works do not work, he is damned.

"To the engineer falls the job of clothing the bare bones of science with life, comfort, and hope. No doubt as years go by people forget which engineer did it, even if they ever knew. Or some politician puts his name on it. Or they credit it to some promoter who used other people's money with which to finance it. But the engineer himself looks back at the unending stream of goodness which flows from his successes with satisfactions that few professions may know. And the verdict of his fellow professionals is all the accolade he wants.

"The engineer performs many public functions from which he gets only philosophical satisfactions. Most people do not know it, but he is an economic and social force. Every time he discovers a new application of science, thereby creating a new industry, providing new jobs, adding to the standards of living, he also disturbs everything that is. New laws and regulations have to be made and new sorts of wickedness curbed. He is also the person who really corrects monopolies and redistributes national wealth.

"But he who would enter these precincts as a life work must have a test taken of his imaginative facilities, for engineering without imagination sinks to a trade. And those who would enter here must for years abandon their white collars except for Sunday."

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Callanish, a Scottish Stonehenge

A group of standing stones was used by Stone Age man to mark the seasons and perhaps to predict eclipse seasons.

Gerald S. Hawkins

The stones and archways at Stonehenge point to the sun and moon as they rise and set during the year (*1*). Between winter and summer the sun rises further to the north every day, and the extreme position on midsummer's day is marked by the heel stone. The heel stone was placed with an accuracy of better than 0.2°, a remarkable precision for the period (2000–1500 B.C.). Between summer and winter the sun rises further to the south every day, and its extreme southern position on midwinter's day is marked by archways in the structure. The rising and setting of the sun at the equinoxes are also marked. Thus, altogether six solar directions are marked.

In a similar way the moon rises at a different point on the horizon every night, but the moon swings from its northern extreme to its southern extreme much faster than the sun does. The moon takes 2 weeks to complete its swing, whereas the sun takes 6 months. For the moon there is a further complication—the slow wobble of its orbit. Without this wobble the full moon nearest midwinter's day would rise over the heel stone every year, and the moon would be furthest north on the horizon at this time. Because of the wobble, the midwinter full moon swings first to the left and then to the right of the heel stone through an angle of about 20°. The moon requires 18.61 years to complete one cycle, and it requires almost exactly 56 years to complete three cycles. The swing of the moon provides 12 extreme positions of the full moon on the horizon that could have been marked by the Stone Age astronomers, in summer and winter, and at the equinoxes—two extreme positions for each of the six extreme positions of the sun. Figure 1 shows these directions for the latitude of Stonehenge, 51°N. (The equinox alignments are unpublished.)

When the full moon rises opposite the setting sun, an eclipse of the moon is possible. An eclipse of the sun may occur 15 days later, when the moon has moved around its orbit to line up with the sun. The periods in which eclipses are possible are known as "eclipse seasons." Their occurrence in the calendar is controlled by the 18.61-year cyclic precession of the moon's orbit, and an eclipse year of 346.620 days contains two eclipse seasons. After 56 years the sequence of eclipse seasons returns to within 3 or 4 days of the starting point in the Gregorian calendar. This fact is confirmed by the commensurate length of 56 tropical years and 59 eclipse years. This is the eclipse cycle which synchronizes most accurately with the tropical year, with a period of less than 90 years.

I have suggested (*2*) that the 56 Aubrey holes at Stonehenge were used to predict the eclipse seasons. These holes are set at equal spacings around a perfect circle. Each hole was dug into the chalk to a depth of about 1½ meters and then refilled with white chalk rubble. Cremated human remains were later placed in the holes, a finding which lends support to the archeological opinion that the holes were ritual pits. By moving marker stones around the circle, changing the position by one Aubrey hole each year, the Stonehengers could predict the particular year in which there would be danger of, say, an eclipse of the winter moon. By means of the 30 archways, the Stonehengers could predict the actual day of an eclipse. The archways were set in a perfect circle within the circle of Aubrey holes, and I have suggested that each gap represented a day of the lunar

The author is professor of astronomy at Boston University, Boston, Mass.; Astronomer at the Smithsonian Astrophysical Observatory, Cambridge, Mass.; and Research Associate at the Harvard College Observatory, Cambridge.

Table 1. Astronomical alignments at Callanish.

Object	Stone	Point viewed from	Azimuth (deg N)	Declination (deg)	Altitude of the horizon (deg)	Error (deg)
Rising midsummer sun	34	29	41.8	+23.9	0.8	+0.2
Setting midsummer sun	20	9	316.2	+23.9	.3	+1.4
Rising sun at equinox	20	23	91.5	+0.0	.8	+0.3
Rising midsummer moon	35	29	163.9	−29.0	.5	+0.1
Setting midsummer moon	10	18	190.1	−29.0	1.3	+0.1
Setting midsummer moon	1	7	191.4	−29.0	1.3	+0.0
Rising midwinter moon	30	35	26.6	+29.0	1.7	−1.4
Rising midwinter moon	33	35	56.0	+18.7	1.0	+0.0
Rising midwinter moon	34	9	32.5	+29.0	1.3	+0.6
Setting moon at equinox	30	33	259.1	−5.2	1.0	−1.0
Midsummer moon at transit	24	28	182.0	−29.0	0.6	1.25

month. By moving a marker stone from one archway to the next each day, a person could follow the phases of the moon and predict the danger of a lunar eclipse, which takes place only at full moon, and a solar eclipse, which occurs at the "new" phase. By observing whether or not the moon rose before the sun set, a Stonehenger could estimate the local time of an eclipse to within an hour. Thus, Stonehenge may well have been a device of such precision and complexity of design as to indicate a level of intellect far surpassing that which we have hitherto been willing to ascribe to Stone Age man.

Stonehenge is a very special monument with no exact counterpart anywhere in the known world. One might expect, however, to find that other stone circles built around 2000 B.C. had a similar astronomical function. As the British archeologist R. S. Newall said, "I don't fancy it [the proposed astronomical function for Stonehenge] will be accepted by archaeologists until other sites that could be used in a similar way are found in Britain or on the Continent."

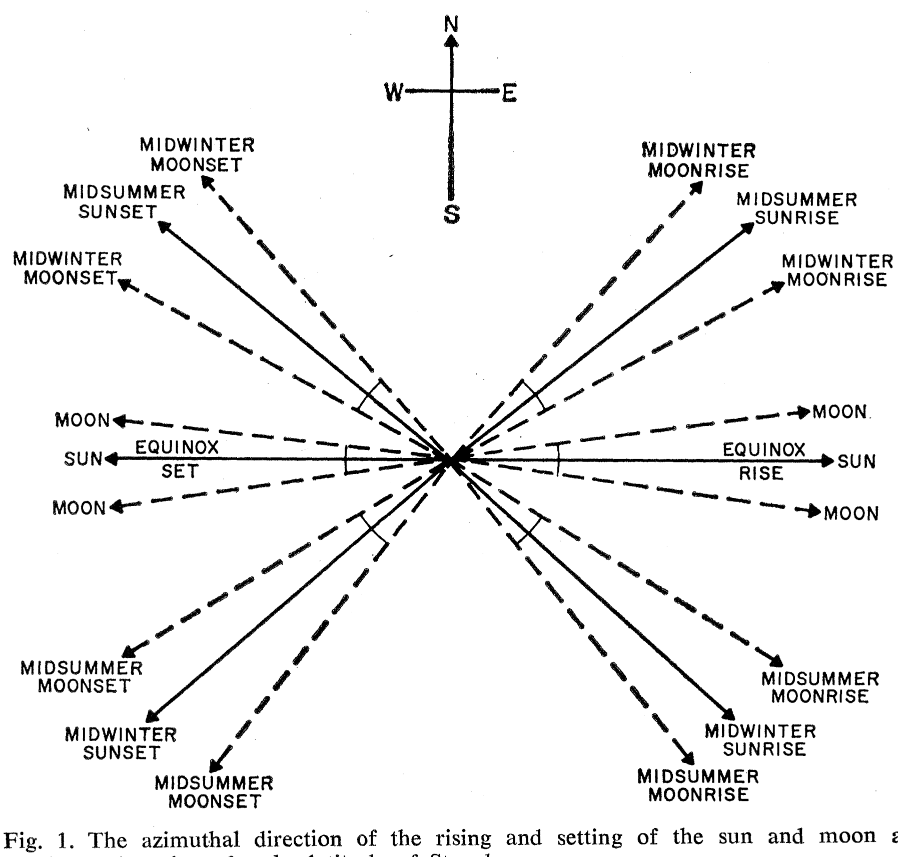

Fig. 1. The azimuthal direction of the rising and setting of the sun and moon at solstice and equinox for the latitude of Stonehenge.

Callanish

Few of the plans of the several hundred megalithic monuments and stone circles in Great Britain have been published, but Somerville has published one (*3*), that of Callanish (Fig. 2). Callanish is a group of large standing stones situated on Lewis, the northernmost island of the Outer Hebrides, a rather desolate spot some 130 kilometers north of Barra. Callanish consists of a ring of 13 stones with a central great stone, an avenue, and other deliberately set rows. Somerville suggested that the avenue was aligned to point to the star Capella at its rising, and that the four stones to the east of the avenue pointed to the rising Pleiades. But a star, as viewed at sea level under even the very best conditions, is less bright by at least six magnitudes than it is when viewed higher in the sky, and Capella at its rising would be faint and inconspicuous. The Pleiades would be invisible to the naked eye. Somerville also suspected one moon alignment, however, and so Callanish becomes a prime candidate for study in the search for megalithic sites that could have been used in ways similar to those proposed for Stonehenge.

The position of all the stones of Callanish was read by Julie Cole, using a rectangular grid, and the azimuths of the lines between any two stones were computed. The azimuth for stone 20 as seen from stone 23 was taken to be 91°.48, an error of 0°.58 in Somerville's published plan, as reported by Thom (*4*), being taken into account. The altitude of the horizon was calculated from contours on the 1-inch (2.5-cm) Ordnance survey map. Allowance was made for atmospheric refraction and parallax in calculating the declination of an object on the horizon.

At Callanish, ten alignments with the sun and moon at their extreme positions on the horizon were found. Furthermore, as inspection of Fig. 2 shows, these alignments are the most important ones in the structure. The error in the setting of the stones is given in column 7 of Table 1. It is expressed as height above the horizon, at sunrise or sunset (or moonrise or moonset), of the lower limb of the sun (or moon) as seen along the line of stones. Errors were found to be minimal when a definition of sunrise and sunset as the time when the lower limb is tangential to the horizon was assumed. This definition of sunrise and sunset seems to have been used by the Stonehengers, particularly with the heel stone, as well as by the people of Callanish.

The latitude of Callanish is of some interest. It is near the Arctic circle for the moon, the latitude where the moon at its extreme declination remains hidden just below the southern horizon. Callanish is 1°.3 south of this critical latitude, and there the full moon at midsummer stands about 1° above the southern horizon every 18 or 19 years. The row of stones from 24 to 28 points to the rising, transit, and setting of the moon along its path at these times, when it appears to come closest to the horizon. Midsummer moonset is over Mount Clisham, the highest peak on Harris, and the avenue points to this mountain. Perhaps this alignment of the moon with the mountain was significant for the Callanish people.

The eastern triangle of stones, with apexes at stones 30, 33, and 35, is interesting. As viewed from stone 35, the swing of the midwinter moon from declination +18°.7 to +29°.0 is marked by the row of stones 30 to 33. On the average, the midwinter moon stays 3 years in each of the three gaps in this row.

Stone 35, in alignment with a second stone, marks three different lunar directions (see Table 1). Most of the stones listed in Table 1 mark at least two lunar or solar directions. This gives added weight to the theory that the astronomical alignments were intentional.

The error in the setting of the alignments is about 0°.5 in altitude. That is to say, the lower limb of the sun or moon was about one-half degree above the point on the horizon to which the line of stones was directed. This is considerably better than the accuracy at Stonehenge, but the greater accuracy is largely attributable to the high latitude. The six directions of the rising or setting sun and the 12 directions of the rising or setting moon are shown for Callanish in Fig. 3. The directions are different from those at Stonehenge (Fig. 1) because of the difference in latitude. The sun (or moon) when rising and setting follows a more slanting path as it crosses the horizon at Callanish than it does at Stonehenge. The path of the midsummer moon, computed for 1500 B.C., is shown in Fig. 4. At Callanish a large change in azimuthal bearing of the sun produces a small change in altitude above the horizon. Thus, the error in azimuthal bearing is about the same as that at Stonehenge. At least some of the errors given in Table 1 arise from errors in the available chart of the structure, from which calculations were made, and from uncertainties concerning the elevation of the horizon. Before a detailed discussion of errors is undertaken Callanish must be resurveyed and measurements must be made of the slope of the ground, height of the stones, elevation of the horizon, and so on.

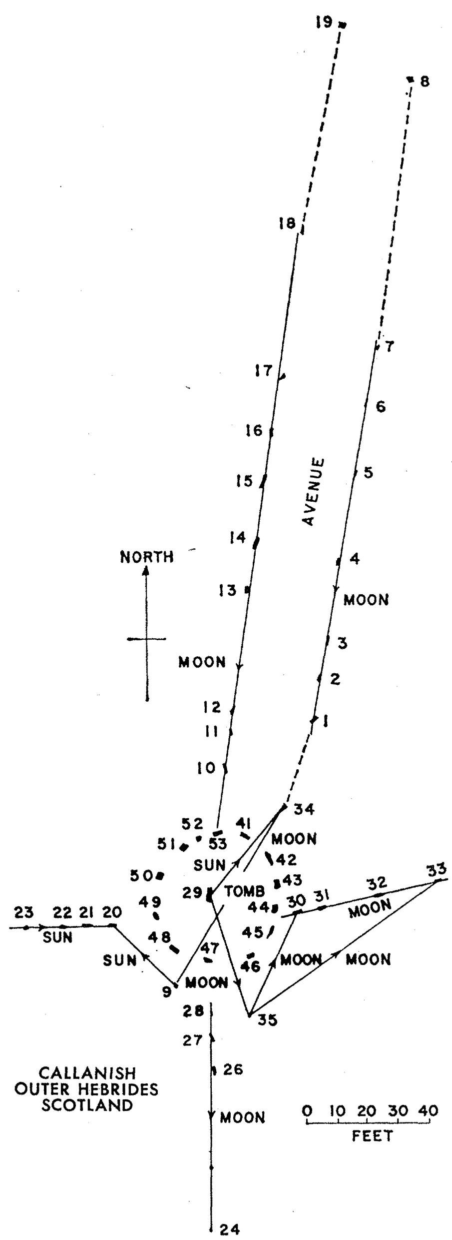

Fig. 2. Plan of Callanish, a group of large standing stones on the island of Lewis in the Outer Hebrides.

Use by Stone Age Man

The most puzzling thing about Callanish is how it was used by Stone Age Britons. I have suggested that Stonehenge was used to mark out the seasons—that the Stonehengers made observations of the moon throughout its 18.61-year cycle in order to establish a lunar-solar calendar and to obtain warning of solar and lunar eclipses. Callanish seems to have been used primarily to establish a calendar, though it may possibly have been used for predicting eclipses as well.

In looking for clues as to how the stones of Callanish were used as a computer to establish a calendar, we find analogies with Stonehenge. Since the circle of stones at Callanish has no solar or lunar alignment I suggest that it is a counting circle similar to the Aubrey holes and Sarsen circle at Stonehenge. The circle at Callanish contains 13 stones, 12 large and 1 small. These numbers are the fundamental basis of a lunar-solar calendar and could have been used for marking off the short years of 12 lunar months and the long years of 13 lunar months. A similar system is still used in the Jewish calendar today. The 19 stones in the avenue, including the "heel" stone (stone 34), provide a basic counting system for this calendar. Such an observational program and calendar formulation in 1500 B.C. would have antedated by more than 1000 years any similar development known to us. The Greek Meton is credited, perhaps apocryphally, with the discovery, in 432 B.C., of the 19-year cycle; this knowledge was not put to use until 312 B.C., during the Seleucid Empire.

The Callanish people may have observed and predicted eclipses, though the evidence is less clear than it is at Stonehenge. A midwinter moonrise over stone 34 would certainly have signaled the danger of a winter eclipse. The requirement for winter and summer eclipses is also marked by the lines for moonset and sunrise at the equinox. When the sun rose in line with stones 20 to 23 and the moon set in line with stones 30 to 33, there would have been danger of an eclipse at midsummer or midwinter. Thus the Callanish people did have the means for predicting winter and summer eclipses from observations made at various times throughout the year. However, consistent prediction

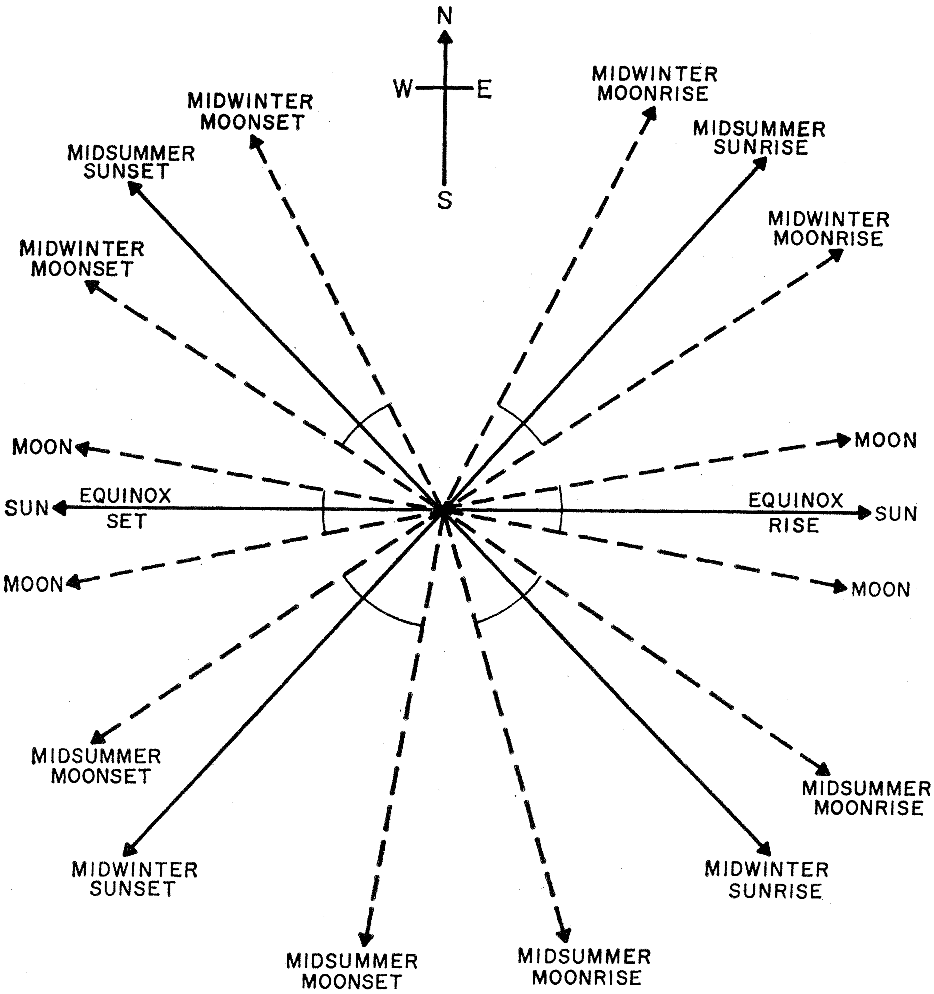

Fig. 3. The azimuthal direction of the rising and setting of the sun and moon at solstice and equinox for the latitude of Callanish.

of eclipses of a moon of a particular time of year, such as the midwinter moon, would have required a 56-year counting cycle made up of intervals of 19, 19, and 18 years. The Callanish people could readily have made such observations by excluding stone 34 every third count around the avenue. Thus, it is just possible that they did have knowledge of the 56-year cycle, though they did not reveal possession of this knowledge, as the Stonehengers did by setting out a circle with 56 marked points.

Although the astronomical alignments are indisputable, the suggestion of a computer use is, of course, conjectural. At Stonehenge the precise circle of 56 Aubrey holes seems to be connected unambiguously with an accurate eclipse cycle which synchronizes with the year of the seasons. At Callanish, on the other hand, excavations have not been completed. We cannot be sure that only 19 stones were set in the avenue, and that only 13 stones were set in the circle. Also, the circle of standing stones is associated with a tomb and is thought by some archeologists to be more recent than, and perhaps unconnected with, the rows of stones.

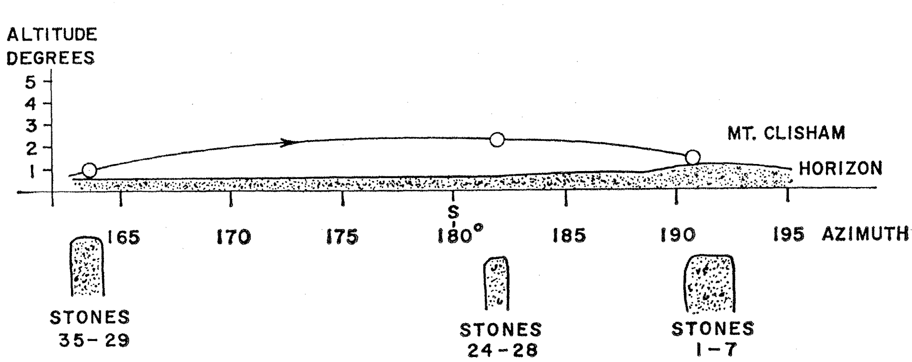

Fig. 4. The apparent path of the full moon at Callanish at midsummer computed for about 1500 B.C.

Conclusion

On the basis of the stone record it appears that the Callanish people were as precise as the Stonehengers in setting up their megalithic structure, but not as scientifically advanced. Callanish is, however, a structure that could have been used much as Stonehenge was. It would be interesting to obtain a date, by the radiocarbon method, for the peat in the area of Callanish, to determine how much older, or more recent, than Stonehenge this structure is. Perhaps the knowledge gained at Callanish was later used in the design of Stonehenge.

These structures are both at critical latitudes. Callanish is at the latitude where the moon skims the southern horizon. Stonehenge is at the latitude where at their extreme positions along the horizon the sun and the moon rise at a right angle on the horizon. From the standpoint of astronomical measurement Stonehenge could not have been built further north than Oxford or further south than Bournemouth. Within this narrow belt of latitudes the four station stones make a rectangle. Outside this zone the rectangle would be noticeably distorted. Perhaps these latitudes were deliberately chosen, and perhaps these people were aware that the angles of the quadrangle formed by the station stones would change as one moved north or south. If Stonehenge and Callanish are related, then the builders may have been aware of some of the fundamental facts which served later as the basis of accurate navigation and led to a knowledge of the curvature of the earth. But if they possessed knowledge of such importance it must have been passed along by word of mouth; no record of it is found in the stones.

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2. ———, *ibid.* **202**, 1258 (1964).
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4. A. Thom, *Math. Gaz.* **45**, 83 (1961).