cairns and no evidence of cremated bones. There are no artefacts or structures indicating domestic use, and no evidence of defensive structures.

However, the astronomical interpretation is not free from difficulties. If the 'rifle-barrel' effect is obtained from the two 'observation boulders' (*B*), what is the purpose of the back platform? While one can obtain a good general view of sunrise over the distant hills from here, it is no longer framed by the rock cleft in the main platform which, together with the standing stones, is a long way below the horizon. MacKie surmised at first that the back platform had a ceremonial function, where large numbers of people could have observed sunrise, with the precise indication of the horizon notch obtained from the observation boulders 'allowing the apparatus to function as an accurate calendrical instrument if needed'.[87] However a shock was in store. Later excavations showed that, contrary to earlier expectation, the two boulders had actually not been moved into place but were entirely natural.[88] It therefore had to be assumed that people in the second millennium BC made a chance discovery of a set of features already roughly oriented towards midsummer sunrise, and improved them. Furthermore, four radiocarbon assays obtained from the main platform yielded dates corresponding to the first millennium AD rather than the second millennium BC.[89]

There are two ways of interpreting the astronomical significance of the horizon foresight itself. The first is that the solstitial alignment was never used to obtain any great precision, so that the distant notch was irrelevant. The second is that the site was used as a precise solstitial marker, the notch being used to determine the solstice by the method of 'halving the difference'. The idea here is that, instead of attempting to pinpoint the exact solstice, people might have used a distant horizon notch to indicate the sun's position a few days earlier and later. This avoids the severe practical difficulties in pinpointing the exact solstice that were discussed in the context of Ballochroy and Kintraw: it is a good deal easier to indicate a day somewhat away from the solstice because the sun's daily movement is much greater (see Astronomy Box 3).[90] The exact date of the solstice could then be determined (retrospectively in the first instance) by counting the days between the pinpointed ones and halving the answer. This presupposes, of course, that it was important to determine the essentially unobservable event of the solstice itself;[91] and also has the pragmatic implication that people must have had some means of recording or remembering the required number of days from one year to the next.

A serious difficulty with the 'halving the difference' argument is the large number of distant horizon notches that can be seen from virtually any location in mountainous country. Picking such a location at random, there is only a relatively small chance that a fortuitous notch will be found exactly at a solstitial rising or setting position of the sun. However, the chances are appreciable of finding an acceptable notch within a degree or so in the appropriate direction from one of the extreme positions. Any such notch is susceptible to the 'halving the difference' argument, so that the mere presence of such a notch in the general direction of the alignment of features at a monument such as Brainport Bay does not constitute any sort of proof that it was used in this way by the people who occupied the site.

Such arguments, if they are to be properly followed through, need to be made more quantitative, and we shall encounter arguments about numerical probabilities shortly, in the context of Stonehenge. But a useful point can be made here. It is possible to formulate a convincing argument on practical grounds that if prehistoric people did precisely pinpoint the solstice at all, they almost certainly did it by using a precise horizon marker not at the solstice itself but close to it, and then 'halving the difference'. Not only was this easier than trying to distinguish tiny changes from one day to the next; it would also have given them a good deal more flexibility in choosing a suitable place from which to make the observations. But on the other hand, the abundance of suitable horizon features contrives to make it almost impossible for us to convince ourselves that any particular one was indeed used for the purpose of solar observations close to the solstice. Neither can we ever prove that it *wasn't* so used; the point is merely that on this subject, as in so many other matters relating to the activities of prehistoric people, the archaeological record (here taken in the broader sense to include the natural environment as well as material remains) is unable to speak to us clearly.

Perhaps the most striking thing about Brainport Bay (as opposed to Kintraw) is that we have platforms that were indisputably levelled by man, apparently in the mid-second millennium BC, although the picture is complicated by a range of activities on the site apparently stretching through to early historic times. The archaeological discoveries seem to indicate that this was not a domestic, defensive, industrial or funerary site, and hence perhaps one intended almost exclusively for ritual use. Furthermore, its situation where a striking distant horizon is seen to the north-east, roughly in the direction of midsummer sunrise, and the fact that several features are aligned in this direction, suggest that the solar connection did not go unnoticed and may well have been of considerable significance to the people who came here.

In trying to take the astronomical interpretation any further than this, however, things rapidly become more complex and fraught with problems. MacKie himself, acknowledging many of the difficulties in interpreting the main alignment, proceeded to place great emphasis upon subsequent discoveries in his efforts to demonstrate that Brainport Bay was a 'calendrical' site where the horizon sun was observed and marked with great precision. There are several further alignments. Fane Gladwin,[92] for example, lists three in the vicinity of the main alignment: one upon midwinter sunrise, one upon midwinter sunset and one upon sunset at the equinox (*b*, *c* and *d* in Fig. 1.15e). The first of these involves viewing the so-called 'pyramid stone' (C_1), a pointed-topped boulder 1·4 m high set in position on the south-east edge of the main platform, from the opposite side of the platform to the north-west. This stone, it is claimed, is sited at the only possible spot where an observer on the north-west side could look upwards from lower ground and align its tip with the high south-east skyline. From here it indicates midwinter sunrise.[93] However, the tip of the pyramid stone is aligned with the skyline from a range of positions to the north-west of the upper platform, not just a single spot. Choosing the optimum observing position to fit the astronomical theory is unconvincing without independent evidence since there is much room for manoeuvre. Similar problems attach to the other proposed alignments.

Upon a ridge some 240 m to the north-west of the main alignment is the so-called Oak Bank stone (*L*), a recumbent stone 3·4 m long which appears to have fallen from its south-east end (Fig. 1.17a).[94] If it did once stand it would have been plainly visible against the sky from the main outcrop. At first, it was thought to be a foresight for midsummer sunset, and a small platform was discovered at the required observing position, a few metres north of the main platform. However, to the disappointment of the excavator, excavation showed that activities at the platform were relatively modern.[95]

But all was not lost. Some 20 m south-east of the Oak Bank stone two outcrops were discovered with unusual carvings on their flat, upper surface in the form of a straight groove *c.* 0·5 m long with a cup mark at the centre (Fig. 1.17b). One of the grooves (*J* in Fig. 1.17a) is oriented at about 80°/260° and the other (*K*) at about 130°/310°. Some 35 m south-west of *L* is a further natural outcrop with a single cup mark (*N*). The first of the cup-and-groove marks was found to be oriented in the west (*e* in Fig. 1.17a) upon a small horizon notch in Siaradh Druim, about 1 km distant, yielding a declination very close to 0° and corresponding to sunset at the equinox.[96] The line from the Oak Bank stone to the cup-marked stone (*g*) indicates a horizon notch about 1·5 km distant. When its upper limb just appeared in this notch, the declination of the centre of the setting sun would have been −23° 51′,[97] very close to the figure obtained for the midwinter sunset alignments at Ballochroy and Kintraw.

These alignments seem impressive but the sceptic may still raise many doubts and objections. First, the notches in question are a mere 1 km and 1·5 km away from the observer. At such small distances changes in ground level and vegetation since prehistoric times may well be significant. Second, despite the astronomical importance attached to one of the two cup-and-groove marks, there does not seem to be any astronomical explanation for the other (*f*), which points to a featureless stretch of horizon well to the right of the midsummer sunset position.[98]

The significance of the cup-marked rock marking the solstitial alignment must be questioned on a number of grounds. We know that the notch in the approximate direction of midwinter sunset from the Oak Bank stone was identified during general forays to explore its calendrical potential, and that the cup

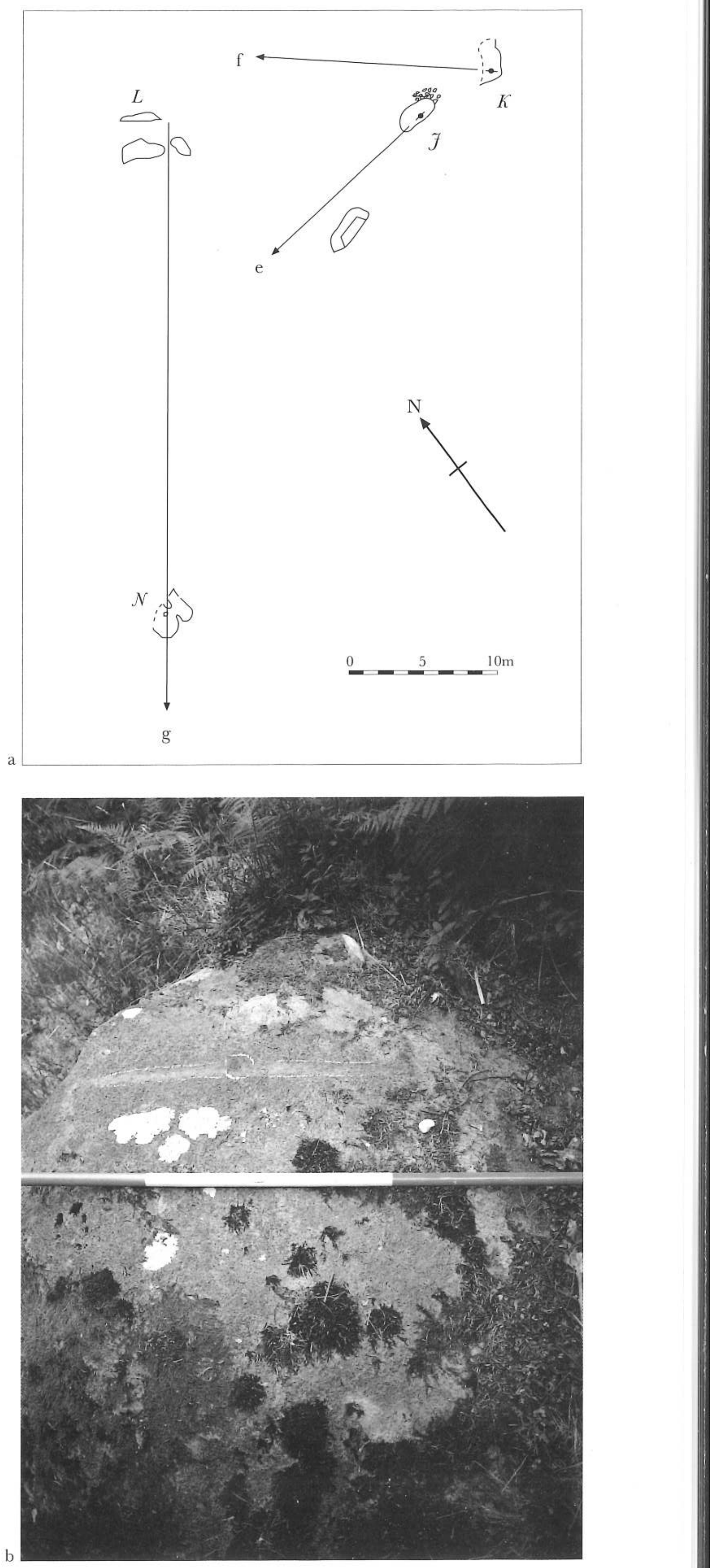


Fig. 1.17 The Oak Bank stone at Brainport Bay and associated solar alignments.

a. Features in the vicinity of the Oak Bank stone. Scales and orientation are approximate.

b. The cup-and-groove mark on stone *K*, emphasised using chalk, viewed from the north.

mark on stone *N* was discovered during a subsequent search along the alignment from the standing stone to the notch.[99] We have no idea how many equally prominent notches were ignored because they were in astronomically uninteresting directions, and how many other cup marks might be lurking unnoticed in the vicinity of the standing stone because they do not lie on astronomical sightlines and were not searched for.

A further problem is that there is no uniformity in the form of proposed horizon indicators: one is provided by the alignment from a standing stone to a cup mark on an outcrop, and the other by a cup-and-groove mark; furthermore, both are entirely different from the platforms, boulders and aligned pair of standing stones of the main alignment. While it would be unreasonable to expect that Bronze Age solar observers used exactly the same sort of device to indicate each alignment, it must nonetheless be acknowledged that the diversity of proposed methods of indication gives the present-day investigator a great deal of scope for assigning spurious astronomical explanations to chance alignments of archaeological features.

A final consideration about the possible astronomical significance of Brainport Bay concerns the nature and precision of the equinoctial alignment. Depending how it is determined, the declination of what is taken to be the equinoctial setting sun might be anywhere from $+0^\circ 8'$ to $+0^\circ 31'$ (for an explanation of this, see ahead to Astronomy Box 5). The declination of the sun setting with its upper limb in the Siaradh Druim notch at Brainport Bay is about $-0^\circ 7'$,[100] which is below the possible range. The Siaradh Druim notch can only be considered a precise indication of the equinox if 'the whole sun was observed in the notch instead of only the upper edge',[101] a proposal that seems to contradict the idea of using the upper limb to obtain great precision in the first place. Finally, there is a deeper problem in relation to supposed alignments upon the equinox, which is a concept not necessarily meaningful outside the Western scientific tradition (see chapter nine and Astronomy Box 8).

In short, it is difficult to agree that the evidence from Brainport Bay 'demonstrates to a high degree of probability that very long, potentially accurate [calendrical] alignments had . . . been devised'.[102] However, the example does serve to demonstrate some of the serious methodological pitfalls that can arise, even where, as in this case, an effort has been made to define a clear philosophical starting point.[103] In practice, the archaeological verification of an astronomical hypothesis has been turned into a cyclical process in which astronomical predictions are tested by directed fieldwork and excavation, then modified and re-tested, and so on. The general principle is fair enough; the problem is that while the archaeological evidence is allowed to modify the specific predictions, for example by adding more potential alignments, it is never allowed to influence the more fundamental hypothesis that Brainport Bay was a high-precision 'calendrical' site.[104] Thus, as contradictory data confront each suggested alignment, more are suggested in an attempt to bolster the calendrical idea, and the structure of 'supporting' evidence becomes steadily more cumbersome. Yet the increasingly attractive alternative, that the astronomy of the main alignment was of lower precision and all other alignments were fortuitous, is never considered. Instead, the idea of archaeological verification has been turned into mere *post hoc* justification, which in this case becomes less and less viable as the weight of evidence builds up against the hypothesis being proposed.

Le Grand Menhir Brisé: a universal lunar foresight?

We shall stray briefly outside Britain and Ireland in order to provide a further illustration of the dangers of *post hoc* justification. Although the Brittany megaliths fall outside the remit of this book they form part of a related tradition that has been extensively studied.[105] Undoubtedly its most spectacular manifestations are the magnificent rows of Carnac, the longest of which, Kermario, consists of seven rows of stones ranging from half a metre to over four metres in height and runs for over a kilometre.[106]

Thom, together with his son Archie and a team of willing helpers, spent many years examining the megalithic monuments of Carnac in detail. A monument that began to attract his special attention was a massive fallen stone known simply as Le Grand Menhir Brisé, the great broken menhir (Fig. 1.18a). Now broken into four pieces, it appears originally to have stood to a height of more than 20 m, and would thus have been the tallest standing stone in Brittany. It is not of local stone and the task of hauling it over 4 km to its present position must have been almost unimaginable.[107]

Over time, the Thoms developed the idea that this huge standing stone was a foresight against which the rising or setting moon could be viewed from a number of different directions.[108] Their fieldwork established that suitable 'backsights' existed at observing positions from which the great menhir could be used to mark each of the eight principal limiting rising or setting positions of the moon (Fig. 1.18b).

The eight horizon positions arise because the motions of the moon are more complex than those of the sun. The moon's declination, like the sun's, varies cyclically between northerly and southerly limits, but on a timescale of a month rather than a year. Added to this, over a longer timescale—on a cycle of roughly 18·6 years—the limits themselves vary. The result is that during every nineteenth year the rising or setting position of the moon sweeps between monthly limits several degrees wider than the annual (solstitial) limits of the sun—these we shall refer to as the 'major limits' or 'major standstill limits'—whereas between nine and ten years later it only moves between narrow limits several degrees inside the annual sweep of the sun—these we shall refer to as the 'minor limits' or 'minor standstill limits'. For a more detailed explanation see Astronomy Box 4. The major limits represent the furthest positions to the north and south ever reachable by the moon. Fig. 1.20 shows schematically the directions of the solstices and the major and minor lunar limits from a location with a level horizon somewhere within Britain or Ireland; the exact azimuths are dependent upon the latitude and horizon altitude.

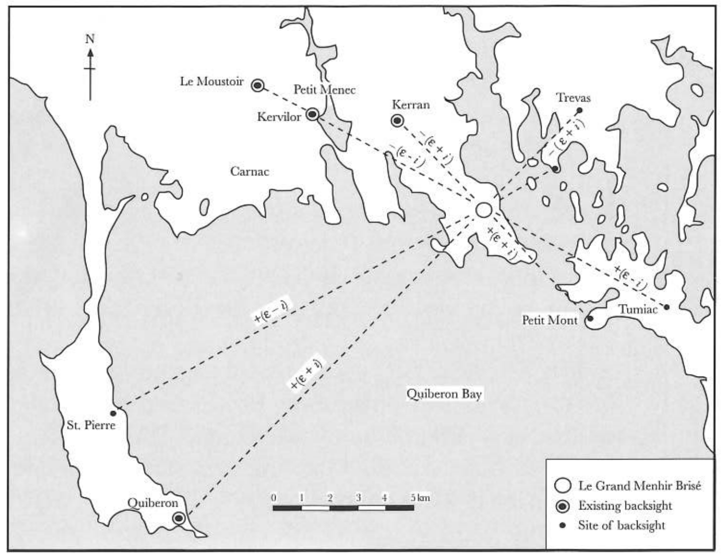
The eight rising and setting positions of the moon at its major and minor limits were considered to be significant by Thom. At first sight, the existence of suitable backsights in all eight directions from Le Grand Menhir Brisé seems very impressive indeed. But we must ask a crucial question: how confident can we be that the putative backsights identified by Thom and his team were actually intended as such? We know how the team went about locating candidates for backsights:

Fig. 1.18 Le Grand Menhir Brisé in Brittany.
a. View of the great menhir from the south-east.
b. The great menhir as universal lunar foresight with eight proposed backsights. After Thom and Thom 1971, fig. 2.

a

they identified the eight lines radiating out from the great menhir upon which such backsights would have to lie and examined what could be found along those lines.[109] Such an approach has an evident danger. The area around the great menhir contains the densest concentration of dolmens and standing stones in the whole of Europe,[110] so one would surely encounter features at least as promising in a great many different directions.[111] It would strengthen the argument in favour of the astronomical interpretation if the putative backsights formed a coherent set of structures archaeologically. They do not. On the contrary: the backsights turn out to be a diverse collection of stones, many of which are small and of doubtful prehistoric provenance: they include several boulders that are certainly natural and one cairn probably built a millennium later in the Iron Age.[112] Finally, there is considerable doubt as to whether the great menhir itself ever actually stood at all: it is possible that it broke during the process of erection.[113]

The lesson to be learned from this is that having developed a particular idea—in this case the notion that the great menhir might have functioned as a universal lunar foresight—a major aim of the original research design should have been to scrutinise that idea as thoroughly, and as pitilessly, as possible in the light of data that could be obtained in the field. An approach which involves walking out along alignments looking for potential backsights, failing to examine other evidence concerning the nature of the features encountered, and ignoring the likelihood of picking up similar features elsewhere, singularly fails to do this. If we are to have any hope of providing meaningful tests of our ideas, and hence of progressing those ideas while keeping them fully in tune with the evidence, then at the very least we must strive to collect and examine our evidence fairly, facing what is contradictory as well as what is confirmatory, coping with the negative as well as the positive.



b

An important aspect of this process, and one that we have already encountered in passing,[114] can be to estimate probabilities (see Statistics Box 1). The questions may be specific—what is the probability that the Newgrange solstice phenomenon could have arisen through factors quite unrelated to astronomy?; what is the probability that eight putative lunar backsights for Le Grand Menhir Brisé could have arisen fortuitously?—but the general aim is always the same: to assess the degree to which the available data lend support to a given idea. The formulation of probability estimates has arisen in discussions of a number of 'classic' astronomical sites, but nowhere more prominently than at Stonehenge itself, to which we shall now turn.

Stonehenge: the astronomer's dream?

Stonehenge (SU 122422) is a monument of considerable complexity. What we see there now (Fig. 1.21) is the cumulative result of a series of constructions and modifications on the same spot spanning as much as fifteen hundred years,[115] as they have survived after a further three and a half millennia. A basic (relative) chronology of the different features at the site was established by Richard Atkinson following his excavations during the 1950s,[116] although more recent investigations and reinterpretations have influenced the picture and the radiocarbon revolution has shifted the absolute dates.[117]

ASTRONOMY BOX 4

THE MOTIONS OF THE MOON, 1: LUNISTICES, STANDSTILLS, AND LIMITING DECLINATIONS

Just as the declination of the centre of the sun varies annually between limits of $\pm\varepsilon$, which it reaches at the solstices (Astronomy Box 3), so that of the moon varies also. In the case of the moon, however, the cycle takes only a month,[1] not a year. Furthermore, there is a complication: the most northerly and southerly declinations reached at the monthly 'lunistices'[2] are not constant from month to month, but themselves vary, over a period of some 18·61 years. The general way in which the moon's declination varies over this longer cycle, which we shall refer to as the lunar node cycle,[3] is shown in Fig. 1.19.

At one stage in each node cycle, the moon travels significantly further north and south each month than the sun does each year. Over a period lasting for about a year, the moon's declination at each lunistice comes close to theoretical outer limits given by $\pm(\varepsilon + i) - P$, where i has the value 5°·15.[4] The amplitude of the monthly oscillation then begins to decrease until, some nine years later, its limits are well within the annual limits of the sun, so that the moon never ventures outside the declination limits $\pm(\varepsilon - i) - P$.

P is a factor that has to be subtracted because of lunar parallax (see Astronomy Box 2) and has a value of around 0°·85 in Britain and Ireland.[5] Thus, for these latitudes in around 3000 BC, the widest monthly declination limits were approximately +28°·3 and −30°·1 while the narrowest were about +18°·0 and −19°·7.

Terminology, and some misunderstandings

The time when the monthly swing of the moon's motions is at its widest is often, following Thom,[6] referred to as the 'major standstill'. Similarly, the time when the swing is at its narrowest is known as the 'minor standstill'. The term is convenient but misleading because the moon in no sense ever stands still. What reaches a maximum or minimum is a theoretical curve: the curve marked by a dashed line in Fig. 1.19b. The moon itself never ceases to hurry backwards and forwards between its monthly declination limits in the north and south.

Often the term 'standstill' is used more loosely, to refer to the limiting declinations themselves, which can cause confusion.[7] Other authors refer to the 'major moon' and 'minor moon'[8] or the 'maximum moon' and 'minimum moon'.[9] The declinations $\pm(\varepsilon + i) - P$ and $\pm(\varepsilon - i) - P$ are sometimes referred to respectively as the 'outer extremes' and 'inner extremes'.[10] This is misleading, at least in the case of the inner extremes, since they are not extreme in any sense; away from the minor standstill the moon passes each of these declinations twice every month.

In this book we attempt to avoid some of the confusion and overtones by using the term 'major standstill limits', or just 'major limits', to refer to the declinations $\pm(\varepsilon + i) - P$ and 'minor standstill limits', or just 'minor limits', for $\pm(\varepsilon - i) - P$. We can then refer, for example, to the moon setting at its northern major limit $[+(\varepsilon + i) - P]$, although when, if ever, it does so within a given lunar node cycle is another matter. It will only set exactly at its northern major limit if the northern lunistice coincides with the major standstill (which can occur at any time in the month), *and* if the time of setting coincides with the lunistice (which can occur at any time of day). There are also practical difficulties and, for higher-precision observations, further complicating factors, which will be discussed in Astronomy Box 7.

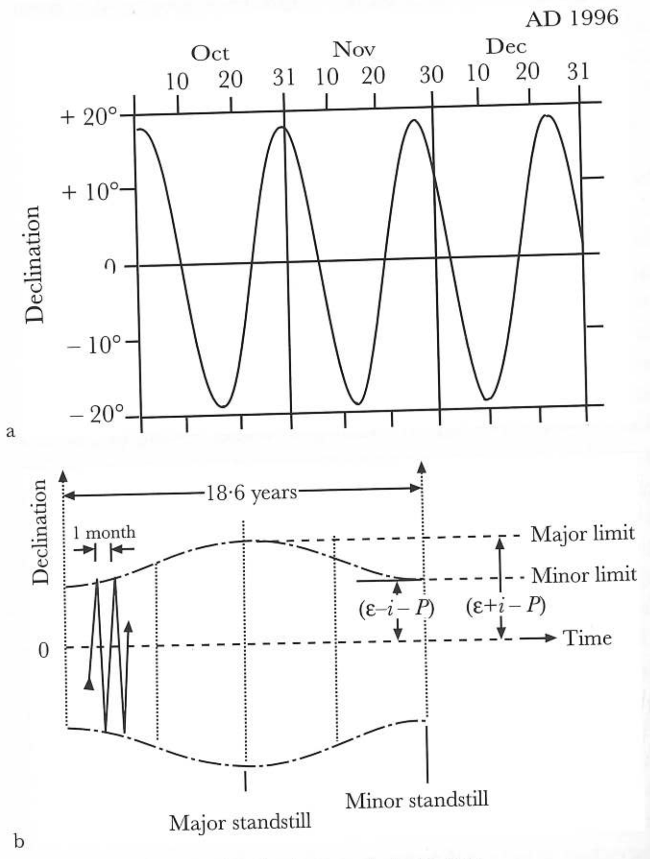


Fig. 1.19 The variations in the moon's declination.
a. The moon's monthly variation in declination (around the time of minor standstill). Adapted from Thom 1967, fig. 3.5b.
b. The form of the variation over a lunar node cycle. The solid line represents the actual path of the moon. The major and minor limits are *declinations*; the major and minor standstills are *times* (see text). Adapted from Thom 1971, fig. 2.2 and Ruggles 1997, fig. 1b.

Directions of possible lunar significance

From any location in Britain or Ireland or at lower latitudes, the points where the major and minor limiting declinations intersect the horizon define eight directions which have often been considered to be of possible significance in the interpretation of alignments of prehistoric monuments in Britain and Ireland. They are illustrated schematically, along with the directions of solstitial sunrise and sunset, in Fig. 1.20.

Exceptions to this rule are locations, particularly in northern Britain, where the southern horizon is so high that the moon will stay below it when close to its southern major limit. An example is Ardnacross on Mull, discussed in chapter seven. At latitudes much above 61° (northern Shetland) the moon stays above the horizon when close to its northern major limit unless there is a high horizon in the north.

Observations of the lunar limbs

The position of the upper or lower limb of the moon as it intersects the horizon can be directly observed, whereas the position of its centre can only be judged. Thus, if we are interested in the idea that lunar observations were made to reasonably high precision, we should consider the possibility that the declinations of the upper or lower limb, rather than the centre, were marked. The various configurations may be summarised as follows, where s is the moon's semidiameter:[11]

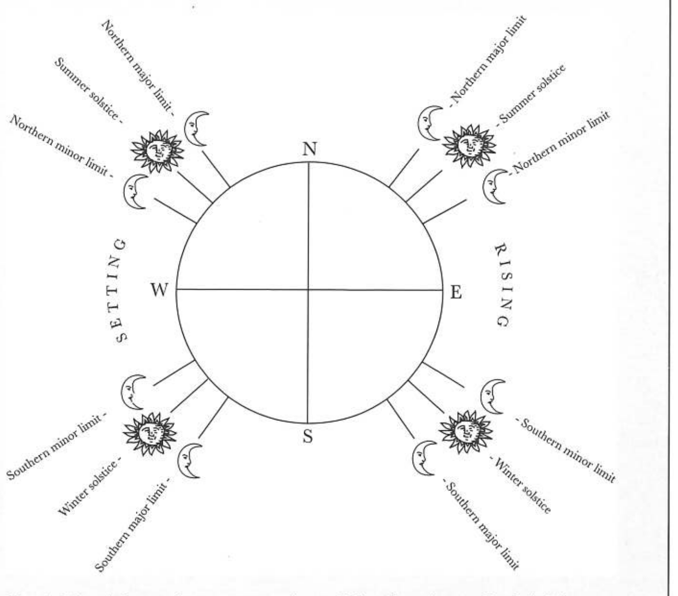


Fig. 1.20 Schematic representation of the directions of solstitial sunrise and sunset together with the major and minor lunar limits for a level horizon at a location in Britain or Ireland. Over the year, the sun rises and sets respectively within the eastern and western horizon arcs delimited by the solstices. Around the time of major standstill, which occurs every 18·6 years, the moon rises and sets within wider arcs delimited by the major limits, moving between these limits and back again once every month. Around minor standstill, mid-way between these times, the rising and setting positions are confined to the arcs between the minor limits. First published as Ruggles 1997, fig. 1a.

	Upper limb	Centre	Lower limb
Northern major limit	$+(\varepsilon + i + s) - P$	$+(\varepsilon + i) - P$	$+(\varepsilon + i - s) - P$
Northern minor limit	$+(\varepsilon - i + s) - P$	$+(\varepsilon - i) - P$	$+(\varepsilon - i - s) - P$
Southern minor limit	$-(\varepsilon - i - s) - P$	$-(\varepsilon - i) - P$	$-(\varepsilon - i + s) - P$
Southern major limit	$-(\varepsilon + i - s) - P$	$-(\varepsilon + i) - P$	$-(\varepsilon + i + s) - P$

For the actual declination values see Astronomy Box 6.

Broadly speaking, Stonehenge 1 was a circular ditch and bank erected in an already well-used landscape around or a little after 3000 BC. The circle of 56 Aubrey Holes was probably (but not certainly) dug inside it at about this time and probably (but not certainly) held a ring of timber posts. Stonehenge 2, around 2900 to 2550 BC, marks a change in emphasis towards timber structures: complex patterns of postholes are found in the interior, as is an enigmatic grid-like formation in the north-east entrance, while the ditch and Aubrey Holes (now without posts) were generally left alone. Later, cremation burials were placed in many of the Aubrey Holes, as well as in the ditch, on the bank, and around the outside of the monument, and parts of the ditch were deliberately backfilled. In broad terms, Stonehenge 1 and 2 replace Atkinson's 'Stonehenge I'.

Stonehenge 3, which broadly replaces Atkinson's 'Stonehenge II' and 'Stonehenge III' and starts around 2550 BC, marks fresh activity on a much grander scale: the arrival of the bluestones and, probably at much the same time, the erection of the Heel Stone and a companion outside the entrance, and

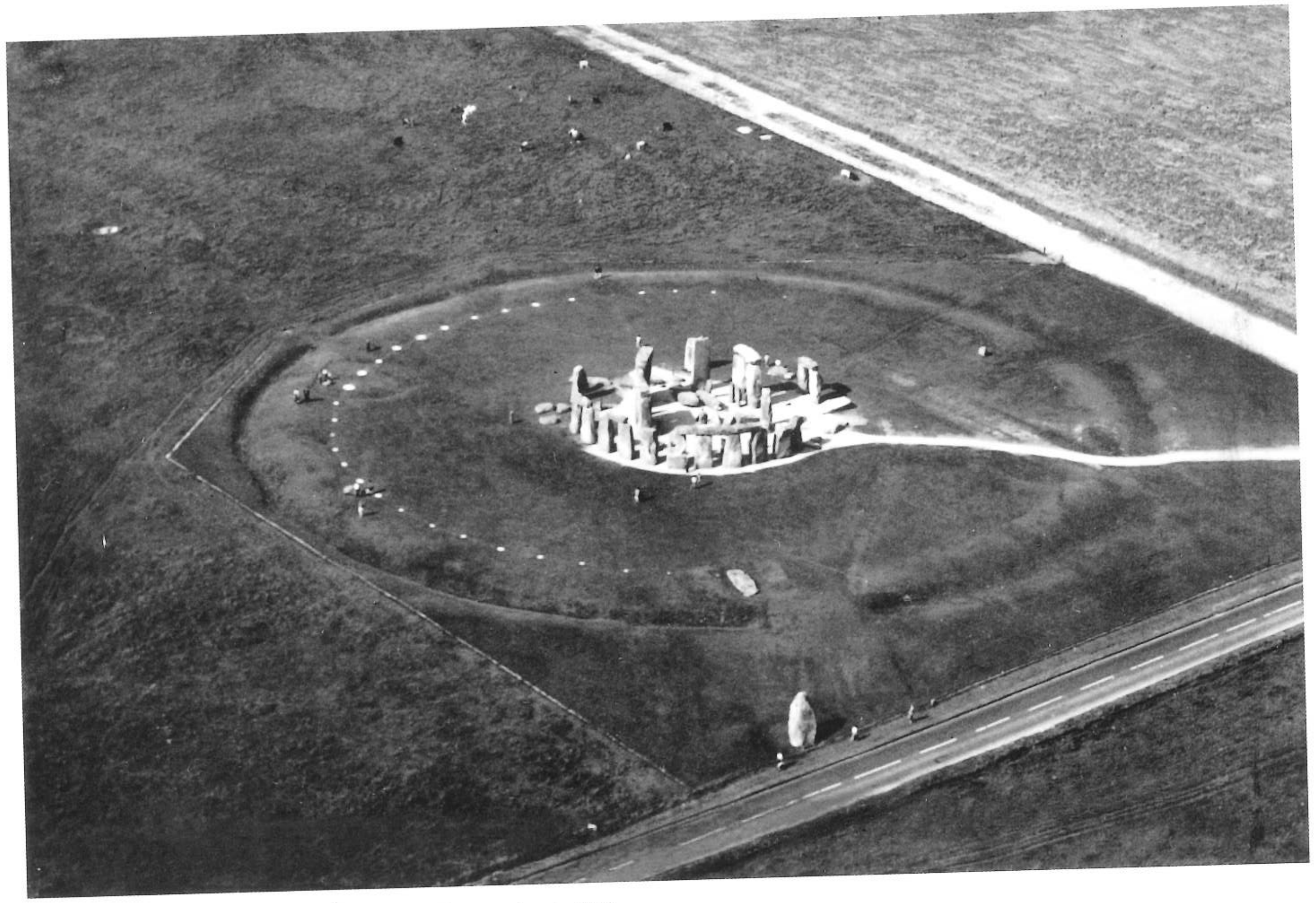


Fig. 1.21 Aerial view of Stonehenge from the north-east, taken in 1963.

the construction of the Station Stone rectangle. About a century later, the giant uprights and lintels of sarsen stone were hauled to the site, carefully dressed, and erected to form the famous circle and horseshoe. Three large unlintelled sarsens were placed across the entrance, possibly at this time also. During the centuries that followed, some of the bluestones were dressed and set first into one position and then another, and a 2·5 km-long avenue was constructed linking the site to the River Avon. The site finally fell into disuse around 1600 BC. For further details see Archaeology Box 3.[118]

The various astronomical ideas associated with Stonehenge are extensive and it would serve no useful purpose to go through them all in great detail here.[119] However, a number of useful general principles can be illustrated by examining some of the arguments and counter-arguments relating to astronomy at Stonehenge.

A recurring theme in these arguments is the position of the Heel Stone. Despite persistent popular belief, it did not provide an exact marker of sunrise on the longest day of the year. It is not in the correct position: as viewed from the vicinity of the geometrical centre of the sarsen circle, the first gleam of the solstitial sun appears well to its left, only moving into line as the sun rises further and moves to the right. In the third millennium BC the sun would have risen even further to the left and been well clear of the horizon before it aligned with the Heel Stone.[120] In any case, an alignment of this nature could never achieve the required precision. This is because the distant horizon is flat, devoid of any natural reference point of the kind discussed in relation to Ballochroy and Kintraw. Instead, the Heel Stone must itself be used as foresight; but since it is only some 75 m distant from the observer, the observing position to be used from one day to the next would need to be specified to within a mere one or two centimetres, less than the distance from one eye to the other.[121] While it has been suggested that the Heel Stone might have served to determine the solstice exactly by a process of halving the difference, even this would have required an observing position precise to 10 cm or so.[122] In general, astronomical observations of the high precision needed to pinpoint a solstice, whether by direct observation or by halving the difference, require a suitably distant foresight. The closer the foresight, the smaller the room for manoeuvre at the observing position.[123]

Hawkins famously claimed that the phenomenon of midsummer sunrise over the Heel Stone was not isolated but merely one of several dozen astronomical alignments incorporated in the architectural design of Stonehenge at different stages in its construction. Working with his interpretation of Atkinson's chronology, Hawkins claimed that Stonehenge I contained no fewer than twenty-four putative alignments upon horizon solar and lunar targets such as the solstices and major and minor limits, marked by pairs of stones and stoneholes and by the directions of stones and stoneholes from the centre of the site (cf. Fig. 1.22a).[124] The probability of this happening fortuitously, Hawkins estimated, was only about six in a million.[125]

STATISTICS BOX 1

PROBABILITY AND ODDS

Terms such as 'probability', 'chance', and 'likelihood', although widely used informally in everyday language—usage that is not avoided in this book—have particular meanings when applied in a formal (mathematical) context. This and subsequent boxes will attempt to elaborate these meanings as far is necessary for a full understanding of the wider arguments being discussed.

Fundamental to many of these arguments is the notion of probability. This is a more complex concept than may appear at first, and one which can be approached in a number of ways and from different philosophical standpoints.[1] The explanation below is intended to be sufficient for most of the discussions in this book. For a different view see Statistics Box 7.

THE CONCEPT OF PROBABILITY

The concept of probability is often conceived through the analogy of a repeated trial or experiment. Suppose that a fair, six-sided die is thrown over and over again a very large number of times, perhaps thousands of times or more, and the results noted. In what proportion of the throws was the result a six? It will be found that the answer is almost exactly one sixth of the throws. If the number of throws is increased to millions the result will be incredibly close to—to most intents and purposes, exactly—$^1/_6$.

The question 'What is the probability that a single throw of the die will yield a "6"?' can be conceived as equivalent to the question 'If I throw the die a very large number of times indeed, in what proportion of throws will the result be a six?'. The answer, then, is $^1/_6$, or 0·1667. Similarly, the probability of throwing a four is also $^1/_6$; the probability of throwing a number greater than three is $^1/_2$. If something is impossible, it will occur with probability 0.[2] If something must happen, it will occur with probability 1. The probability of throwing a number between one and six inclusive is 1; the probability of throwing a seven is 0.

The notation P(*A*) is generally used to denote the probability of event *A*. Thus if *A* is the 'event' that the next throw of a die will yield a six, $P(A) = {}^1/_6$.[3]

The probability of an event such as throwing a six with a die is independent of what has gone before. Even if a six has already been thrown six times in a row, the probability of it happening again is still $^1/_6$ (always assuming the die is not a loaded one). The probability of two independent events both occurring is obtained by multiplying together their individual probabilities: thus, the probability of throwing a 6 twice in a row is $^1/_6 \times {}^1/_6$, or $^1/_{36}$. The general rule is

$$P(A \& B) = P(A) \times P(B) \qquad \ldots (S1.1)$$

where *A* and *B* are independent. It extends to any number of events *A*, *B*, *C*, etc. provided they are all independent of one another.

ODDS

Some people prefer to think in terms of odds rather than probabilities. Suppose that the odds of 'Astronomer's Apprentice' winning the 4.30 race at Ascot are 10 to 1 against. This means that if I place a bet of £1 on the horse, I will win £10 (plus getting my stake of £1 back) if it wins the race. If the bookmaker's odds are a fair reflection of the probability of the horse winning the race, then if it were possible to run the race over and over again very many times, I would eventually break even. In what proportion of races does the horse need to win so that this is the case?

The answer is not one race in every ten, as might be expected, but one race in every eleven. In this case, for every expenditure of 11 × £1, I will receive one bounty of £11 (£10 winnings + £1 stake). Thus, odds of 10 to 1 against correspond to a probability of $^1/_{11}$. Similarly, odds of 100 to 1 against correspond to a probability of $^1/_{101}$.

In general, odds of *n* to 1 against correspond to a probability of $1/(n+1)$ and vice versa. 'Evens' (odds of 1 to 1) correspond to a probability of $^1/_2$ or 0·5. Odds of '*m* to 1 on' are equivalent to 1 to *m* against, and hence correspond to a probability of $1/((1/m)+1) = m/(1+m)$. Thus odds of 6 to 4 on (= 1·5 to 1 on) correspond to a probability of $^{1\cdot5}/_{2\cdot5} = 0\cdot6$.

'THE CHANCES ARE . . .'

When people say that the chances of something happening are 68%, they tend to mean that the probability of that something happening is 0·68. However, to say 'there is one chance in three' of something happening is more ambiguous: it may be interpreted as 'the probability of that thing happening is $^1/_3$' or as 'the odds against that thing happening are 3 to 1' (i.e. the probability of it happening is $^1/_4$). The difference between these two possibilities for the statement 'there is one chance in *n*' may be negligible if *n* is large, but clearly for small *n* it can be very significant. It is best simply to avoid this turn of phrase where a quantitative argument depends on it.

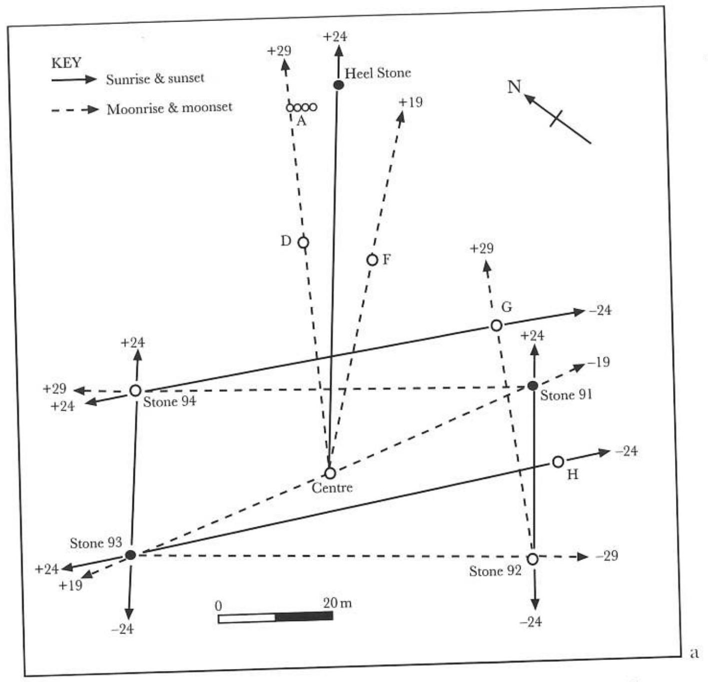
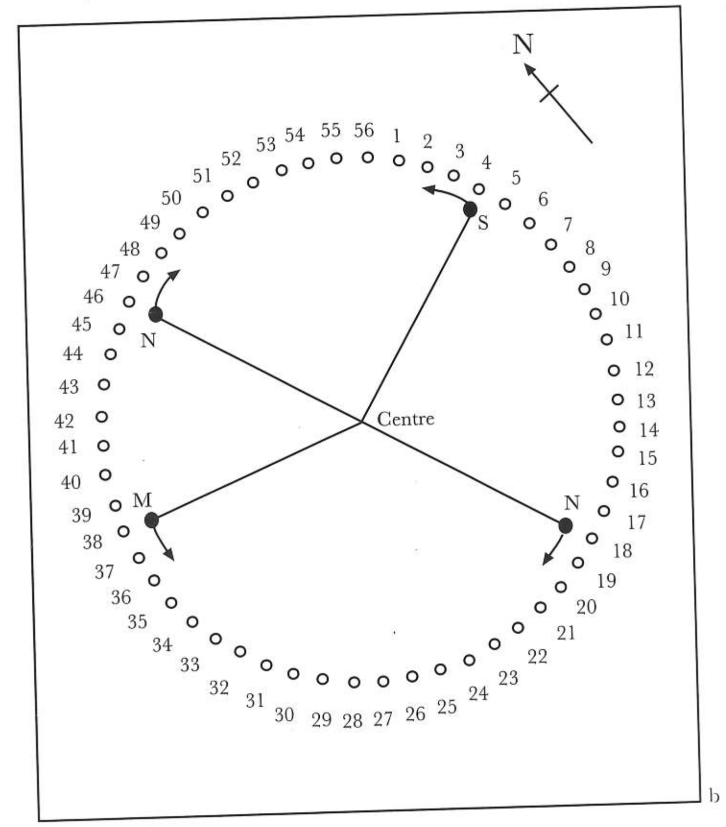


Fig. 1.22 Hawkins's and Hoyle's interpretations of what they took to be 'Stonehenge I'.
a. Some of Hawkins's alignments between pairs of stones and stoneholes. After Hawkins and White 1970, fig. 11. The full set of alignments discussed in the text is shown in *ibid.*, fig. 14.
b. Hoyle's scheme for eclipse prediction using the Aubrey Holes. After Hoyle 1977, fig. 5.1.



There were, however, three fundamental flaws in Hawkins's calculations, and when these are corrected, the probability of chance occurrence increases to better than evens (Statistics Box 2). The probability calculation is further undermined by the fact that the data are non-independent,[126] by the lack of *a priori* justification for the points chosen in the first place,[127] and by archaeological doubts about some of those that were.[128] To cap it all, some of the chosen targets make no sense astronomically.[129]

Another notorious idea worthy of mention is that the 56 Aubrey Holes could have been used to predict eclipses, by moving stakes or stones around the holes according to given rules and noting when they reach certain significant configurations (see Fig. 1.22b).[130] This raises questions of how such elaborate devices could have been set up without extensive record-keeping, for which there is no independent evidence.[131] There is also the fact that as eclipse predictors (as opposed to mere predictors of periods when eclipses definitely could *not* occur) they would have been highly unreliable,[132] and that simpler methods for doing the same thing are possible anyway.[133] Finally, other explanations of the 56 Aubrey Holes abound,[134] demonstrating just how easy it is to fit an explanation to this particular number (and perhaps to any other number) of holes.

The main problem with all these explanations is that they pay little or no attention to the archaeological evidence. Atkinson believed that the Aubrey Holes had been dug and almost immediately refilled many centuries before the station stones were put in place, so that the two aspects of Hawkins's astronomical interpretation of Stonehenge I could not have functioned simultaneously.[135] It is now thought likely that the Aubrey Holes first held a ring of timber posts, many of them being used later for cremations and other ritual—or at least formal—deposits (see Archaeology Box 3). Different as these two scenarios are, it is difficult to square either of them with the idea of the holes being containers for tally-markers. Perhaps most importantly of all, excavations elsewhere have shown that in its early phases Stonehenge was merely one of a number of broadly contemporary circular enclosures and henge monuments around Britain and Ireland, inside many of which were placed rings of timber posts and/or pits. For example, Aubrey Burl has listed ten sites containing pit circles where the number of pits in the ring varies from seven to forty-four or forty-five.[136] This must cast the severest doubt upon arguments that the actual number of Aubrey Holes at Stonehenge was of particular significance.[137]

The generation of new astronomical interpretations of Stonehenge gradually lost momentum during the 1970s, although in 1976 and 1977 some outlandish theories still continued to be published in *Nature*.[138] In 1975 the Thoms published a theory of Stonehenge as a universal lunar backsight, paralleling their earlier theory of Le Grand Menhir Brisé as a universal lunar foresight,[139] but their proposed artificial foresights did not stand up to archaeological reappraisal.[140] A decade passed before Stonehenge astronomy began to make a reappearance in the context of wider archaeological studies of Stonehenge,[141] which will be examined in detail later in chapter eight.

A number of points concerning procedure can nonetheless be made at this stage. The first is that attempting probability estimates from multiple alignments at a single site, although attractive in theory, can be highly misleading for a number of reasons, even when the calculations are done correctly. In particular it is very difficult to ensure, and hence to demonstrate to others, that the selection of data for such an analysis has been done in such a way that it is not influenced by the astronomical possibilities in the first place; and it is almost impossible to isolate questions of possible astronomical alignment from other design criteria that would directly relate one structural orientation to another, and hence to arrive at a set of data that can reasonably be argued to be independent of one another. Yet both criteria must be satisfied if the probability estimates derived are to have any useful meaning at all.

A second point is that it can be dangerous to rely on excavated features, even if the currently available evidence is fully taken into account and fairly interpreted. Not all of the site has been excavated and new discoveries can completely dislocate current theories, the prime example being the stone adjacent to the Heel Stone whose existence was discovered during a small salvage excavation in 1979.[142] On the other hand attempts to use archaeological evidence to refute astronomical theories can backfire. Thus Atkinson's argument against Hawkins's and Hoyle's interpretations of the Aubrey Holes as an eclipse predictor, on the grounds that the Aubrey Holes were refilled very soon after being dug,[143] is undermined by more recently published evidence suggesting that the holes may well, in fact, have contained timber posts at first and been subsequently left open after the posts were removed.[144]

Archaeologists have been quick to criticise Stonehenge astronomy where it has been subsequently invalidated by archaeological discoveries, as in the case of Peter Newham's interpretation of alignments from the Heel Stone and station stones to three large postholes some 250 m to the north-west, discovered when the present car-park was being built in 1966.[145] They subsequently turned out to be of Mesolithic date, holding great timber poles (very possibly more akin to totem poles than to posts, and not necessarily standing erect at the same time) predating Stonehenge 1 by over four thousand years.[146] Yet it is surely unreasonable to expect any astronomical interpretation to be any less reliant upon the current state of knowledge than wider archaeological interpretations, or any less susceptible to change in the light of new evidence. On the other hand, it is equally unreasonable for anyone putting forward an astronomical interpretation not to take the available archaeological evidence fully into account.

A final point concerns differing interpretations. At Stonehenge, as at Ballochroy, many debates are never finally settled. Interpretations may and likely will continue to differ, even where the archaeological evidence seems unequivocal. Thus Rodney Castleden postulates that a cult-house might have existed at the site of Stonehenge in Mesolithic times, from which the timber poles in what is now the car park might indeed have marked midsummer sunset.[147] Then again, Christopher Chippindale uses environmental evidence that indicates a discontinuity of occupation at Stonehenge to argue that there could not have been a continuously developing astronomical tradition,[148] whereas Castleden uses evidence from a wider archaeological context to argue that there was social continuity and continuity of tradition in the general vicinity of Stonehenge, so that even if the site itself was temporarily abandoned, the astronomical traditions that were reflected there when significant activity resumed were directly developed from those that had gone before.[149] Archaeological evidence can often cut both ways.

CLASSIC SITES: SOME LESSONS

Undoubtedly, great personal satisfaction may be derived in exploring a stone monument, investigating the potential alignments, identifying horizon features, taking measurements, calculating declinations, and formulating an astronomical explanation for the site's construction and layout. In doing so, one may feel somehow 'in tune' with the mysterious people who erected the stones. Such a feeling doubtless motivated Sir Norman Lockyer as he surveyed numerous stone rings in the early years of this century, and it certainly motivated Alexander Thom in later decades.[150] There are, however, a great many pitfalls awaiting the aspiring archaeoastronomer.

In examining past interpretations of some of the 'classic' sites of megalithic astronomy a number of dangers will have become evident to the reader, such as *post hoc* justification, circular argument, and perhaps most of all the tendency to emphasize those data that confirm a preconceived set of ideas while ignoring those that do not. How then can we prevent this sort of thing continuing to happen?

One possible answer, as we have seen, is to try to estimate the probability that observed astronomical alignments could have arisen fortuitously, that is through a combination of factors quite unrelated to astronomy. But probability estimates of this sort at a single site are fraught with difficulties, not just because of the need to select the basic data fairly but also because of the whole question of non-independence.

If it is dangerous to rely on excavated features, as we concluded at Stonehenge, how much more dangerous it must be to rely on those features that remain conspicuous above the surface, in the absence of excavation. Standing stones may well have shifted in the thousands of years since their erection, or even been re-erected in relatively recent times, unbeknown to the modern investigator. Features just as important as the large standing stones that we can pick out so easily now may well be inconspicuous in the absence of excavation, or may have disappeared completely, as at Ballochroy. Even what is apparently a simple monument may have been used and modified over a considerable period, and excavations can reveal unexpected complexity beneath the ground.[151]

When all these procedural dangers and restrictions are recognised, the potential for saying anything with any reasonable degree of confidence at a single site may seem severely limited, certainly frustratingly so for the would-be archaeoastronomer hoping to derive the astronomical significance of a particular monument. There is a further problem. Evidence on astronomical alignments is one step further removed from the interpretative process than most material evidence studied by archaeologists: no-one would deny that a piece of Bronze Age pottery was intentionally made, recognised as a piece of pottery and used by Bronze Age people, although we can argue over its function and meaning; but was an astronomical alignment of Bronze Age structures that may be obvious to us necessarily intended, recognised or used by the people who built those structures? Some archaeologists may expect the archaeoastronomer to prove beyond all doubt that a given astronomical alignment was intentional before they consider it further:

STATISTICS BOX 2

PROBABILITIES OF CHANCE ALIGNMENTS UPON ASTRONOMICAL TARGETS

Any alignment of man-made structures upon a horizon point of apparent astronomical significance, such as a particular rising or setting point of the sun or moon, is susceptible to the question 'Did it arise by intention, or as a result of factors quite unrelated to astronomy'? Where several alignments can be considered together, we can pose the question 'What are the chances that this many alignments of apparent astronomical significance could have arisen fortuitously (that is, as a result of factors quite unrelated to astronomy)?' An answer may be obtained by the use of a straightforward mathematical formula. How meaningful this answer is will depend on what initial assumptions are made and upon a number of other factors.

SHOOTING AT A TARGET: THE FORMULA

Suppose that we have a number of alignments pointing at places on the horizon which have apparent astronomical significance, and wish to estimate the probability that this many astronomical alignments could have arisen fortuitously.

Borrowing from Hawkins and White,[1] we can use the analogy of a blindfold marksman, who is repeatedly spun round before firing a shot which hits the horizon in a random place.[2] Scattered around the horizon are a number of astronomical 'targets': ranges of horizon that could be construed as astronomically significant. We can calculate the probability that the marksman will hit exactly *r* targets in *n* shots. The answer, known as Bernoulli's formula, is

$$\frac{n!}{r!(n-r)!}p^{r}(1-p)^{n-r} \qquad \ldots\text{(S2.1)}$$

where p is the proportion of the horizon occupied by astronomical targets or, equivalently, the probability that the marksman will hit an astronomical target in a single shot.[3] $r!$ indicates the factorial of r, namely $r \times (r-1) \times (r-2) \times \ldots \times 1$ (note that $0! = 1$).

It follows that the probability that the marksman will hit at least r targets in n shots is

$$P = 1 - \sum_{s=0}^{r-1} \frac{n!}{s!(n-s)!}p^{s}(1-p)^{n-s} \qquad \ldots\text{(S2.2)}$$

where the sigma symbol indicates that the formula must be evaluated with $s = 0, 1, 2$, etc. up to $(r-1)$ and the results summed.

For example, if $p = 0{\cdot}1$ and the marksman has 100 shots, then the probability of him hitting at least ten targets is 0·55, or somewhat over $^1/_2$; but the probability of him hitting sixteen or more is 0·04 or only $^1/_{25}$, and the probability of him hitting at least twenty-eight is less than 0·000001, or one in a million.

The smaller the probability that the astronomical alignments could have arisen by chance, the more likely it is that they were in fact intentional. There is a tendency to adopt a certain probability level, perhaps 0·05 or one in twenty, as indicative that the astronomical hypothesis should be accepted in favour of non-astronomical alternatives. However, to do this is to introduce an artificial barrier in what is in fact a continuous scale. It is clear, though, that we would be unwise to take a set of astronomical alignments as intentional if they could have arisen by chance with a probability as great as, say, one in five; whereas we would be unwise to ignore them if the probability of chance occurrence is as low as, say, 0·001 or one in a thousand.

APPLYING THE FORMULA IN PRACTICE: DETERMINING THE PARAMETERS

Before formula (S2.2) can be applied, it is vital to follow certain procedures in order to arrive at suitable values for the proportion of the horizon occupied by astronomical targets, *p*, the number of shots, *n*, and the number of astronomical 'hits' *r*. If unsuitable values are used, the result obtained may be at best misleading and at worst completely meaningless.

First, there is the question of how the astronomical targets are defined (and hence the determination of *p*). This will involve assumptions about perceived margins of error: how far away from a theoretical astronomical target must an alignment be before we would cease to accept it as indicating that target? We have no *a priori* justification for making any particular choice; and worse, if our choice is based upon the data themselves, then it may be tempting to choose that value that gives the smallest value of *P* and hence makes the alignments appear least likely to have arisen by chance. Suppose, for example, that we notice that several alignments fall between 1°·0 and 1°·1 away from theoretical astronomical targets; if we then assume that the margin of error is 1°·1 rather than 1°·0, so as to be sure to include all these extra alignments as 'hits' without expanding the target area very much, and *P* is reduced as a result, then we are weighing the odds in favour of the alignments appearing deliberate. The least we can do in this circumstance is to consider both margins of error in turn, and compare the results.

Related to this is the issue of which theoretical targets might be construed as potentially significant in the first place. There are many possibilities, including particular rising and setting positions of the sun and moon as well as those of other celestial bodies. If the choice is made on the basis of the data (for example, if lunar targets are included but solar ones excluded on the basis that many lines appear to point at lunar targets in the first place) then, once again, a circularity will have entered and the result will be weighed unfairly in favour of the alignments appearing deliberate.

A set of issues attaches to the selection of data, i.e. what constitute the alignments that are chosen for consideration in the test. If *n* is to be a true reflection of the number of shots made by the marksman, we need to include not only all the alignments of possible astronomical significance but also all those alignments that might equally well have been identified as putative astronomical indications had they pointed at an astronomical target. It is all too easy to spot the former, but requires much greater discipline and determination to make a fair estimate of the latter. An ideal procedure from the statistical point of view might be to select all alignments for consideration before any oriented site plans are examined or before any surveys are carried out, but this may not be feasible or desirable in practice. Many more specific issues relating to data selection are addressed in Part One of this book.

THE EXAMPLE OF STONEHENGE I

Many of these issues are best illustrated by an example, and it is here that Hawkins's interpretation of Stonehenge I is useful. We shall examine the claim that twenty-four out of fifty possible alignments are of astronomical significance (see chapter one, note 124), and that the probability of this happening fortuitously is only 0·000006.[4] In fact, three errors have been made.[5]

First, one should calculate the probability of at least, rather than exactly, twenty-four alignments having arisen fortuitously, using formula (S2.2) rather than (S2.1). This increases the probability slightly, to 0·000008.

Second, there are many more than fifty possible alignments between pairs of those points considered by Hawkins at Stonehenge I. There are fourteen such points, comprising stones and stoneholes and also the geometrical centre of the monument. Within fourteen points there are ninety-one possible pairs. But Hawkins is prepared to consider alignments in either (or, in many cases, both) directions between the points in a pair, so the total is actually twice this, or 182. The number of possibilities may be reduced by eliminating alignments which can be argued to be inherently unlikely, such as those marked by two points very close together and those towards, rather than away from, the centre (which to our knowledge was unmarked); but the total is still at least 111.[6] The probability of at least twenty-four fortuitous hits out of 111 shots is 0·37, more than one in three.

Third, there is the question of margins of error in the astronomical targets. Hawkins and White considered eighteen astronomical targets, allowing a possible error of up to 2° in each. Eighteen targets each 4° wide cover 72°, or a fifth of the horizon, so Hawkins assumed $p = 0{\cdot}2$. In fact, three of the twenty-four alignments are over 2° from their target, so shouldn't have been included as hits at all.[7] The probability of at least twenty-one fortuitous hits out of 111 shots is 0·65, considerably better than evens. Alternatively, we could increase the width of the target ranges to 5°, enough to include two of the remaining three alignments, but now the probability that what is observed could have arisen by chance increases to 0·88.[8]

Other difficulties with Hawkins's interpretation of Stonehenge I are dealt with in the main text.

A CAUTIONARY NOTE: THE ASSUMPTION OF INDEPENDENCE

The alignments being considered must effectively be independent of each other, otherwise the analogy of the blindfold marksman breaks down. Take, for example, a row of five standing stones, oriented in one direction to an acceptable degree of precision upon an astronomical target such as midsummer sunrise. If we were to consider the alignments formed by all pairs of stones at that monument, we would arrive at the conclusion that ten out of twenty possible alignments were astronomical, since they all point in the same direction. Really we only have one hit out of two shots,[9] not ten out of twenty, because since the stones form a row, all ten orientations in each direction must of necessity be the same. If, say, $p = 0{\cdot}1$, the probability of at least one hit out of two shots arising fortuitously (from formula S2.2) is 0·19, or roughly one in five, whereas that of ten hits out of twenty is 0·000007, or seven in a million. It is clear, then, that making the assumption of independence falsely can lead to grossly misleading results.

ARCHAEOLOGY BOX 3

STONEHENGE AND ITS ARCHAEOLOGICAL CONTEXT

The earliest constructions at Stonehenge of which we are aware were built around or a little after 3000 BC[1] in an area where there had been considerable human activity for at least a thousand years (Fig. 1.23a, b). During the previous millennium the site of the future Stonehenge appears to have been within the domain of influence of a causewayed enclosure known as Robin Hood's Ball, one of five major causewayed enclosures in the Wessex chalk uplands. Each of these was an important focal point and was surrounded by a cluster of long barrows built during the earlier part of the fourth millennium BC[2] (see also Archaeology Boxes 2 and 4). Two cursuses, the longer of which runs for almost 3 km across undulating landscape, were probably constructed shortly before 3000 BC, a little to the north of the later site of Stonehenge.[3] The presence of such monuments indicates that the process of forest clearance was by this time well advanced, and environmental evidence (Archaeology Box 5) confirms that earlier patches of woodland had now largely disappeared and the landscape consisted predominantly of open grassland.[4]

Stonehenge 1: c. 3000–2900 BC

Stonehenge 1 (Fig. 1.24a) was built at a time when causewayed enclosures were falling into disuse. It was a circular earthwork enclosure; a ditch was excavated using antler picks and the chalk fill was used to build a bank on the inside, forming a ring about 100 m across. There was a 15 m-wide entrance gap to the north-east and two narrower entrances to the south, one of which was later blocked. The ditch was built over a short space of time, possibly fifty years at most; the date can be established quite accurately from radiocarbon dating of antler picks found in its base.[5]

A circular ring of fifty-six holes known as the Aubrey Holes—spaced quite regularly at intervals of between 4·5 m and 4·8 m centre to centre[6]—is encountered just inside the bank. Exactly when the Aubrey Holes were dug is more difficult to determine. The fact that the geometrical centre of the Aubrey ring coincides with that of the ditch and bank suggests that these features were broadly contemporary, but there is no conclusive evidence.[7] The Aubrey Holes probably held a ring of timber posts but, again, this is not certain.[8]

A number of other features—postholes in the interior of the monument (see below), over fifty smaller stakeholes in the outer part of the north-east entrance (also see below), and three postholes discovered under the bank on the south-east side—may also belong to this phase, and one or more of them may even predate the construction of the ditch and bank, although there are arguments why this seems unlikely.[9]

Stonehenge 2: c. 2900–2550 BC

Within no more than about a century of its construction, the ditch and bank monument began to be modified, apparently in line with the tradition of 'henge' monuments (see Archaeology Box 2) that were now starting to be built in many parts of Britain, including three—Durrington Walls, Woodhenge, and Coneybury—within just 4 km of Stonehenge (Fig. 1.23c).[10] Land in the region was increasingly coming under cultivation, and there is evidence of settlement within 1 km of Stonehenge.[11]

The emphasis at Stonehenge itself seems to have switched. A number of timber structures were built in the interior: this is clear from the presence of a large number of postholes within 20 m of the centre, variously interpreted as a roundhouse or one or more circles of wooden posts,[12] together with what appears to have been a 'passageway' leading towards the southern entrance (Fig. 1.24b).[13] Some fifty postholes in a grid-like formation across the north-east entrance were probably (but not certainly) also dug at this time,[14] as were a line of (at least) four holes, labelled the 'A' holes, placed across the axis some 20 m outside the north-east entrance.[15]

Meanwhile, much of the ditch was allowed to fill naturally, as were the Aubrey Holes, now devoid of posts.[16] Later, cremation burials—sometimes along with other items such as bone skewer pins, pottery fragments, and objects of flint and chalk—were placed in several of these; cremation deposits were also placed in the upper ditch, on or just inside the bank, and around the outside of the monument.[17]

Stonehenge 3: c. 2550–1600 BC

During the next thousand years the landscape in the vicinity became intensively farmed, with the appearance of permanent field systems, farmsteads and settlements.[18] When it was not being used for food production, organised labour was clearly available on a vast scale, not only at Stonehenge but also at the great henge of Durrington at Woodhenge.[19] Stonehenge itself underwent one modification after another. It is not possible, at least on current evidence,

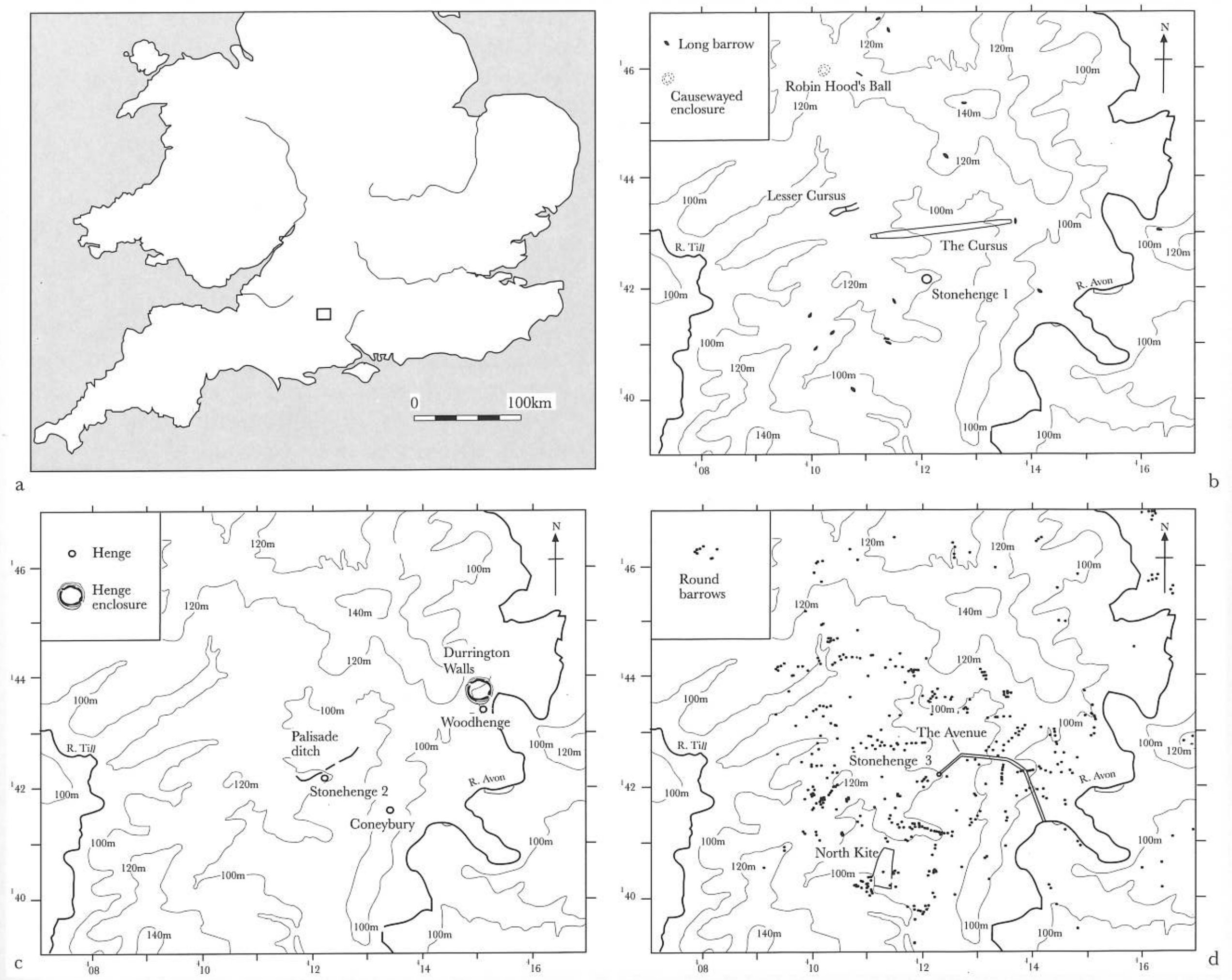


Fig. 1.23 Landscape and monuments in the vicinity of Stonehenge.
a. Location of the Stonehenge area.
b. *c.* 4000 BC to 3000 BC (after Cleal *et al.* 1995, figs 33 and 35).
c. *c.* 3000 BC to 2500 BC (after Cleal *et al.* 1995, fig. 57).
d. *c.* 2500 BC to 1500 BC (after Cleal *et al.* 1995, fig. 78).

to provide a definitive sequence of events but a tentative succession of construction episodes can be identified within the interior of the monument and, separately, on the periphery by the entrance and outwards to the north-east.

The interior

At around 2550 BC the decision was made to construct circular settings in stone rather than wood. The bluestones were brought to the site then, on an extraordinary journey of several hundred kilometres, mainly by river and sea, from the Preseli Mountains of south-west Wales.[20] They were erected, possibly already dressed, in a setting that may have formed the north-eastern arc of a double circle, or a more irregular figure (Fig. 1.24c).[21] In any case, the focus of attention may well have been the Altar Stone, a slab of green sandstone acquired from a place on the bluestone route from the Preseli Mountains and erected on the south-west side of the double circle, opposite the entrance.[22] This subphase is now identified as Stonehenge 3i.

About a century later, the giant sarsen stones weighing 25 tonnes or more were hauled from the Marlborough Downs some 29 km to the north of Stonehenge, and erected to form the famous ring of thirty uprights joined by lintels together with an inner horseshoe of five trilithons (Stonehenge 3ii) (Fig. 1.24d).[23] It is likely that the smaller bluestones, now dressed, were also erected at this time, but exactly where and in what formation is not clear (Stonehenge 3iii).[24] Subsequently, they were set out as an oval and circle respectively within the sarsen trilithon horseshoe and circle (Stonehenge 3iv). The northern

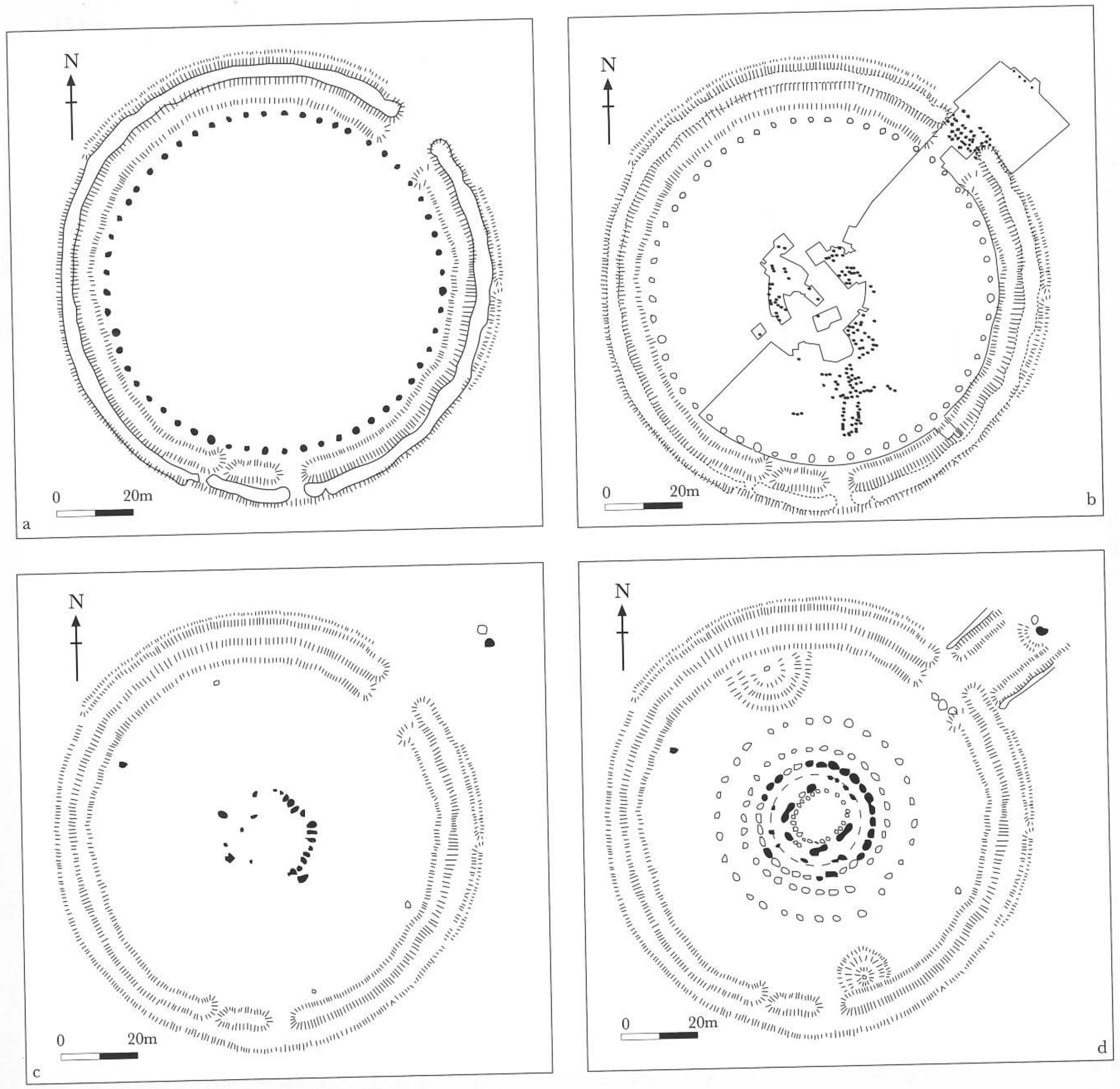


Fig. 1.24 Phases in the development of Stonehenge.
a. Stonehenge 1 (*c.* 2950 BC) (after Cleal *et al.* 1995, fig. 256).
b. Stonehenge 2 (*c.* 2900 to 2550 BC). The limits of excavated areas are shown (based on Cleal *et al.* 1995, fig. 66).
c. Stonehenge 3i and 3a (*c.* 2500 BC) (after Cleal *et al.* 1995, fig. 256).
d. Stonehenge 3ii and 3b onwards (*c.* 2400 BC to 1600 BC), simplifying the different subphases (after Cleal *et al.*, 167).

arc of the oval was later removed to produce an inner bluestone horseshoe (Stonehenge 3v). Finally, two concentric circles of holes were dug outside the sarsen ring (Stonehenge 3vi), apparently as part of a remodelling plan that was subsequently abandoned.[25]

The periphery

It is unclear precisely how these events related to the sequence of events at the periphery. The Heel Stone,[26] a large, unworked sarsen block, was probably erected at an early stage, together with a companion stone a couple of metres to its north-west,[27] forming a pair some 20 m away outside the north-east entrance.[28] It seems most likely, but is by no means certain, that the four Station Stones were also erected at about this time,[29] forming a subphase (Stonehenge 3a) oriented on a different axis from the earlier phases and which is broadly contemporary with Stonehenge 3i (Fig. 1.24c).[30]

Later, a narrow ditch was dug around the Heel Stone, which probably (but not certainly) implies that the companion had been removed by this time, and two of the Station Stones were replaced by mounds (the 'North Barrow' and 'South Barrow') surrounded by ditches. These events may well have been contemporaneous with each other (Stonehenge 3b) and roughly contemporaneous with Stonehenge 3ii (Fig. 1.24d). The Heel Stone ditch was soon refilled.[31] The avenue, a pair of earthen banks roughly 20 m apart running for 2·5 km from the north-east entrance of Stonehenge to the River Avon (Fig. 1.23d), was constructed between about 2250 BC and 1900 BC (Stonehenge 3c), and on current evidence seems most likely to have been broadly contemporaneous with Stonehenge 3iv. It is not known whether it was constructed as one (long) operation or in a number of separate stages.[32]

At some time during Phase 3 three sarsen uprights were placed close together, but without a lintel, across and just inside the entrance. One of these survives as the so-called 'Slaughter Stone', which stood until the seventeenth century.[33] There are two possible stoneholes situated on the axis, midway between the two sides of the avenue, between the entrance and the position of the Heel Stone and its companion, but it is not certain that they actually held stones and whether, if they did, the stones that they held were placed elsewhere before or after.[34]

While some of the details are unclear, it is indisputable that during the early stages of Stonehenge 3 there was a marked change in direction of the axis of symmetry of the monument, which was shifted clockwise by several degrees.[35] However, the evidence does not support Atkinson's idea that the earthwork entrance was widened so as to bring it into line with the avenue and the new orientation, by backfilling the first few metres of the ditch on the south-east side.[36] Instead, it seems that backfilling took place at various points around the ditch, including both sides of the entrance, during the earlier Stonehenge 2.[37] When the avenue was built, the bank to the south-east of the old entrance remained, extending across about a third of the end of the avenue and perhaps continuing to restrict access to the monument.[38]

The environs

During this time, round barrows were built in concentrations in the vicinity of Stonehenge (Fig. 1.23d). There are a number in the immediate vicinity (within 500 m),[39] but the main concentrations are along ridges about 1 km away to the north-west (Monarch of the Plain and others), north-east (Cursus group), east (King Barrow group) and south (Normanton Down group) where they were prominently visible from Stonehenge.[40]

There is a profound difference between the data collected by an archaeoastronomer and an archaeologist. Data for the latter is something that can be grasped, measured, conserved or visited; it has tactile qualities. The archaeoastronomer has first to prove the existence of the data that is used, before any analysis from which valid conclusions are sought, can be attempted.[152]

While it is unrealistic to expect 'proof', it does not seem unreasonable to demand a fair degree of confidence that a given astronomical alignment was intentional before proceeding towards interpretation. But how, then, can such confidence be established? We have seen that probability arguments are highly problematic at single sites. A clue is provided by the example of the Aubrey Holes at Stonehenge. In attempting to answer his critics, Newham asked the question 'Why the necessity for 56 holes? Why go to the trouble of dividing a circle into a relatively complex number?'[153] The probable answer is that no-one did, very possibly no-one even counted them; and that the number 56 arose through a combination of factors quite unrelated to astronomy. As we have seen, this becomes evident as soon as a comparison is undertaken with similar sites[154] and no repetition of the number 56 is found.

A further example of the value of looking beyond a single site is provided by the example of Carn Ban (NR 991262), a Clyde tomb (see Archaeology Box 2) on the Isle of Arran.[155] The passage of this tomb is oriented upon a horizon point with a declination of +23°·9, close to the position of the midsummer rising sun.[156] Taken by itself it may be tempting to surmise that this astronomical orientation was intentional, but there are twenty-one other Clyde tombs on Arran with measurable orientations, and these face all around the compass, with a wide spread in declinations.[157]

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

2

Backsights and Foresights

The Work of Alexander Thom and its Reassessment

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

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

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

THOM'S APPROACH: THE FOUR LEVELS

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

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

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

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

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

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

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