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The Midwinter Sun at Viking Settlements in North America and the North Atlantic Islands – Calculations Compared with the Icelandic Sagas

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1. Introduction

Half a century ago the remnants of a small short-lived Nordic settlement were discovered and excavated on Newfoundland in eastern Canada; see Ingstad (1965). This was the first archaeological confirmation that Vikings had actually lived on the American continent. The settlement, known as L'Anse aux Meadows, is located at the northernmost tip of Newfoundland. Quite recently another probable Viking settlement was discovered considerably further south, at the other end of Newfoundland, by Parcak (2016). It is known as Point Rosee, and is located on the south-western tip of Newfoundland.

Viking sailings to America are treated already in the old Icelandic sagas. According to them a Norwegian-Icelandic Viking, Eiríkr Rauði (Erik Röde, Erik the Red), moved to Greenland in 985 together with a number of his fellow Icelanders. He had a son called Leif Eiríksson. In the year 1000 Leif sailed with 35 men from Greenland to settle on the east coast of North America, in an area named Vínland by them. A few years later another 160 Vikings, among them Leif's brother and sister, moved to the same place. Thus the first Viking settlement on the American continent was created. However, it lasted for only some years. This was partly because of external problems due to emerging native inhabitants, partly because of internal problems due to the uneven ratio of men to women (there were too few of the latter). Although no permanent settlement seems to have been established, repeated sailings to the American coast have been recorded since then, e.g. in order to cut trees.

Now, in the Icelandic sagas there is some specific information on certain positions of the sun at midwinter as seen from Leif's settlement; the deviation from the corresponding positions at home is pointed out. This information in the sagas might be compared with astronomical calculations of the midwinter positions of the sun. Such calculations and comparisons will be performed here for three locations in North America: the two discovered Viking settlements presented in the beginning and also a suggested one never confirmed by archaeological evidence. In addition, two locations in Greenland and Iceland will be treated. Similar calculations with more limited applications were performed in an earlier publication by the author (Ekman, 2002); the methods used there will be used also here. In order to facilitate the reading the methods will be explained in full also in this publication, with some amendments.

2. The Icelandic sagas and the sun at Leif's settlement

Most of the information on the first Viking settlement in America is to be found in two Icelandic documents dating from about 1250. One is the Eiríks

saga rauða or Eriks Rödes saga, i.e. Saga of Erik the Red. The other is the Grænlendinga saga, i.e. Saga of the Greenlanders. The first one is said to stem from Eirík, the father of Leif who led the first expedition. The second one is said to stem from Thorfinn, the leader of the large expedition a few years later. These two Icelandic sagas disagree on a number of minor points but agree quite well on the main issues.

Leif's settlement in North America was called Leifsbúðir (Leifsbodarna, Leif's sheds), situated at a small inlet called Hóp. In the description of this settlement in the Greenlanders' saga there is a piece of astronomical information of great interest. It says, translated from the version of the text in Larsson (1999):

"The days there were of more equal length than on Greenland and Iceland; the sun had *eyktarstaðr* and *dagmálastaðr* on the shortest day of the year."

The words in italics in the quotation denote certain azimuths (horizontal directions) of the sun, used by the Vikings to specify times for meal breaks at work (Lárusson, 1961). "Eykt" is related to "eight", and connected to their division of the horizon into eight octants, while "dagmál" is related to "daily meal", indicating a meal break.

It is not known exactly what azimuths the Viking explorers meant by the above concepts. However, there is an Icelandic law (Grágás) dating from about 1260, containing a written definition. This definition was interpreted by Storm & Geelmuyden (1886). The law states, according to them:

"It is *eykt* when the sun has passed two thirds of the south-western octant ('útsuðrsætt') and has one third left."

The word *eykt* here is simply the event when the sun is in the horizontal direction of *eyktarstaðr*. This means, as is nowadays mostly accepted, that *eyktarstaðr* corresponds to an astronomical azimuth of

$$a = 45°/2 + 2 \cdot 45°/3 = 52.5°$$

as illustrated by Figure 1 (close to southwest). This was an important azimuth since the sun's position there defined when work was to cease at the last day of the week. *Dagmálastaðr* is the corresponding azimuth on the other side of the meridian, i.e. - 52.5° (close to southeast).

It should be pointed out that the Vikings seem to have been well acquainted with astronomical navigation and, thereby, with observing the

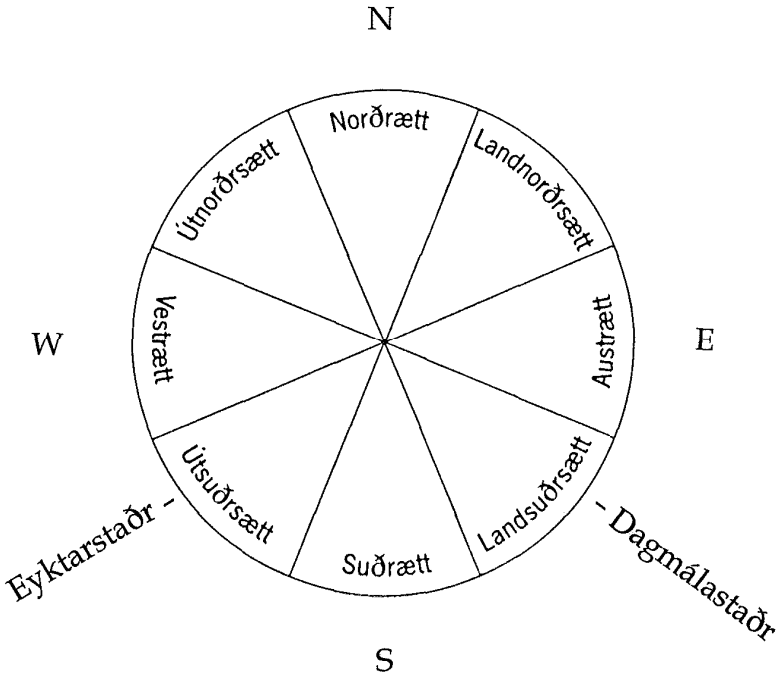

Figure 1. Eyktarstaðr and *dagmálastaðr* in relation to the Viking horizontal octants and the four cardinal points.

altitude and azimuth of the sun. Around 1150 Oddi Helgason, known as Stjörnu-Oddi ("Star-Oddi"), made a compilation of the sun's daily maximum altitude on Iceland during the course of a year (Barfod, 1967; Ekman, 2011), a quantity useful for navigation. The altitudes there are given in "half wheels", one "wheel" being equal to the sun's angular diameter.

We will now perform various solar calculations to investigate how different locations of Viking settlements agree with the solar information in the Greenlanders' saga and the old Icelandic law.

3. The sun's midwinter altitude at *eyktarstaðr* in North America

We first calculate the altitude of the sun at *eyktarstaðr* on the shortest day of the year, i.e. at midwinter, for the two hitherto known or probable Viking settlements in North America. These are, as said in the Introduction, L'Anse aux Meadows on northern Newfoundland, discovered by Ingstad (1965), and Point Rosee on south-western Newfoundland, discovered by Parsac (2016). In addition we include Chegoggin on southern Nova Scotia, suggested by Larsson (1992, 1999) as the location of Leif's settlement on the basis of the Icelandic sagas, modern maps and personal travels.

The altitude (height) h of the sun above the horizon can be computed by applying spherical trigonometry to the fundamental astronomical triangle; see Figure 2. The spherical law of cosines yields

$$\sin\delta = \sin\varphi\sin h - \cos\varphi\cos h\cos a \qquad (1)$$

(see e.g. Smart, 1962). Here φ is the latitude of the settlement, a is the azimuth of the sun, and δ is the declination of the sun. In our case we want to study the sun at the shortest day of the year, i.e. at winter solstice. Hence h must be a small quantity, allowing us to safely put cos h = 1. This makes it possible to solve (1) for h through

$$\sin h = \frac{\sin\delta + \cos\varphi\cos a}{\sin\varphi} \qquad (2)$$

The sun's azimuth at *eyktarstaðr* is, according to Section 2, a = 52.5°. The sun's declination at midwinter, i.e. at the winter solstice, is equal to the inclination of the ecliptic to the equator. This inclination undergoes a slow decrease due to the gravitational attraction of the planets on the Earth,

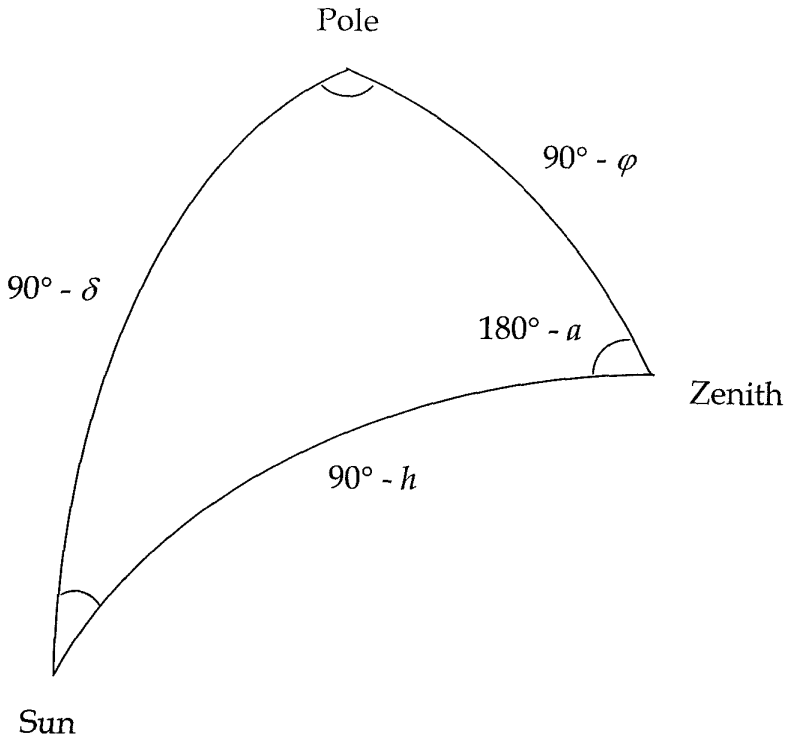

Figure 2. The fundamental astronomical triangle involving the sun.

perturbing the Earth's orbit around the sun. The inclination and, thereby, the sun's midwinter declination for the year 1000 can be calculated according to Meeus (1991); we find δ = - 23.6° (today - 23.4°). Inserting the above values together with the latitudes of the actual and suggested settlements into (2) we obtain values of the altitude h. However, at low altitudes like this, refraction in the atmosphere will cause the sun to be observed slightly higher than at its astronomical position, at the altitude h_o. The refraction is a function of the altitude of the sun as given e.g. by Hoyle (1977). For the three cases we now obtain the following results.

Case 1: L'Anse aux Meadows, φ = 51.6°:

h = - 1.6°, h_o = - 1.2°

Case 2: Point Rosee, φ = 47.8°:

h = 0.7°, h_o = 1.2°

Case 3: Chegoggin, φ = 43.9°:

h = 3.2°, h_o = 3.4°

Thus, at L'Anse aux Meadows the midwinter sun at *eyktarstaðr* would be below the horizon by 1.2°, at Point Rosee above the horizon by 1.2°, and at Chegoggin above the horizon by 3.4°. The sun's angular diameter is 0.5°, so that in terms of the Viking unit of wheels (sun diameters) the sun at this event could not be seen at all at L'Anse aux Meadows, whereas it could be seen 2 wheels above the horizon at Point Rosee, and 7 wheels above the horizon at Chegoggin. Consequently, at the two latter places the sun would have been visible at *eyktarstaðr* at winter solstice, as described in the Greenlanders' saga. At Point Rosee it would have been visible just above the sea horizon, at Chegoggin also in a moderately hilly landscape (e.g. just above a 60 m hill at a 1 km distance).

4. Error in altitude due to uncertainty in *eyktarstaðr*

How accurately could the Vikings determine the position of the sun in the sky? And how much would an error in the determination of *eyktarstaðr* influence the observed altitude of the sun?

An estimate of the uncertainty in the determination of the position of the sun may be given by the errors in Stjörnu-Oddi's solar table. According to

Ekman (2011) the error in the observed altitudes of the sun there amounts to ½° - 1°. Assuming, for safety's sake, the error in observed azimuths under the American circumstances to be twice as large, we might consider a possible error in observed azimuth here to be between 1° and 2°.

Now, from equation (2) we may conclude that an error Δa in the azimuth of the sun would cause an error Δh in its altitude of

$$\Delta h = 0.7\ \Delta a$$

This relation is valid under the conditions given by the numerical values in Section 3. Thus an error in the determination of *eyktarstaðr* of between 1° and 2° (3 wheels) would cause an error in the observed altitude of the sun of 1° (2 wheels). Applying this to L'Anse aux Meadows we find that this is not sufficient to turn the invisibility there of the sun at *eyktarstaðr* into visibility. Applying it in the opposite way to Point Rosee we find that this is not sufficient to turn the visibility there of the sun into invisibility. Thus, even allowing for a reasonable observational uncertainty, L'Anse aux Meadows does not agree, while Point Rosee does agree, with the solar information in the Icelandic sagas.

5. The sun's invisibility at *eyktarstaðr* in Greenland and Iceland

Obviously there is a latitude north of which the midwinter sun cannot be observed at *eyktarstaðr*. This latitude can be found by inserting δ and a from Section 3 into (1), together with h = - 0.6°. The last-mentioned value differs from 0° to compensate for the horizontal refraction. Solving for φ, which requires an iteration, we find φ = 49.9°. A similar result was found already by Storm & Geelmuyden (1886), although their method of calculation was not presented.

Leif and his Viking settlers came from Greenland and were born on Iceland, both on latitudes well north of 49.9°. For how long time during winter was the sun not visible at *eyktarstaðr* there? This can be found out by again using formula (1), now in order to calculate the sun's declination, which varies with the time of the year. Putting cos h = 1 we have

$$\sin\delta = \sin\varphi \sin h - \cos\varphi \cos a \qquad (3)$$

Leif and most of the other settlers came from Brattahlid on south-western Greenland, where φ = 61.0°. They were born in different parts of Iceland, but Iceland can here be represented by its central place Thingvellir,

where $\varphi = 64.3°$. Inserting these latitudes together with $h = -0.6°$ and $a = 52.5°$ into (3), we find $\delta = -17.7°$ for Bratthalid and $\delta = -15.9°$ for Thingvellir. These solar declinations correspond to the dates

11 November - 31 January	for Brattahlid
5 November - 6 February	for Thingvellir

Thus at the Viking home districts in Greenland the sun at *eyktarstaðr* was invisible during winter for nearly 3 months, and in Iceland for precisely 3 months. The visibility of the sun at *eyktarstaðr* even in the middle of the winter at Leif's new settlement in North America must have appeared a considerable contrast to what the Vikings were used to.

6. Conclusions

Our calculations of the midwinter sun at *eyktarstaðr* for the different Viking settlements in North America have shown the following.

1. The Viking settlement at L'Anse aux Meadows on northern Newfoundland does not fulfil the solar condition in the Icelandic sagas. Here the midwinter sun could not be observed at *eyktarstaðr* at all, even allowing for a reasonable observational uncertainty based on that of Stjörnu-Oddi.

2. The recently discovered probable Viking settlement at Point Rosee on south-western Newfoundland does fulfil the solar condition in the Icelandic sagas. Here the midwinter sun at *eyktarstaðr* could be seen by the Vikings 2 wheels (sun diameters) above the sea horizon, enough for also allowing an observational uncertainty of the kind above.

3. Any point on the south coast of Newfoundland with a view over the sea, as well as points further south, would fulfil the mentioned condition. On southern Nova Scotia, at the suggested but never confirmed settlement there (Chegoggin), the midwinter sun at *eyktarstaðr* would be seen 7 wheels (sun diameters) above the sea horizon. It could also be observed there in a moderately hilly landscape.

The corresponding calculations for the central Viking places in Greenland and Iceland have shown the following, in contrast to above.

4. At Brattahlid in Greenland the sun was impossible to observe at *eyktarstaðr* for nearly 3 months during winter.

5. At Thingvellir in Iceland the sun was impossible to observe at *eyktarstaðr* for a full 3 months during winter.

Referring to the recently discovered probable Viking settlement on south-western Newfoundland the results in this publication show, for the first time, that Vikings in North America most likely did observe the midwinter sun at *eyktarstaðr* as stated in the Icelandic sagas.

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