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REFRACTION AND PRECISE LUNAR ALIGNMENTS

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ABSTRACT

During a major standstill the maximum declination of the moon at successive lunations varies by only a small amount. Observing the extreme north/south position of the moon would require an alignment of high precision. Alexander Thom believed that this had been done in the Early Bronze Age. Most of the claimed sites are in Scotland.

Atmospheric conditions, especially variation in temperature and pressure can cause variation in atmospheric refraction, particularly at very low altitude. Large variations have been found to be common in Chile and North America as result of which Bradley Schaefer has stated that the results claimed by Thom would not be possible. However there is no reason *per se* why atmospheric conditions in other parts of the world should be relevant to Scotland. Investigations in Scotland have found that refraction variation, even down to one degree altitude, is typically less than one minute of arc. It is concluded, therefore, that it is unreasonable to claim that refraction variation elsewhere would prevent the possible existence of precise lunar alignments in Scotland. Recent investigations by the present author, provides evidence for the possible existence of such alignments.

KEYWORDS: Low level refraction, Chile, Scotland, temperature gradient, temperature inversions.

1. INTRODUCTION

Schaefer and Liller (1990) analysed values for refraction variation at low altitude from a number of different locations in the Americas finding much larger values than expected. As a result they concluded that determination of accurate alignments was not possible; in particular the claim by Alexander Thom for the existence of precise lunar alignments. Their results are considered later following a discussion of the apparent movements of the moon.

The moon comes to its major standstill every 18.6 years. During the standstill the maximum monthly declinations, both north and south, lie in the region of about ± 29°, which is about five degrees greater than that of the sun at the solstices (Figure 1).

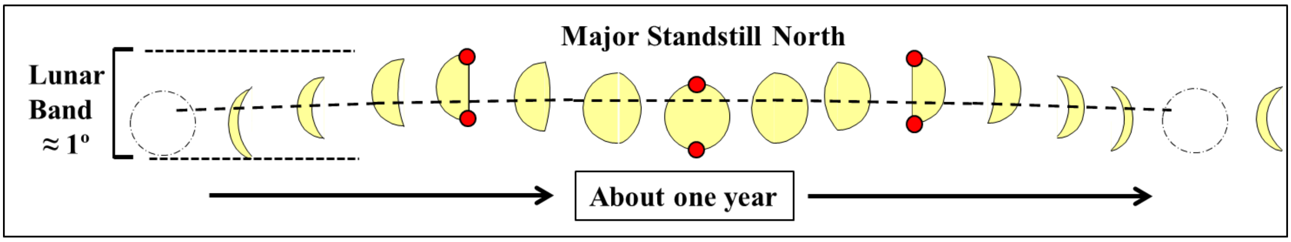

Figure 1. The extreme positions of the moon at a major standstill

The images in Figure 1 are one month apart. Between each, the moon moves to its southern maximum declination, where the lunar phase is opposite, before returning north. The reverse scrolling phase pattern continues in a snake-like pattern after the standstill. At the next major standstill the phase pattern is displaced about three months to the right.

During the standstill period the maximum declination of the moon, both north and south, lies within a range of about 20′ for about a year. Only the lunar positions marked by a red dot, when the moon is at the top or bottom of the 'wobble', are unique. These positions are the 'key' declinations. The moon at these key declinations is always at the quarters or full moon; or new moon which cannot be observed. The moon's movements, the Lunar Band and related matters are described by Gough (2016).

By using a suitable horizon feature as a foresight the 'key' lunar positions, when viewed from a marked backsight, could, in principle, be found. However given the small variations in declination, measurement of the order of ± 2′ of arc precision would be necessary. Alexander Thom believed that he had found a number of precise lunar alignments and deduced that they had been set up in the Early Bronze Age (Thom, 1971).

Light rays from celestial objects are refracted by the atmosphere, increasingly so as the horizon is approached. Tables of standard corrections to be applied are published. However these cannot allow for random deviations in refraction which can occur at very low altitude, and which are usually caused by variations of temperature and pressure. Such effects can lead to significant refraction deviations at altitudes below one degree and particularly so for negative altitudes.

Using the results of measurements made from sites in Chile together with a number from elsewhere, Bradley Schaefer claimed that the large deviations found in refraction near the horizon showed that Thom's results were not possible. He wrote "…the historically important claim by A. Thom that British megalithic sites were used as accurate lunar observatories is shown to be wrong because the needed accuracy is much greater than can be obtained for long averaging intervals." (Schaefer and Liller, 1990). The Chile results were based on timed observations of the setting sun from Cerro Tololo, 2215m, and Vina del Mar, 120m, both near the west coast of Chile. These were combined with observations from North America by other observers. The overall conclusion was that refraction deviation was much greater than previously thought, with a rms value of about 4′ of arc but with much larger values occurring. Deviations in refraction will result in errors in calculated declinations with corresponding errors in azimuth on the horizon (Sampson, 2000). Schaefer and Liller (1990, 804—5) argue that such large refraction deviations would prevent the claimed azimuth accuracy required for precise lunar alignments as proposed by Thom.

Exton (1992) expressed reservations concerning the validity of Schaefer and Lillers' assertions. He discussed how they had allowed the, not unexpected, very large refraction deviations observed from Cerro Tololo to dominate their findings. However, this has not prevented use of their results by others to doubt the possibility of significant precision in archaeoastronomy: "…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. (Ref. Schaefer and Liller, 1990)." (Ruggles, 1999, 25).

2. ATMOSPHERIC REFRACTION

2.1. REFRACTION MEASUREMENTS IN SCOTLAND AND THEIR IMPLICATION

A fundamental question concerns the applicability of the above results to Scotland where the atmospheric conditions are likely to be very different from the regions considered by Schaefer and Liller. Five sets of observations of the setting sun from three different sites were made by the present author in 2008 to 2015. Timed theodolite measurements were made of the upper and lower limbs of the setting sun. Most were in the altitude range from 4° down to 1° altitude, but with one site near the sea to 0° altitude. The difference between the observed and the calculated refraction gives the deviation (Figure 2).

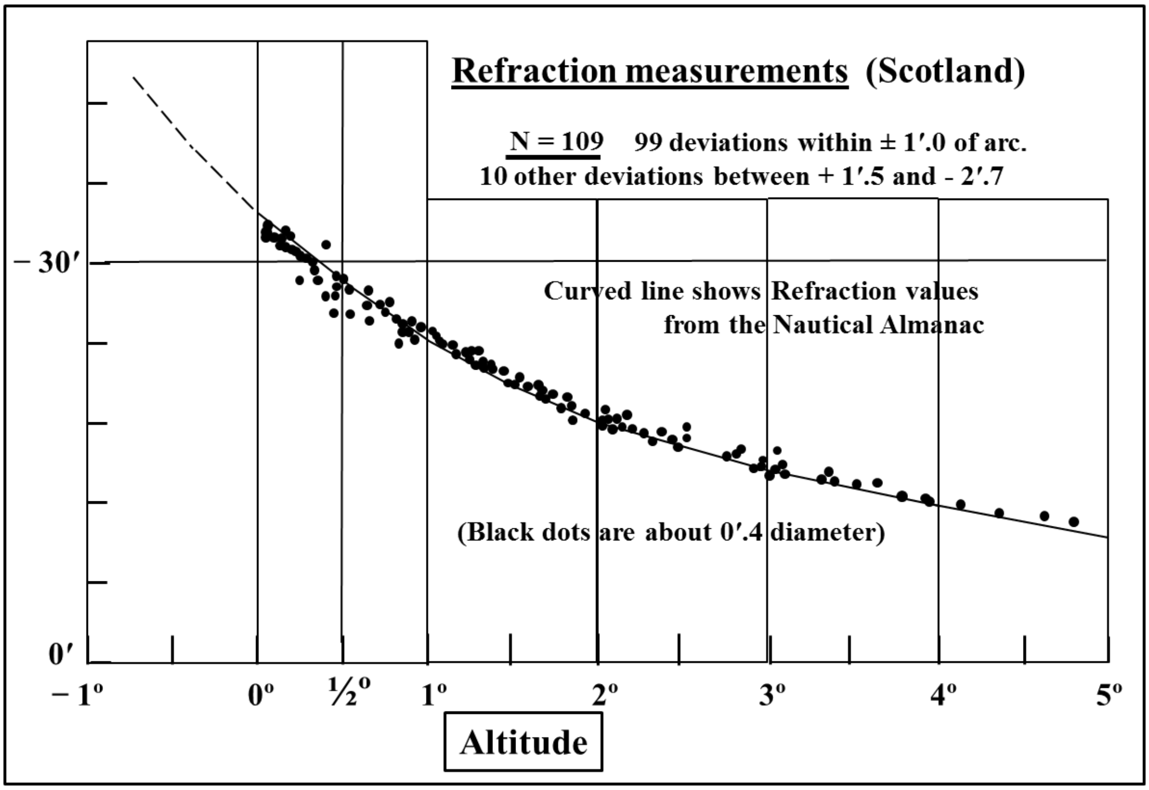

Figure 2. Refraction measurements in Scotland

The large deviations given by Schaefer and Liller, which are not supported by observations in Scotland, can be explained as follows:-

- They consider observations of the sun at the horizon or adjusted to the horizon.
- The Chile observations have negative altitude.
- The sightlines are generally long – especially so from Cerro Tololo.
- The west coast of Chile at the latitude of about 30° south commonly has a temperature inversion layer.
- Day/night temperature variations in the plains of Nebraska are likely to be significant (Schaefer and Liller, 1990, 801).

Schaefer acknowledged that the Chile observations were likely to be affected by temperature inversions. However he claimed that temperature inversions were ubiquitous "…Schaefer and Liller (1990) have shown that significant thermal inversions are ubiquitous and will drastically change the refraction near the horizon." (Schaefer, 1993, 157).

Such a claim, as a general statement, is questionable. In Scotland temperature inversions are not common. When they do occur it is usually on clear, calm nights and in hilly regions. The cold air falls down the hillsides to pool in the valley bottom leaving warmer air above. The inversions are almost always short lived and are easily dispersed by wind or sun.

2.2. LOW ALTITUDE ATMOSPHERIC REFRACTION

In order to avoid as far as possible atmospheric effects, astronomers usually observe celestial objects near culmination. Only with the relatively recent advent of archaeoastronomy, with observations commonly below 5° altitude and even down to 0° altitude, has an interest been taken in low level refraction. Alexander Thom investigated refraction at low altitude. From his home at an elevation of about

140m in south west Scotland there are good views of distant hills, mountains and two lighthouses. In the 1950s he made some 600 theodolite measurements of altitudes in a wide variety of conditions. He was mainly concerned with the effects on refraction of changing temperature gradients. He concluded that the effects could be large but that they were mostly the result of larger than usual temperature gradients near the observer and mainly in the first 100m height above the observer (Thom, 1958, 1971). The variable refraction values for the two lighthouses discouraged him from placing much reliance on potential sites with negative altitudes.

Overall, Thom concluded that while refraction deviation could, on rare occasions, give anomalous results, under normal conditions observations down to an altitude of about 1^o were reliable to ± 0′.5 of arc with almost no problems above about 4^o altitude. (Thom, 1971, 61; 96—7). Later investigations led him by the mid-1970s to the view that lines below 1^o altitude could be reliable, writing: "An examination of the very full table of refraction published by the Nautical Almanac shows that, providing the observed altitude is not negative, there is not much trouble about refraction. We draw attention to work done on refraction measurement (Thom, 1958). At very low and negative altitudes the refraction becomes significant but only a few lines like this exist." (Thom and Thom, 1982, 79—80).

Thom used his many refraction measurements of observed distant features in the altitude range of about $0^o.4$ to $1^o.0$ to determine values for the refraction coefficient. This he defined as $K = rT^2/LP$ where r = observed (terrestrial) refraction in seconds of arc, T = absolute temperature in ^{o}F, L = length of ray in feet and P = barometric pressure (inches of mercury) (Thom, 1958; 1971). , Thom found an average value for K of 7.5 The values varied with the time of day and the seasons; the extreme range of individual results was 5 to 13. The values averaged for time of day were in the range 6.5 to 9.0.

Schaefer (1990, p. 802) analysed Thom's results. He writes:- "If the sight lines that Thom measured are typical for the atmosphere, then K will be proportional to the astronomical refraction." He then discusses how K can be used to estimate the variance in R_o. (R_o is the standard refraction value at 0^o altitude and is about 0^o57 or 35′ of arc.)

He then uses a programme he had written (Schaefer, 1989) and continues:- "Hence, the observed variation in K must be at least doubled so as to get a lower limit on variations in R_o." He goes on to deduce that:- "…the standard deviation of the variation ranged from $0^o.05$ to $0^o.09$…." And:- "As discussed earlier, these variations are likely to be at least doubled when the line of sight extends to outside the atmosphere. Hence Thom's data give a variation in R_o of $0^o.18$ or larger." Finally:- "…for the conditions in Scotland, the astronomical refraction on the horizon has a standard deviation of >$0^o.18$, while the range is >$0^o.62$."

The assumptions that Schaefer uses to obtain this result may or may not be valid, but it does not agree with what is found in Scotland.

It is recognised that the temperature gradient can cause changes in refraction values at low altitude (Schaefer and Liller, 1990, 801; McCluskey, 2017). A study of timed observations of the setting and rising sun was carried out from two very different sites; Edmonton and Barbados (Sampson et al., 2005). Edmonton has a continental climate and experiences large daily temperature variations, whereas Barbados, being surrounded by the sea, has a much smaller temperature variation. Both had nearby research stations making regular weather balloon temperature measurements. The refraction standard deviations at sunset found for Edmonton and Barbados were $0^o.118$ and $0^o.012$ respectively. These values correlated closely with the standard deviation surface temperature gradients which were 0.0405 C^om^{-1} for Edmonton and 0.0065 C^om^{-1} for Barbados.

2.3. *PRECISE LUNAR ALIGNMENTS*

The region of Argyll and the islands of Mull and Islay in western Scotland was investigated. There are 92 standing stone sites in this region. All except four remote sites were visited. Forty two sites could not be assessed due to trees, stones fallen or stones with no indicated direction. The remaining 46 sites were assessed. Standing stones with a flat face, stone pairs and short rows can give an indicated direction.

Fourteen of these sites had no alignment. Eleven of these sites can be explained as probable 'waymarkers'; for example five stones on Mull near the medieval pilgrimage island of Iona (Ruggles, 1984). The other three sites that gave no alignment consisted of a pair, a short row; and a stone that is probably medieval.

The declinations found for the remaining 32 assessable sites, each with an indicated direction, were compared with the key declinations to be expected for the sun and moon in the late Neolithic/Early Bronze Age. Sixteen of the sites gave one or more calendrical alignments (Thom, 1967, 107—117). The remaining sixteen sites all gave lunar alignments. Five of these lunar alignments were very short, each being less than 700m in length, and so may not be reliable. The eleven remaining sites all gave a precise lunar alignment (Gough, 2016). The site of Ford in Argyll is used as an example. Lat. 56^0 10′.5 (NM 8668 0333) Canmore ID 22802 (Figure 3).

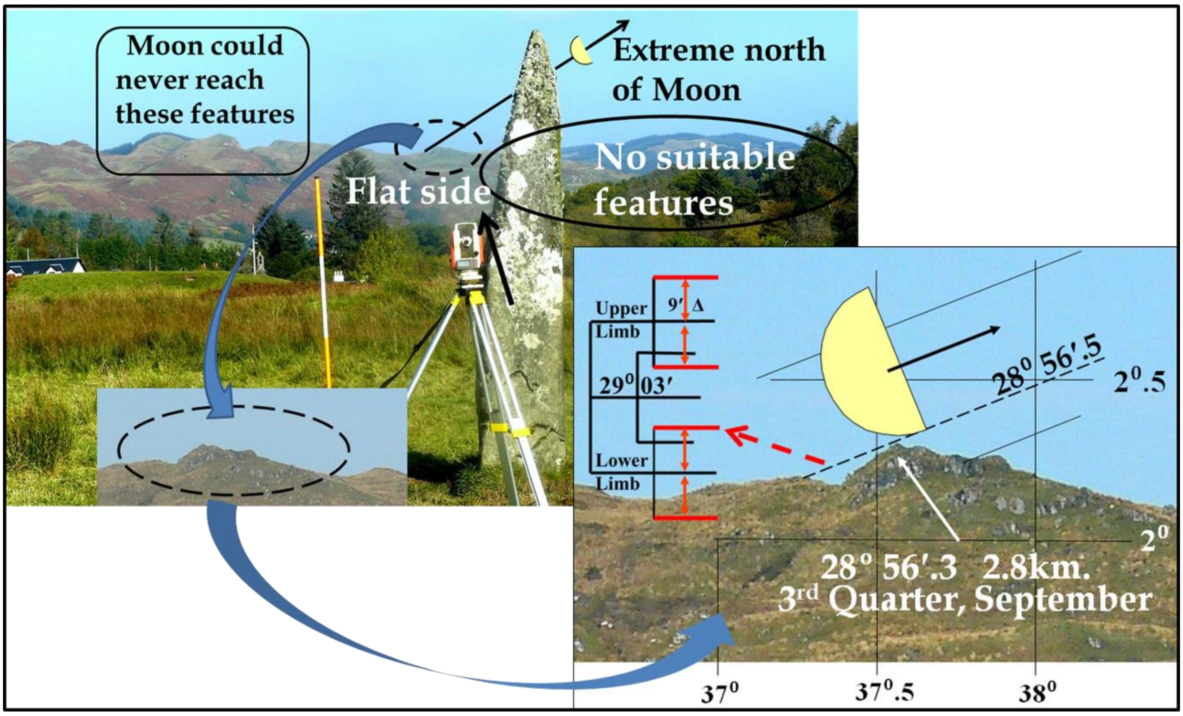

Figure 3. Precise lunar alignment at Ford, Argyll

The flat left flank of the menir indicates the region of a small prominent rocky feature. There are no other suitable horizon features in the vicinity. The moon, *c.* 1700 B.C.E., is at its extreme north with positive 'wobble'. Use of the lower limb would ensure that the moon would be clearly visible before the alignment was reached.

All eleven of the sites had at least one return visit and the details re-measured. The azimuth range determined for each site was typically less that ± 0′.3 of arc. This value includes sun/theodolite measurements used to convert the plate bearing to the true azimuth. In a separate investigation, a total of 1500 degrees of hilly horizon was assessed in order to test for the likely occurrence of chance alignments. These regions contained 30 lunar bands. Three chance alignments were found which is 1 in 10. Thus the possibility that the eleven alignments found could be due to chance is vanishingly small ; $p \approx 10^{-11}$ (Gough 2016).

2.4. THE IMPLICATIONS OF PRECISE LUNAR ALIGNMENTS

As briefly discussed earlier, the claim that Thom's precise lunar alignments were not possible depends upon the large refraction deviations found in Chile and North America which would result in significant azimuth variation and hence declination changes (Schaefer and Liller, 1990, 804—5; Sampson, 2000).

In a later paper Schaefer (2000, p. 126) repeats his claim regarding the effect of azimuth uncertainty with specific mention of Scotland. "For the latitude of Scotland, low horizons will yield a full range of azimuth variations (for a given declination) comparable to a full degree. In essence, for many sites, refraction variation rules out the possibility of high-accuracy alignments."

It should be noted that the eleven precise lunar alignments in the region were all within *c.* ± 2′ of arc of one of the four 'key' declinations. There were no 'near misses'. The measurements made to determine these precise alignments depend upon there being small azimuth variations. It follows that refraction deviations at the time of the measurements must also have been small. Furthermore, if we accept that these alignments were intentionally set up in prehistoric times, with presumably night-time observations, then we can infer that refraction deviations were also small in prehistory; otherwise the alignments could not have been set up.

3. SUMMARY

Refraction deviations sufficiently large to prevent the measurement of precise alignments do occur at altitudes of about 0º, and particularly at negative altitudes. The large refraction deviations found by Schaefer and Liller depends almost entirely upon their observations from high elevation sites and hence with markedly negative altitudes. Thus Cerro Tololo (2215m) and Mauna Kea (4205m) together gave a standard deviation of 0º.27 (16′.2 of arc) while the lower site at Vina del Mar (120m) in the same geographical region as Cerro Tololo, gave 0º.048 (3′.0 of arc) (McCluskey, 2017, 331).

The small refraction deviations found in Scotland by the author are consistent with low temperature gradients. Scotland has a maritime climate under the influence of the North Atlantic Drift, the terrain is generally hilly and it is usually windy. These factors would be expected to have the effect of smoothing temperature anomalies.

During the site assessments, in order to determine the horizon profiles, precise measurements of altitude and azimuth of typically eight horizon features were made at each site. Several of these measurements were re-checked after a few minutes. Nearly all sites had at least one return visit; some two or three returns. Thus in total over a thousand measurements were made. None of these measurements suggested anomalous refraction values.

All but one of the eleven alignments had an altitude above one degree; an altitude region where, in Scotland in the present investigation, the refraction deviations observed were nearly always less than one minute of arc. The majority of Thom's claimed lunar alignments have altitudes above one degree (Thom, 1971, 76).

4. CONCLUSIONS

Schaefer and Liller based their claim that precise alignments in Scotland were not possible on a number of assumptions. Namely: that the large refraction deviations found in some regions of the world can be expected to occur in other unrelated geographical regions including Scotland; that Thom's alignments were of sufficiently low altitude; and that temperature inversions are ubiquitous. The evidence found in Scotland does not support their claim.

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