Navigation of the *James Caird* on the Shackleton Expedition

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In 1916, Frank A Worsley famously navigated the 22½ foot (6.9 m) *James Caird* from Elephant Island to South Georgia Island on a mission to seek rescue for the other 22 men of the Shackleton Expedition. The 800 nautical mile (1,500 km) journey remains one of history’s most remarkable feats of seamanship in a small boat on treacherous seas. The contents of the original log book of the voyage, housed at Canterbury Museum in Christchurch, New Zealand, have been interpreted. Photographic images of the navigational log book are provided along with a transcription that allows all characters to be read. The numbers appearing in the log have been independently recomputed and the navigation principles and procedures used to obtain them explained in detail.

**Keywords:** celestial navigation, chronometer, dead reckoning, Elephant Island, Ernest Shackleton, Frank Worsley, Imperial Trans-Antarctic Expedition, *James Caird*, noon sight, time sight, South Georgia

**Introduction**

The Imperial Trans-Antarctic Expedition of 1914 under the command of Sir Ernest Shackleton consisted of 28 men and planned to cross the Antarctic continent from the Weddell to the Ross Sea via the South Pole. Their vessel, *Endurance*, captained by New Zealand born Frank Worsley, departed the Grytviken whaling station, South Georgia on 5 December 1914. *Endurance* became trapped in sea ice and was eventually crushed and abandoned on 27 October 1915. Camping on the ice until 9 April 1916, the Expedition launched three small boats from a point 60 nautical miles (110 km) from Elephant Island. They reached Cape Valentine on the eastern tip of Elephant Island on 15 April and relocated to Wild Camp near Cape Belsham on the northern coast on 17 April.

Currents and prevailing winds made reaching Cape Horn or the Falkland Islands an unlikely prospect and favoured South Georgia as a possible destination where help could be sought. With the Antarctic winter approaching, Shackleton, Worsley and four others set off on 24 April in the 22½ foot (6.9 m) *James Caird* that had been modified and heavily ballasted for the journey. Their success in reaching South Georgia was due in no small part to Frank Worsley’s superlative skills as a navigator and seaman. Under conditions that were physically challenging and permitted only a limited number of celestial sights to be taken, he was able to navigate to South Georgia and eventually land on 10 May.

The original log book from the voyage resides at Canterbury Museum. Its contents would have been familiar to any practising navigator of the time but generally the numbers that appear are sparsely labelled, which makes their meaning challenging for the modern reader to decipher. Moreover, the methods of celestial navigation
employed by Worsley, although common at the
time, differ from the standard practice as it is
taught today.

The purpose of this paper is to preserve an
understanding of the navigational calculations
that Frank Worsley performed in order to
complete the crossing to South Georgia. The
section ‘Nautical Navigation – Definitions
and Principles’ discusses celestial navigation
generally and the methods used in computations
distance and course. The section entitled
‘Frank Worsley’s Navigation’ describes in detail
how the navigation was done in practice during
the voyage. The key component in determining
longitude is the maintenance of an accurate time
standard which is discussed in the section ‘Time
Keeping’. The ‘Locations’ section lists the places
mentioned in the log and discusses how their
positions were determined. A brief outline of the
voyage is then given followed by a description
of some of the specifics of the log itself. It was
found that with effort all entries in the log could
be read and its pages accurately transcribed.
The pages from the original log are shown
interleaved with their transcription in Appendix
A. Using the input information that Worsley had
available, the calculations in the log have been
labelled and replicated in Appendix B.

**Nautical Navigation – Definitions and
Principles**

This section defines the various navigational
quantities used in the computations that appear
in the log book. Enough detail is provided to
give the reader an accurate understanding of the
underlying principles involved. The explanations
are expected to be intelligible to someone with a
working knowledge of basic trigonometry. No
attempt has been made to trace the historical
developments leading up to the terms or
methods described as this is considered to be
beyond the scope of this work.

**Celestial Navigation**

A navigator can estimate a vessel’s position by
carefully keeping track of its speed and course
from a known starting point by a process known
as ‘Dead Reckoning’ (DR). Over time, errors
accumulate and it is necessary to correct the DR
position using celestial navigation to obtain a
fix. This corrected position will be referred to as
an ‘Observed Position’ (OP), which is consistent
with terminology used by Worsley (1916b).

In traditional navigation, numbers are
unsigned but have an associated name of N, S,
E or W. Rules on when to add or subtract are
applied according to whether the values are
of the same or contrary name. Following this
tradition, values in the formulas that follow
are taken to be positive and the arithmetic
operations shown are those relevant to the
navigation of the *James Caird*, i.e. the observer’s
latitude and longitude are S and W respectively
and the Sun’s declination is N.

Celestial navigation uses the measured
altitude of a celestial body, such as the Sun,
to determine the observer’s location on the
Earth. The altitude, as measured by a sextant,
gets various corrections applied to it and then,
along with the time of observation, is used to
determine the side lengths and vertex angles of
the Navigational or PZX Triangle on the celestial
sphere. When that triangle is projected onto the
Earth’s surface a spherical triangle like the one
shown in Figure 1 is created.

The particular navigational triangle in Figure
1 represents a sight made by Worsley on the
afternoon of 7 May 1916 when he was located at
the point labelled Z nearing South Georgia. The
sextant is used to measure the angular distance
from the horizon generally to the lower limb
of the Sun. The result is commonly denoted as
$H_s$. Sight reduction, however, requires the true
altitude of the Sun's centre, $H_o$, which is obtained
by applying various corrections to $H_s$. Principal
amongst these are:

- **Dip of the horizon**: The finite size of the Earth
causes the horizon to be depressed from the
horizontal direction by an amount that varies
as the square root of the height of the observer’s
eye.

- **Refraction**: The bending of light by the Earth's
atmosphere causes objects to appear higher than
they actually are. The effect is greater the closer the object is to the horizon.

Semi-diameter: If $H_s$ is measured to the Sun's lower limb it must be increased by half the Sun's angular diameter to get to the centre.

The value of $H_o$ provides a direct measurement of the angular side length of the navigational triangle labelled Zenith Distance, which will be denoted ZD. The zenith is the point directly overhead at the observer's position and hence $ZD = 90° - H_o$.

The point labelled X is the sub-solar point or the location on the Earth where the Sun appears directly overhead at the time the sight was made. It is determined by calculation from information in the *Nautical Almanac* and by reading Greenwich Mean Time (GMT) from a ship’s chronometer. The angular distance of the sub-solar point, X, from the South Pole, P, is the Polar Distance (p.d.) and is related to the Sun’s declination, $\delta$, by p.d. = $90° + \delta$.

If the observer’s latitude at the point Z is denoted $L$ then the length of the remaining side of the triangle is the colatitude, $90° - L$.

The angle LHA at the South Pole vertex of the navigational triangle is the Local Hour Angle. It is the angle measured from the observer’s meridian in a westerly direction to the meridian through the Sun.

At Local Apparent Noon (LAN), the Sun is on the observer’s meridian making LHA = 0 and the navigational triangle collapses into a line shown dashed in Figure 1. In that case it is evident that p.d. = ZD + colatitude, which may be rearranged to $L = ZD - \delta$. Thus measuring the Sun’s altitude as it crosses the meridian allows the observer’s latitude to be directly determined. This is the ‘noon sight’, which is the simplest sight to make and reduce.

Greenwich Mean Time is a uniform time scale determined by the average or mean motion of the Sun and is read from clocks and chronometers synchronised with those at Greenwich. Apparent Time is the time measured by a sundial or sextant with noon occurring when the Sun crosses the observer’s meridian. The elapsed time between successive meridian passages can differ over 24 hours by up to 30 seconds. The cumulative effect is that the Apparent Time will lead or lag the Mean Time by up to 15 minutes approximately, depending on the time of year. The difference is called the Equation of Time: $EqT = \text{Apparent Time} - \text{Mean Time}$. It was a key quantity in the navigation of the time and was tabulated in detail along with the Sun’s coordinates in the *Nautical Almanac*.

Measuring the angle LHA gives the Local Apparent Time (LAT) elapsed since LAN. Greenwich Apparent Time (GAT) is obtained by adding $EqT$ to the GMT determined by means of a chronometer. The difference between GAT and LAT, when converted to angular measure, gives the ship’s longitude.

Note that the LHA is not measured directly. Rather the Sun’s true altitude, $H_o$, its declination, $\delta$, and the observer’s latitude, $L$, are combined to compute the LHA. This procedure is known as taking a time sight.

Conversely if the observer is at a position of known longitude, its difference from the longitude obtained from the time sight allows the chronometer error to be determined. This

![Figure 1](image-url)
process is called rating the chronometer.

**Distance and Course**

Although generally not the shortest route, for practical convenience ships tend to follow rhumb line courses in which a constant compass bearing is maintained along the track. On the spherical Earth, calculations of rhumb line distances and bearings are achieved by introducing varying degrees of approximation.

A nautical mile (approximately 1.85 km) in the north-south direction along a meridian subtends 1 arc minute of latitude anywhere on the Earth’s surface, however a nautical mile along a parallel of latitude, \(L\), spans \(\sec(L)\) minutes of longitude. Equivalently a 1 arc minute track along the same parallel is \(\cos(L)\) nautical miles in length. As a ship traverses a track with a north-south component, the ratio of the length of a minute of longitude to a minute of latitude changes continuously but in many situations rhumb line distances and courses can be computed with adequate accuracy by treating the Earth’s surface as if it were a plane rectangular grid with fixed spacing between the lines of latitude and longitude.

If a rhumb line track begins at latitude \(L_1\), and ends at latitude \(L_2\), then under so-called middle-latitude sailing, the ratio of length of a minute of latitude to length of a minute of longitude is taken to be \(\sec(M)\) where \(M = \frac{1}{2} (L_1 + L_2)\) is the average of the beginning and ending latitudes.

**Frank Worsley’s Navigation**

Worsley performed a combination of noon sights for latitude and time sights for longitude. He used traverse tables to adjust the longitude to account for the vessel’s run until or since noon and obtained a noon position that was entered into the log book. Today this would not be considered modern navigation but was the method still in widespread practical use at the time. The modern approach relies on plotting a line of position (LoP) on which the observer is located. It is tempting to speculate on how feasible it would have been to perform this technique in the wet and violently moving environment of the *James Caird*.

**Sight Reduction**

The reduction of a celestial sight to obtain a position on the Earth requires:

- corrections for dip of the horizon, refraction, semi-diameter and possibly others to obtain the true altitude of the body above the horizontal or equivalently its true zenith distance
- coordinates in the sky of the body observed
- a means of performing calculations involving trigonometric functions.

For these purposes Worsley had his navigation books of which he says:

*My navigation books had to be half-opened, page by page, till the right one was reached, then opened carefully to prevent utter destruction. The epitome had had the cover, front and back pages washed away, while the Nautical Almanac shed its pages so rapidly before the onslaught of the seas that it was a race whether or not the month of May would last to South Georgia* (Worsley 1998: 116).

The epitome here refers to a navigational text providing the altitude correction and containing logarithm and trigonometric tables. The position of the Sun is taken from the monthly pages of the *Nautical Almanac*.

**Noon Sights**

Weather permitting, noon sights are the easiest sights to perform. Near the time of LAN the Sun’s altitude is watched until it peaks. As it approaches maximum, it slows and the altitude remains fairly constant over the course of several minutes and accurate timing is not required.

Noon Sights appear in the log on 26 and 29 April. As discussed in the section on celestial navigation, the reduction is a simple arithmetic evaluation of

\[ L = ZD - \delta \]  

and is laid out in the form
Observed altitude of Sun's lower limb  \( H_s \)

True altitude of Sun's centre  \( H_o \)

Sun's true zenith distance  \( ZD=90°−H_o \)

Sun's declination  \( \delta \)

Latitude  \( L=ZD−\delta \)

The boxed quantities are to be entered.

On 4 May, the log shows the inverse of this calculation being performed in preparation for a noon sight that is unrecorded. The DR latitude and Sun's declination are used to compute the altitude at which the Sun's lower limb is expected to be observed. This would then be used to preset the sextant to simplify taking the sight.

**Logarithms**

Long multiplications by hand are converted into addition by the use of logarithm tables, which considerably reduces the time and effort required and was the standard method used to perform such calculations.

The logarithm of a positive number less than 1 is negative and to avoid the need for subtractions such values are represented with 10 added to them, which effectively serves to track the sign. If the addition of logarithms results in a value greater than 10, then the rule is to reject the 10 and take only the first digit to the left of the decimal point.

Considerable effort was made to arrange calculations in a form that could be efficiently evaluated using logarithms. Equation (2), in which the right hand side is a product of trigonometric functions, is an example of this.

**Time Sights**

The ideal time sight is taken when the Sun is due east or west. The reason for this is that in these configurations errors in latitude have no influence on the resulting longitude. As the Sun moves nearer the meridian the time sight becomes a less sensitive measure of longitude and more susceptible to errors in latitude. Sights taken when the Sun is low to the horizon are subject to increased uncertainties in refraction. Weather or latitude and time of year may limit how far off the meridian the Sun can be usefully observed. During the *James Caird*'s voyage in latitudes between 61°S and 54°S during late April and early May, the Sun rose above the horizon a little north of NNE. A time sight was taken on 26 April at just 56 minutes time from LAN which is far from the ideal geometry, but was the only sight made.

On Elephant Island a time sight was taken to rate the chronometer on 24 April just prior to departure. Time sights underway were made on 26 and 29 April, 3 and 4 May and three on 7 May. With one exception, all used the Sun's lower limb, which is indicated in the log by the symbol \( O \). One of the sights on 7 May was made through cloud with no clearly defined limb visible. The estimated position of the centre of the Sun was brought down to the horizon and the sight recorded with symbol \( O \). Worsley wrote:

> … the conditions for observing were most unfavourable. It was misty, the boat was jumping like a flea, shipping seas fore and aft, and there was no “limb” to the sun, so I had to observe the centre by guesswork. Astronomically, the limb is the edge of the sun or moon. If blurred by cloud or fog, it cannot be accurately "brought down" to the horizon. The centre of the spot is required, so when the limb is too blurred you bring the centre of the bright spot behind the clouds down to the horizon. By practice, and taking a series of "sights", you can obtain an average that has no bigger error than one minute of arc. (Worsley 1998:137)

To determine longitude, the observer takes a time sight in which the Sun's altitude is measured when it is well off the meridian and obtains the LHA by evaluating the formula

\[
\text{hav}(\text{LHA}) = \sec L \csc\left(\text{p.d.}\right) \times \cos \frac{S}{2} \sin \left(\frac{S}{2} - H_o\right)
\]

where \( S = H_o + L + \text{p.d.} \).
The product of trigonometric functions on the right hand side of equation (2) is an arrangement that can be efficiently evaluated using logarithms. The function hav \( \theta \) is the haversine (half versed sine) and is defined as

\[
\text{hav} \theta = \frac{1}{2} (1 - \cos \theta) = \sin^2 \left( \frac{\theta}{2} \right)
\]

The LHA was then extracted by inverse look up in a table of the logarithms of haversines. When haversine tables are not available, the trigonometric identity to the right allows the LHA to be extracted from tables of logarithms of sines. This introduces additional steps and is not the procedure followed in the log.

Time sight reductions all follow a standard layout shown in Table 1 and is an evaluation of equation (2) using logarithms with the boxed quantities to be entered.

In the course of the calculation, longitudes are expressed both in terms of angles and in time. These are distinguished here by the use of the degree symbol ‘°’ and superscript ‘h’.

In the log book the leading digit is suppressed in logarithms in time sight reductions.

### Distance and Course

For a rhumb line course from a position with latitude, longitude \((L_1, \lambda_1)\) to position \((L_2, \lambda_2)\) lying at a distance \(D\) and course direction \(C\) measured eastward from north the fundamental equations of middle-latitude sailing are:

\[
\begin{align*}
\text{D.Lat.} &= L_2 - L_1 = D \cos C \quad (3a) \\
\text{Dep.} &= D \sin C \quad (3b) \\
M &= \frac{1}{2} (L_1 + L_2) \quad (3c) \\
\text{D.Lon.} &= \lambda_2 - \lambda_1 = \text{Dep.} \sec M \quad (3d)
\end{align*}
\]

D.Lat. and D.Lon. are the changes in latitude and longitude over the track respectively. The quantity Dep. is the distance over ground of the track in the east-west direction along a parallel of latitude. It is the departure from the initial meridian and is confusingly known simply as the ‘departure’. The relationship between these quantities is illustrated graphically in Figure 2 along with the units, nautical miles (NM) and/or minutes of arc, in which they are specified.

The notation and conventions employed here are later used in the discussion of traverse tables.

<table>
<thead>
<tr>
<th></th>
<th>(H_o)</th>
<th>(L)</th>
<th>(\log_{10}\sec L)</th>
<th>(\log_{10}\csc \text{ p.d.})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Latitude</td>
<td>p.d. = 90° + (\delta)</td>
<td>(S = H_o + L + \text{p.d.})</td>
<td>(10 + \log_{10} \cos \frac{1}{2} S)</td>
<td>(10 + \log_{10} \sin (\frac{1}{2} S - H_o))</td>
</tr>
<tr>
<td>Polar distance</td>
<td>(\frac{1}{2} S)</td>
<td>(\frac{1}{2} S - H_o)</td>
<td>hav. (\Sigma = 10 + \log_{10} \text{hav}(\text{LHA}))</td>
<td>reject the 10!</td>
</tr>
<tr>
<td>Sum</td>
<td>(\frac{1}{2} S)</td>
<td>(\frac{1}{2} S - H_o)</td>
<td>hav. (\Sigma = 10 + \log_{10} \text{hav}(\text{LHA}))</td>
<td>reject the 10!</td>
</tr>
<tr>
<td>Half-sum</td>
<td>(\frac{1}{2} S)</td>
<td>(\frac{1}{2} S - H_o)</td>
<td>hav. (\Sigma = 10 + \log_{10} \text{hav}(\text{LHA}))</td>
<td>reject the 10!</td>
</tr>
<tr>
<td>Remainder</td>
<td>(\frac{1}{2} S)</td>
<td>(\frac{1}{2} S - H_o)</td>
<td>hav. (\Sigma = 10 + \log_{10} \text{hav}(\text{LHA}))</td>
<td>reject the 10!</td>
</tr>
</tbody>
</table>

**Table 1.** Standard layout of time sight reductions, which is an evaluation of equation (2).
Traverse Tables

Traverse Tables are essentially look up tables used to solve the unknown parts of plane right triangles such as the one shown in Figure 2. For a given angle, \(C\), and distance, \(D\), traverse tables list \(D\), \(D \cos C\) and \(D \sin C\) in columns typically labelled Dist., D.Lat. and Dep. respectively. Tabulated values for \(D\) extend up to a few hundred nautical miles. The tables are shown stylistically below

<table>
<thead>
<tr>
<th>Traverse Table</th>
<th>(C^\circ)</th>
<th>Dist.</th>
<th>D.Lat.</th>
<th>Dep.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td>-</td>
</tr>
<tr>
<td>(D\rightarrow)</td>
<td>(D \cos C)</td>
<td>(D \sin C)</td>
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</tr>
</tbody>
</table>

From equation (3d), \(D.Lon. = \text{Dep.} / \cos M\). This calculation may be done by reverse look up of the value of Dep. in the D.Lat. column of the traverse table for course, \(M\), and reading D.Lon. from the Dist. column.

<table>
<thead>
<tr>
<th>Traverse Table</th>
<th>(M^\circ)</th>
<th>Dist.</th>
<th>D.Lat.</th>
<th>Dep.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tr>
<tr>
<td>(D.Lon.\leftarrow)</td>
<td>(\text{Dep.})</td>
<td>-</td>
<td>-</td>
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<td></td>
</tr>
</tbody>
</table>

In practice this may require interpolation in one or both of \(M\) and Dep.

When the required distances exceed the tabulated range in the tables, the values for some fraction of the required distance can be looked up and the final results scaled up accordingly. This technique was used in the log book with a scale factor of \(1/2\) to compute the remaining distance and course to the destination on 29 April and

Figure 2. Graphical representation of quantities used in rhumb line course and distance calculations. NM indicates that a value is expressed in units of nautical miles

3 May but not on 4 May or subsequently as the remaining distance then fell within the range covered by the tables.

Dead Reckoning by Traverse Table

For a known course, \(C\), and distance run, \(D\), the traverse table immediately gives D.Lat. and Dep. For an initial position with latitude, longitude \((L_1, \lambda_1)\) the middle latitude is then:

\[
M = L_1 + \frac{1}{2} \text{D.Lat.} \tag{4}
\]

The longitude difference, \(D.Lon\), is then obtained by reverse look up of Dep. in the traverse table for latitude, \(M\). The DR position, \((L_2, \lambda_2)\), is

\[
L_2 = L_1 + \text{D.Lat.} \\
\lambda_2 = \lambda_1 + \text{D.Lon.}
\]
In the log this calculation is used in two ways:

1. The boat’s position at noon on the previous day is advanced by the distance and course of the day’s run to give the boat’s DR position at noon for the current day.

2. The estimated latitude and observed longitude from a time sight is advanced or retarded by the distance and course run to noon.

**Distance and Course to Destination by Traverse Table**

Before setting out on the voyage of the *James Caird*, Worsley performed a direct calculation of the course and distance from Cape Belsham to a point 46° of longitude or 27 nautical miles (50 km) west of Wallis Island off South Georgia using rearrangements of equations (3).

On the voyage he made use of traverse tables. From the boat’s current position \((L_1, \lambda_1)\) the distance and course to the destination \((L_2, \lambda_2)\) is required.

D.Lat. and D.Lon. are obtained by equation (3a) and (3d) with the middle latitude, \(M\), being computed by equation (4). Looking up the value of D.Lon. in the column labelled “Dist.” of the traverse table for latitude, \(M\), allows the corresponding departure value to be read from the column labelled “D.Lat.” because, from equation (3d), \(\text{Dep.} = \text{D.Lon.} \cos M\).

In practice when the middle latitude, \(M\), is not close to an integer the procedure may be performed for adjacent values, one above and one below, and the value of Dep. computed by interpolation.

The distance, \(D\), and course, \(C\), to the destination are then extracted from the traverse table by a reverse look up in two variables. The traverse table is searched for a location where the values obtained for D.Lat. and Dep. are found together in their respective columns. The distance is then read from the Dist. column and the course from the angle at the top of the table in which the values are found.

**The Navigator’s Daily Work**

Weather permitting, the navigator took an antemeridian (A.M.) time sight when the Sun lay sufficiently far off the meridian. The altitude was measured, and the chronometer time noted, but the observation was not reduced at that time, because the knowledge of the actual latitude was lacking. The latitude by dead reckoning from the previous noon was maybe 21 hours old, and therefore less reliable. It was better to wait until noon, only a few hours ahead, to get a latitude determination that was nearer in time to the longitude observation.

At noon, the navigator determined his latitude as the Sun culminated, i.e. reached its greatest altitude, bearing due north. This noon latitude was then moved backwards to the time of the A.M. observation. The course and distance sailed between the A.M. observation and noon were estimated and with the aid of the traverse tables, D.Lat. was found and combined with the noon latitude to get the latitude to insert into the time sight formula, equation (2). The A.M. longitude was calculated as described earlier and then moved forward to noon using the D.Lon. Thus the day’s noon position by observation was determined.

If no A.M. sight was possible for any reason, then a post-meridian (P.M.) sight for longitude could be used together with the noon latitude, to determine the noon position. The work involved is analogous to that already described, the difference was only that the noon latitude was moved forward to the time of the P.M. sight and the resulting longitude moved backwards to noon.

The dead reckoning position at noon was also noted. If no celestial observations were possible on a particular day, dead reckoning was continued until an observed position was available. That observed position was then used as the starting point for next day’s dead reckoning.

A day in this context is the interval between two successive LAN’s. If sailing eastwards, the day’s length was less than 24 hours; if sailing westwards a little more than 24 hours.
Time Keeping

The LHA of the Sun is measured westwards from the observer’s meridian and gives LAT directly. It is therefore quite natural and convenient that in nautical time keeping for the purposes of celestial navigation, a new day was taken to begin at noon. The zero hour in time then occurs when LHA = 0. In 1916, the *Nautical Almanac*, in common with *Astronomical Ephemeris*, tabulated positions for Greenwich noon. This is the 0 hour in the Julian Day system, which continues to be used in astronomical applications today. Worsley records his chronometer times using this astronomical time convention. Dates given in the log, however, follow common civil reckoning. In some cases in the log, 24 hours is added to the time to facilitate the calculation of longitude.

The Chronometer

The determination of longitude requires GMT as read from the ship’s chronometer and it is crucial that its error and rate be accurately determined. Writing approximately 7 years after the voyage, Worsley gave the following description: ‘This English chronometer, an excellent one of Smith’s, was the sole survivor, in good going order, of the twenty-four with which we set out in the *Endurance*.’ (Worsley 1998: 101). In the log it is referred to by the serial number 192/262 and takes the form of a large pocket watch that is now in the collection of the Scott Polar Research Institute of Cambridge University, United Kingdom (Reference number: N: 999a). Worsley describes how in the trek across South Georgia, ‘I carried…the chronometer, with which I had navigated the boat. This was slung around my neck by lampwick, inside my sweater, to keep it warm.’ (Worsley 1998: 191).

Although Worsley never mentions it directly there is some evidence for a second chronometer aboard the *James Caird*. The National Maritime Museum in Greenwich, United Kingdom houses a chronometer by Thomas Mercer (Object Id: ZAA0029) that is ‘Believed to have been used on Shackleton’s 800-mile open boat journey to South Georgia on the *James Caird*, after his ship the *Endurance* was crushed in ice.’ This is a boxed chronometer and in its lid there is a note stating: ‘Punta Arenas, 14th Sept 1916, Watchmaker Fallor No. 985 Calle Roca has overhauled & placed in repair to my satisfaction, the chronometer used by me in the relief of my men on Elephant I’, E. H. Shackleton.

Even if not in full working order, it may have been used for timing short intervals such as when sight times are averaged as in the log on 26 April where a correction given as ‘Fast 29’ is applied and again on 3 May where ‘Slow 46’ appears. Neither value is consistent with the known error for the Smith chronometer. The correction is thus most probably the difference between the Mercer and the Smith, a comparison between the two being made either immediately before or after the sights were taken.

Rating the Chronometer

In the early twentieth century marine chronometers were mechanical devices, essentially a spring clock. The chronometer was wound each day at the same time, in the same way, so as to use the same portion of the spring. Extraordinary care was taken to not expose the chronometer to variations in temperature in order to minimise the drift. Nevertheless mechanical chronometers of the time were subject to certain systematic errors. Chronometer Error (CE) is the difference, fast or slow, between the chronometer’s time and GMT. Chronometer Rate (CR) is the rate of change of the CE and stated as the number of seconds gained or lost per day. The determination of the CE and CR was a critical task of the celestial navigator and they would be measured and recorded as the opportunity arose. This procedure is known as rating the chronometer. It was the norm for any given chronometer to have an associated CE as they would almost never be reset to GMT. Rather the recorded CE was updated by the CR daily. A CR of zero seconds per day indicates that the chronometer is running at a constant rate and acting as a perfect clock. On 24 April 1916 the Smith chronometer was determined to have a
CE of 11°55′ slow and a CR losing 5′ per day.

As noted earlier rating the chronometer can be performed by comparing the longitude of a known position with the longitude obtained by a time sight but a number of other methods exist. In particular the timing of the disappearance and/or reappearance of stars in lunar occultations provides a means of determining CE. This method was also used by Worsley and Reginald James, expedition physicist, to rate the chronometers.

In March 1916, while camped on the drifting ice of the Weddell Sea, Mount Percy on Joinville Island off the tip of the Antarctic Peninsula came into view. James wrote: After the crushing of the ship on October 27, 1915, no further occultations were observed, but the calculated rates for the watches were employed, and the longitude deduced, using these rates on March 23, 1916, was only about 10′ of arc in error, judging by the observations of Joinville Land made on that day. (Shackleton 1920 Appendix 1).

In the log entry for 24 March, Worsley makes several notes that show he was using Nordenskjöld’s book (Nordenskjöld and Andersson 1905) as his chart reference for latitudes and longitudes of known headlands. However, he describes the charts as evidently only intended for the general public thus not the close accuracy of [position] for Mt Percy necessary to correct [chronometer] and consequently ‘will not allow any change to [chronometer] in [the] meantime.’ (Worsley 1916a: 86).

The original page from the log and its full transcript can be found in Appendix A.

New opportunities to rate the chronometers arose when Clarence Island was sighted on 7 April, 1916 (Shackleton 1920) as their entrapment in the ice was coming to an end. The navigational log book (Worsley 1916a: 88) states: ‘of Clarence Pk [to] be 61°12′ S + 53°40′ W [would] make my [chronometer] 192/262 [too] far East, or in other words it is 50 seconds slower than I had: This conclusion is based on the observation that on 9 April, while under way to Elephant Island, their dead reckoning position fell 12.5′ west of expectations.

Amongst the materials housed at Canterbury Museum is the detached page of the log containing entries from 4–8 September, 1915. On its back (Worsley 1916a: 12) a table can be faintly seen listing the daily anticipated CE from 10 to 26 April 1916 based on a CR of losing 5 seconds per day. These values cover the period of the Expedition’s passage from the icepack to Elephant Island. They show the adjustment of 50 seconds slower being applied to the CE on 18 April which is the day following the Expedition’s arrival at the relative safety of Wild Camp on Elephant Island. The CE for 24 April is given as 10°51′ slow.

On Elephant Island on 24 April 1916, the morning of departure of the James Caird for South Georgia weather conditions permitted a time sight to be made. Worsley (1916b) wrote ‘I jubilantly welcomed this opportune appearance of the sun for without it we should have been placed in a still more difficult & dangerous position making S. Georgia than we were.’ and in (Worsley 1998: 101) ‘Immediately after breakfast the sun came out obligingly. The first sunny day with a clear enough horizon for rating my chronometer.’ No noon sight for latitude was possible.

Using the CE of 10°51′ the log entry for 24 April gives the longitude from the time sight as 54°19′45″W. Comparing this to the assumed longitude for Cape Belsham of 54°50′W indicates that the chronometer had lost an additional 2°1′ and gives a CE of 12°52′. Worsley apparently rejected this result as being too large and chose instead to ‘allow 1 minute + 4 sec more slow’ yielding a CE of 11°55sec slow’ with the justification that the longitude of Cape Belsham is ‘only approximately known.’ The CE of 11°55′ slow is underlined in the log and the CR is taken to be losing 5 seconds per day. The log entry for 25 April shows a table of the anticipated CE for each day based on these values.
The adjustment effectively moves Cape Belsham 14'25" or 7 nautical miles to the east of its previously assumed position and provides some safety margin against overshooting South Georgia. In the log entries for 26 and 28 April, Worsley corrects his longitude by 16' to the west. The reason for this is unclear but it effectively undoes the earlier easterly adjustment. It is not done subsequently and the time sights on 4 and 7 May were reduced using a CE of 12°45' and 13' slow respectively without further correction.

On sighting South Georgia on 8 May Worsley (1916a) in his log concludes that ‘[Latitude] proved to be correct within about 2 [miles. Longitude] ditto but [chronometer] was much slower than I had allowed which made us about 20 [miles or] so distance further astern than [observation] showed’.

At that time the course was roughly easterly and at 54°S latitude the distance of 20 miles translates into an additional CE of around 2½ minutes slow. Of this 57 seconds is accounted for by the adjustment made to the time sight on 24 April and the remainder is consistent with a CR of 10 seconds per day rather than 5.

It should be noted that numbers in the diary (Worsley 1916b), which was likely written sometime after the voyage took place, differ from those in the log. For 24 April a CE of 12°52' slow is given with a CR losing 7 seconds per day. The stated CE is as it was obtained from the time sight at Cape Belsham without adjustment and the CR may have been inferred from it.

### Locations

The log lists a number of locations and the positions that Worsley had for them.

- **Cape Belsham**: 61° 4' S 54° 50' W
- **Wallis Island**: 54° 0' 38° 14'
- **Bird Island**: 54° 0' 38° 0'

Cape Belsham is a prominent headland to the west across the bay from the small Cape Wild (now Point Wild). This is where the Expedition finally encamped after their initial landing on Cape Valentine on the eastern tip of Elephant Island. The bay was given the name West or Glacier Bay and has the Furness Glacier at its head. A survey map of the area by expedition member Reginald James (Wordie 1921: 24, fig. 4; Burley 1972: 307, fig.3) is shown in Figure 3. The landforms are distinctive and leave no doubt as to the location of the camp or the geographic feature that the Expedition identified as Cape Belsham. In his diary, Worsley (1916b) uses the phrase ‘Cape Belsham (where our camp was situated)’ and both he and James adopt the same longitude for Wild Camp and Cape Belsham.

In Worsley’s own words, the longitude of Cape Belsham is ‘only approximately known to us’ (Worsley 1916a). This introduced a potential uncertainty for navigation as its position was used to rate the chronometer. In his diary, Worsley states that he ‘assumed’ the position of Cape Belsham, an uncertainty that surely bedevilled him.

It is known that Worsley based his estimate for the position of Cape Belsham on ‘doubtful little chartlets in Nordenskjöld’s book, *Antarctica*’ (Worsely 1916b). The reference here is to Nordenskjöld and Andersson (1905) and the chartlet on page 77 of that volume² bears the caption ‘The latest map of W. Antarctica before the Belgian [1897-1898] and [Nordenskjöld’s] Swedish [1901-1904] expeditions (after Fricker)’.

Neither of the referenced expeditions visited Elephant Island. As indicated it is an English relabelling of a chart appearing in Antarktis

<table>
<thead>
<tr>
<th>Longitude of Cape Belsham</th>
<th>54° 50’ 0”</th>
</tr>
</thead>
<tbody>
<tr>
<td>Longitude by Time Sight</td>
<td>54 19 45</td>
</tr>
<tr>
<td>Difference</td>
<td>30’ 15”</td>
</tr>
<tr>
<td>Difference in time</td>
<td>2m 1s slow</td>
</tr>
<tr>
<td>Chronometer Error</td>
<td>10m 51s</td>
</tr>
<tr>
<td>“allow”</td>
<td>1 4</td>
</tr>
<tr>
<td>Adjusted CE</td>
<td>11m 55s</td>
</tr>
</tbody>
</table>

² In Worsley (1916b), the caption for this chartlet reads: ‘The latest map of W. Antarctica before the Belgian [1897-1898] and [Nordenskjöld’s] Swedish [1901-1904] expeditions (after Fricker)’.
(Fricker 1898: 122), which in turn was taken from Stieler’s Hand-Atlas (Stieler 1891 No. 7). The area of the chartlet around Elephant Island is shown at twice actual size in Figure 4. Given its small scale of 1:8,000,000, it is remarkable that the position Worsley obtained for Cape Belsham is within 2¼ nautical miles of the position as it is known today.

Leith Harbour, on the northern shore of South Georgia where the Stromness whaling station was located, is mentioned as being 62 nautical miles (115 km) from Wallis Island and 53 nautical miles (98 km) from Bird Island, which both lie to the west of South Georgia.

Figure 3. Survey map by Reginald James from May 1916 showing the location of and area surrounding Wild Camp where 22 members of the Shackleton Expedition spent 4½ months awaiting their eventual rescue on 30 August 1916. Reproduced by permission of The Royal Society of Edinburgh from Wordie (1921). All rights reserved.

Figure 4. Section of the chartlet from Nordenskjöld and Andersson (1905: 77) used for the estimation of the longitude of Cape Belsham on Elephant Island. Shown twice actual size. All rights reserved.
The Voyage to South Georgia

Despite the obvious perils that the voyage to South Georgia in a small boat entailed, Worsley was confident in his abilities while also being aware of Shackleton's unvoiced concerns: ‘For me, used to boat work, surf landings and every kind of craft, this passage was an adventure - a too uncomfortable and dangerous one - but still an adventure. To him [Shackleton]…it must have been more menacing, even appalling.’ (Worsely 1998: 107).

The James Caird was prepared for the journey but in Worsley’s opinion was over ballasted by about five hundredweight (250 kg), which made it slow, stiff and jerky: ‘It kept us constantly wet all passage, so causing much unnecessary misery.’ (Worsley 1998: 103).

Shackleton, Worsley, McNish the carpenter and three others set sail around noon on 24 April 1916. After battling gale force winds and being struck by what would today be recognised as a rogue wave (Worsley 1998: 130), on 8 May the presence of seaweed and increasing bird life indicated that land was near. The DR position at noon fell at a point in the interior of South Georgia and within about half an hour land was sighted almost exactly 14 days since their departure. Hurricane force winds from a south westerly direction forced them to beat off the lee shore until they subsided and the crew were only able to land in King Haakon Sound after nightfall on the 10th.

Figure 5 shows a sketch map in the collection of Canterbury Museum of the area surrounding King Haakon Bay signed by F A Worsley.

![Figure 5](https://example.com/figure5.jpg)

Figure 5. Frank Worsley’s sketch map of King Haakon Bay and its surroundings. Canterbury Museum 2001.177.19
Figure 6 shows the track of the *James Caird* from Elephant Island to South Georgia showing positions from the log book at noon each day. Dead reckoning (DR) positions are shown as open circles, \(\bigcirc\), and observed positions (OP) as solid dots, \(\bullet\). The dotted line is the rhumb line course from Cape Belsham on Elephant Island to a point 27 nautical miles west of Wallis Island.

Figure 6 shows the track of the *James Caird* from Elephant Island to South Georgia. The plotted positions are those given in the log at noon each day. Dead reckoning positions are denoted by open circles and observed positions that have been corrected by noon or time sights are shown as solid dots. The observed position on 26 April and dead reckoning position on 27 April lie only half a nautical mile apart and are shown as half solid and half open dots. The dotted line is the rhumb line from Cape Belsham on Elephant Island to the point 27 nautical miles (50 km) or 46' of longitude west of Wallis Island. In this Mercator projection the length scale in the legend is drawn for latitude 57°34' S, which is the rhumb line's middle latitude. The track made good is generally held to windward of the direct rhumb line and begins to turn east when the parallel of South Georgia is reached some 150 nautical miles (250 km) west of the island. This is a seaman-like approach that gives margin for uncertainties in longitude.

On 7 May, Worsley recounted: ‘I told Sir Ernest that I could not be sure of our position to 10 miles, so he would not agree to my trying to weather the northwest end of South Georgia, for fear of missing it. We then steered a little more easterly, to make landfall on the west coast.’ (Worsley 1998: 138).
The Log Book of the James Caird

Pages of the original log book of the James Caird (Worsley 1916a) are reproduced in Appendix A along with their transcripts keeping as close as possible to the format of the original. The numbers in the log have been used to replicate, annotate and explain the calculations as shown in Appendix B.

In both the log and the transcript, noon positions by Dead Reckoning are underlined while Observed Positions are double underlined. In some cases the D.Lat or D.Lon. used to obtain these positions are seen faintly nearby in the log book pages.

Throughout the log Worsley records the wind speed using terms such as ‘moderate breeze’ and ‘gale’ that are associated with well-defined ranges on the Beaufort Wind Force Scale. On 7 and 8 May, Beaufort Weather Codes are used to record the conditions: ‘BC[partly cloudy] to 6 A[M] when it became foggy’ and ‘wind NxE [Beaufort] 5–6 O[vercast]M[ist]R[ain]’ (Worsely 1916a).

The log ends on 13 May, 1916 with a noon sight taken near a small cove on the south side of King Haakon Bay, as shown in Figure 5, where they had landed a few days earlier. Shackleton (1920, Ch. IX: 190) writes, ‘A noon observation on this day gave our latitude as 54°10’47” S., but according to the German chart the position should have been 54˚12’ S. Probably Worsley’s observation was the more accurate.’

Shackleton is correct in his assessment but as it turns out the outcome is largely fortuitous. In the log the correction of 9’20” applied to the Sun’s lower limb is consistent with incorporating the dip of a sea horizon. From the cove, the north shore of King Haakon Bay lies at a distance of around 2 nautical miles and for the stated height of eye of 12 feet no sea horizon is visible. The Sun’s altitude would be measured from the far waterline, which requires that the dip short of the horizon be used and for which the appropriate total altitude correction is 8’30”. However, in addition the Sun’s declination was entered in the noon sight reduction as 18°22’53” N. This is obtained by interpolating values tabulated daily in the Nautical Almanac (1916:51) but should actually be 18°23’53” N. Astoundingly, this is the only such error made during the voyage of the James Caird and it almost exactly cancels the error in the dip leading to the stated latitude of 54°10’47” S being very close the true value.

Acknowledgements

This project began with an obscure listing to Worsley’s navigational logbook at Canterbury Museum. The information contained therein was cryptic, washed out and smudged. Instead of a great read of a heroic journey, it turned out to be a grand puzzle. I (Brad Morris) mentioned that I had a copy of the log in passing and George Huxtable leaped forward, playing the critical role in cracking the code. George has passed, but we could not have done this without him. Thank you again George! Other members of NavList (www.fer3.com/navlist) have contributed over the years, until nearly every character has been decided. It may be impossible for us to recall each individual, yet Henry Halboth stands out as a major contributor in helping to decipher the chronometer issue. The authors also thank David Castle for locating and making available information in Worsley’s diary (Worsley 1916b).

Endnotes

1. In its modern incarnation the Nautical Almanac also gives the altitude corrections along with sight reduction tables for line of position navigation.
2. In addition to the chartlet on page 77 (Nordenskjöld and Andersson 1905), there is a fold-out chart at a scale of 1:5,000,000 attached to its back cover. This chart shows Elephant Island displaced to the east and it is unlikely that it was used as the source of Cape Belsham’s longitude.
References


Appendix A

Images of pages from Frank Worsley’s Navigational Log Book (Worsley 1916a) that relate to the navigation of the *James Caird* from Elephant Island to South Georgia over the period 24 April to 13 May 1916 are shown here along with their transcriptions. The log book is damaged with rips, smudges and water immersion. In the process of transcription every effort has been made to preserve the spacing and actual characters used by Worsley.

Also shown is the log entry and its transcript for 24 March 1916 when Worsley attempted to rate his chronometers using Mount Percy on Joinville Island while camped on the Weddell Sea ice.
Cape Delahay 61°48' 54°50' W Dec 10.19649
46 W of Wallace 54°40' 39°0 + Log Dist 2.623.25
420 950 - = Log Dist 2.819.74 = 661
Cos In Lat 57°34' = 9.729.42
Log Dist 69.50 2.917.17
12.707.14 56.20
Yulete High 1.75
Log Dist 410 2.623.25
= Yan Co = 50°30' E 10.08 33.59

Monday, April 24th

Wild Camps for Rating Chart 1968

10.51
24°00 10 8°21' 1/2 AN 71.4: Rd 55.0 61.4 215.24 Could be obtained 4
24°01 54 102°51' 191.03 Long of Delahay being
21°4° 35' 12°17 827.95 wind 60° 30°
2°17 1.9 86°85 996.05 102, allow 1 minute
54°19' 48' 77°47 144 37 slow = 11.55 Sec slow

York departure from Wild Camps in James Cares at 22

North from Cape = WSW 60° 1/2

19° April 25th 12°0 9.60 Losing 5 Sec
30° 12.19
28° 12.15
29° 12.29
80° 12.25
**Navigation of the James Caird on the Shackleton Expedition**

<table>
<thead>
<tr>
<th>Location</th>
<th>Bearing</th>
<th>Course</th>
<th>Distance</th>
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</thead>
<tbody>
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<td>Cape Belsham 61°4'S 54°50'W</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>46°W. of Wallis 54°4 39 0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>+Log Dlat</td>
<td>2.623 5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>= Log Dist</td>
<td>2.81974</td>
<td>= 661</td>
</tr>
<tr>
<td>Cos M Lat 57°34'</td>
<td></td>
<td>9.729.42</td>
<td>To Wallis = 27</td>
</tr>
<tr>
<td>Log DLong 950</td>
<td></td>
<td>2.977.22</td>
<td>To Leith Harb 62</td>
</tr>
<tr>
<td></td>
<td>+Log DLat</td>
<td>2.623 25</td>
<td></td>
</tr>
<tr>
<td>=Tan Co=N50°30'0'E</td>
<td></td>
<td>10.083 89</td>
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**Monday April 24th**

Wild Camp for Rating Chron

<table>
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<tr>
<th>Time</th>
<th>Course</th>
<th>Bearings</th>
<th>Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>24.40.1</td>
<td>Q</td>
<td>8°21 ½’ AM Sext</td>
<td>No Obs for Lat</td>
</tr>
<tr>
<td>+ 1 53</td>
<td>61.4</td>
<td>315.34 cd be obtained +</td>
<td></td>
</tr>
<tr>
<td>24 41 54</td>
<td>102.51 ½</td>
<td>011.03 Long. of C. Belsham being</td>
<td></td>
</tr>
<tr>
<td>21 4.35</td>
<td>172.17</td>
<td>827.95 only approx known to</td>
<td></td>
</tr>
<tr>
<td>3.37.19</td>
<td>86.8 ½</td>
<td>990.05 us, allow 1 min +4 sec more</td>
<td></td>
</tr>
<tr>
<td>54°19’45”</td>
<td>77.47</td>
<td>144 37 slow = 11 min 55 sec slow</td>
<td></td>
</tr>
</tbody>
</table>

PM

Took departure from Wild Camp in “James Caird” at 12/30
Steered NNE 8° then E1° to a break in the stream ice here being
E+W. Mean of Courses to noon on 25th = N64°-Wind to 4° WNW6-
to 6ASE to NxE

Tuesday to Noon to West 6-4

**Tuesday April 25th**

North 64° from CWild = WSW 6 o’cast 60°0’S 54°50’W

<table>
<thead>
<tr>
<th>Time</th>
<th>Course</th>
<th>Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chron 192</td>
<td>April 25th 12°0’ slow losing 5 sec</td>
<td></td>
</tr>
<tr>
<td>26°</td>
<td>12 5</td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>12 10</td>
<td></td>
</tr>
<tr>
<td>28°</td>
<td>12 15</td>
<td></td>
</tr>
<tr>
<td>29°</td>
<td>12 20</td>
<td></td>
</tr>
<tr>
<td>30°</td>
<td>12 25</td>
<td></td>
</tr>
</tbody>
</table>
Wednesday April 26

DR N S 110 ° 77.8 77 8 155 54.4 54.5
23 29
4 26.9 2.26 6 0.15 50 AM N 5 59 46 5 04 48
30 10 + 2 15 59 50 298 85
23 1 4 5 2 28 21 103.3 10 19 23
2 26 18 6 11 119 12 24 93 W SW Gale 45 20
2 26 22 10 89 36 98 23 49 cloudy
50 32 30 72 46 1.37 34 Heavysnow 59 47 44

Thursday 27 April

Chron 10.3 12 10 121 N 59 46 50 48
N 24 Gale W SW Gale equally

Friday 28 April

59.52 S 50.0 W allowing 50.0
Light N NW with W SW Gale
114 4 more Slow rain for rain
Wet NW NW Gale
Camps 50 16 Chron 12 15 15 59 52 50 16

Saturday 29 April

11 48
10 7 30 N S 110 8 5 DR 2 4 km
4 19 45 12 2 81 86 5.6
58 37 45
24 59 5 11 21 AM
2 24 58 48 28 65 58 28 50 2
2 47 104 28 119 19 99 27 4 16 3 21
2 1 19 41 17 29 61 74
3 12 1 8 47 18 9 36 18
1 1 50 40 75 1 92 9 11
Cloudy, heavy, West
Lumpy Sea
Wednesday April 26th

DR N45°E 110°  =  77.8°  77.8°  = 153°  54°50’  58°42’  52°17’

2.23.29  2.23.29  15°50 AM  2. 33°  NE  W  59°46’  50°48’

26  7  26. 7  2.26. 6 O  15°50 AM  2.15°  59  50°  298.85°

30 10  + 2.15°  5950°  2.28.21°  103.32°  012.23°  16°38°

fast  29°  23.6.11°  179.12°  843.93°  WSW gale  73. 20.30°

2.26. 6  3.22.10°  89.36°  982.33°  sq. cloudy  13°  32.46°

50°32 30’  73.46°  137 34°  Heavy seas  59°47.44°

for ratg  + 16°

50.48.30

Thursday 27th April

Chron 192/262  12°  10°  slow  59°46’  50°48’

N° gale o’cast + misty squally

Friday 28th April

59°52’S 50°0’ W allowing AM o’cast PM Cloud

Light NW to fresh W° o’cast + mist

1st more slow for rating from Wild High NW swell

Camp = 50°16’  Chron 12°15° slow.  59°52’  50°16’

Saturday 29th April

16° 43’

16° 52  30°

73. 7. 30° N35°E85° DR 24hrs  58.42°  48°40°

14. 29. 45° =9.8N6.9E = 13°  58°38°  50°0°

58. 37. 45°  27°W. of Wallis  to 27°W Wallis

24. 59. 5°  11°21’AM  =54°4’39°0’ N53°E  458m

+ 2. 42°  58. 48°  285.65°  58.38.50.0°  N53°E  458m

25 1 47°  104.28°  013.99°  274°  660=365.8  548°

21. 39. 41°  174.37°  671.74°  137°  330°

3. 22. 6°  87.18½  986.83°  56°  184.5°  Fresh W° to WSW breeze

50°31½°  75°. 57½°  958.21°  57°  179.7°  Cloudy+misty High

13½°  4.8°  lumpy sea

50° 18°  1.6°

182.9°

365.8°
Sunday 30th April

DR. N 35°E 78° N 1° 59.4 44.7 84

Hove N SWS gale heavy sea 0° east

Monday 1st May

DR. N 40° E 90°

DWS SSW moderate heavy bumpy

Wood lying 5 Scott heavy faced up 0° east

Tuesday 2nd May

N 50° E 45° Strong SWS

O’Cull Camp

Wednesday 3rd May

SW/S/WS/SSW/WS/SE

Cook 114° W 12° 40° 40° 16° 16° 16° 16° 16°

N 5° E 85 48° 66° 14°

14° 37° 4° 14° 4° 14° 4° 14° 4° 14° 4°

21° 21° 5° 3° 11° 10° 4° 01° 4° 5° 0° 8° 8°

17° 17° 17° 17° 17° 17° 17° 17° 17° 17° 17°

21° 21° 4° 86° 38° 96° 57° 133° 133° 133°

2° 2° 2° 2° 2° 2° 2° 2° 2° 2° 2°

45° 50° 5° 12° 1° E 45° 35° W

Wed 5th May

DWS SWS/SSW light

Good sea, sky swell fine clear

weather. Able to reduce some parts of our clothing from wet and damp.
Sunday 30\textsuperscript{th} April

N 58.38 \textdegree\textdeg 0

DR N35\textdegree E 78 mls 63.9 44.7 = 84

Hove to SW/S gale Heavy sea o'cast

Monday 1\textsuperscript{st} May

DR 57.34 48.36

N40\textdegree E 30m

drift SSW mod gale heavy lumpy sea

boat lying to sea \ding{213} heavily iced up o'cast

Tuesday 2\textsuperscript{nd} May

N50\textdegree E 45m Strong SW/S breeze 57.11 48\textdegree 1'

o'cast lumpy sea 28.9 34.5 56.42 46 58

Wednesday 3\textsuperscript{rd} May

SW/S to W/S mod br A chron 12\textsuperscript{th}40\textsuperscript{s} slow 56\textdegree 42' 46\textdegree 58'

N55\textdegree E 85 48.8 69.6 = 125 55 53 44\textdegree 53'

slow 46 56\textdegree 13' 45\textdegree 38'

24.27 11\textdegree 14' Q AM N33\textdegree E 12 = 12'E

24.27.55 56.23 256.78 Bird I To W.P.\textdagger B.I. N63\textdegree E 294

+ 3.11 105.40 016.44 54\textdegree 0'S 38\textdegree 0'W To Leith Harb \textsuperscript{53}

24.31.6 173.17 767.75 56.13.45.38 347

21.27.44 86.38 \frac{1}{2} 985.76 133. 458=262

3. 3.22 75.24 \frac{1}{2} 026 73 66

45\textdegree 50\frac{1}{2}' W -12\frac{1}{2}' E = 45\textdegree 38' W

Blue sky passg cloud

PM Mod WSW to SSE light. Mod.sea, S ly swell Fine clear

weather Able to reduce some parts of our clothing from wet to damp
Thursday 4th May

DR. N 50° E 80° 49.5 49° 29.8

Winds A N 50° E 5° 3.2 N 3.4 E = 4° 49° 29.8

15° 26.26 D 15° 26 30 AM eye10t

25° 34° 59.2 17° 59.7 16° 59.7 16° 59.7

Noon 145° 9.30 17° 30.5

5° 34° 8 24.7 67

25° 34° 29.1 0.17.09

17° 39° 24 88 34 Q 80 52 C 4 min clear wind clean

44° 50° 15° 72° 58° 64° 40°

Friday 5th May

S E fresh bumpy squally E coast lumpy 55° 39° 44° 43

confused sea 48 W with clear

DR. N 50° E 95°

Walls 54° 48° 35° 14° W

burst of p.m. wind

Banda. N 79° E 163°

Saturday 6th May

Most NW gale E coast clear weather

54° 30° 42° 36°

lumpy N 60° E 1 1 PM. Node E. sea too heavy 1 52

To Caranz.

DR. N 30° E 16° 139° 8.0

1 PM S 80° E 38° 10 1 57° 1

54° 4 38°

Walls 94°

N 76° E 9°
Thursday 4th May

DR N45°E 70° 49.5 49.5 = 88'
Chron A N50°E 5° 3.2N 3.8E = 7'
25.6.26 O 15°26'30"AM eye 10ft
slow 12.45 9.30
25.19.11 15°36' 1.36.52
+ 3.18 55.34 247.61
25.22.29 105.58 017.09
22.23.8 177.8 398.18
2.59.21 88.34 980.52
44°50'15" 72.58 643.40

SE fresh breeze squally o'cast lumpy
confused sea + SW swell clear wr

Fri 5th May

DR N50°E 95°
Wallis 54°4'S 38°14'W
Breeze failg to 8PM when
shifted to NNE light and gusty

Sat 6th May

Mod N/W gale o'cast clear weather
lumpy N° sea 1PM. Hove to, sea too heavy
to carry on.

1916 -
Sunday 7th May

NNW gale still NW and fresh above 100 knots. AM. Then carried on course for 54° 26' 40° 04'.

The land still NW. May 4th. 2nd. 1 4

NW wind. DC. to F. with it, some fog. 54° 28' 39'

DR. S6° E. 12° 6° 0.4 E

N70° E. 2° 9° 36'

N18° E. 18° 4.9

2.5° 24° 3.0

25° 24° 3.4

27° 24° 3.3

17° 24° 3.4

8° 17° 24° 3.2

7° 16° 23° 4.9

11° 15° 24° 3.8

2° 19° 24° 3.6

8° 21° 6.6

1° 54° 11° 5.6

1° 54° 11° 5.6

1° 54° 11° 5.6

1° 54° 11° 5.6

N68° E. 11° 13° 22.

1° 54° 11° 5.6

5° 26° 4.7

5° 26° 4.7

2° 5° 3.4

3° 36° 4.4

39° 11'

39° 34' 4.4

5.10.49 P.M. N68° E. 11° 13° 22.
1916  
Sunday 7th May

NNW gale High NW sea
Hove to till 1AM Then carr'd on again for the land. Mod NW/N breeze + sea + high NW swell. BC to 6 A when it became foggy.

DR S60° E 12m 6S 10.4E 
N70° E 28 9.6 26.3

54°38' 39°36'

Slow 13°0' 3.6N 36.7 38 96

25.24.51 Q 16°55' AM 1 11 41 Bird 1st N56°E 68
+ 3.32 54.39 237.64 Leith Harb 53
25.28.23 106.49 018.98 121
22.48.19 178.23 149.45
2.40. 4 89.11½ 978.88
40° 1' 72.16½ 384 95 Most unfavourable conditions for obs's. Misty with

23.19.38 Q 7°21' AM boat jumping like a flea
+ 3.32 54.4½ 238.09 +no limb for early AM
23.23 10 106.47½ 018.92 sight. Noon Lat prob
20.44 22 168.50 988.08 ably correct within
2.38.48 84.25 988.84 a 10 mile limit
39°42' 77 4 233 93

5.10.14 Q 9°49'P.M. N68°E 14m 5.2 13.0 = 23'
13 54° 8 Lat proved to be correct within
5.23.14 9°57 about 
+ 3.33 54.33 236.58 ^2m Long. ditto but Chron was
5.26.47 106.52 019.10 much slower than I had
2.50 3 171.22 876.62 allowed which made us
2.36.44 85.41 986.40 about 20 miles of distance further
39°11' 75.44 118 70 astern than Obs's showed

23 39.34 Noon
Monday 8th May

Windy, force 4-5 NW. Waves crested east. 5-48. 39 34

12.30 P.M. sighted land approaching 2 miles.

Island NE

Windy, force 4 NE

O'Hara Island

Southwards 1-5 N.W. by d.

3 P.M. Brought out boat and wind N.W. 5-6 O.M.R.

From 2 m. offshore

Very bad lumpy confused sea.

Ward 11 feet narrow & NW increasing to gale with

N. wind & lumpy sea hal

Tuesday 9th May

Very lumpy weather

Windy, force 5-6 NW. By N.E.

Very heavy swell. Height 2-5 meters. Height 8-10 meters. Hardly a breath of wind.

Ward 10-12 feet. Narrow & W. by N. with gale SW. SW.


Wednesday 10th May

At 9 A.M. we fell west of the last land. NW. By N. wind. In brick

Weighed anchor and made for the North End. K. Hackett R. By 6 o'cloc

5 P.M. landed at Cape S. Shortly after K. Hackett D. By 9 o'c

Brookland Farm. Thursday 11th May.


Ward very good but a little rough. Neared E by S.E. by 6 o'cloc

Clear weather some haze.
Monday 8th May

Mod to strong NNW to WNW breezes o’cast
misty + foggy with some clear intervals
W½ + N½ swells + lumpy confused sea
DR N78°E 90° 18.7 88.0 =152

12.30 PM sighted land about 9m ahead, extending 2 miles off Bad Reef

3P.M. stood off Star tack wind NxE 5-6 OMR from 2m off shore Heavy W½-swell
Very bad lumpy confused sea
Stood off for night wind WNW increasg to a gale with rain snow sleet + hail

Tuesday 9th May

rain hail snow sleet
Very heavy WNW to S.SW gale ^ Very heavy swell + high x sea
Nearly blown on shore had to beat under reeferd lug, strain ing boat heavily. With great difficulty cleared main Id + An nenekov Id by dark. Wind soon after S.SW stood West wind + sea moderatg. Heavy W½-swell

Wednesday 10th May

8A Wind fell very light + backed to NW preventing us mak ing towards Wallis Id stood in for K. Hachon B for ice 5PM Landed at Cove S. side ent. to K. Haakon Bay Cd. not haul boat clear of surf Midnight boat broke adrift managed to secure her with 4hrs work + stood by her to daylight

Thursday 11th May

Camped in small cave dried some clothes + began to cut Caird down she being so heavy we cd. not handle her or haul her clear of surf. Noon hauled boat well clear of surf. Cooked old albatross very good but a little tough. Light Mod E to SEly breeze Clear weather some showers
Friday 12th May

Cutting down Cane. Bringing in Cane all the way. Making out the beds. Sheets etc. as far as the area.

Saturday 13th May


1st do. Sails finished. All 4 at Night. To be 17° 17′

9.20

This day corresponds with that 21st. 17° 21 20

Start for inside 4.4.1 H. H. 00 7.30. 6.23 40

May 16th within 1°. My position should be Dec 18. 22. 53.

Then one correct the bearing of the coast. 27 Dec 54. 16. 47 S.
1916
Friday 12th May
Cutting down Caird. Bringing in young albatross for food
devouring to dry clothes with slight success so far as they
are heavily soaked with saltwater. Strong SW breeze
clear wr

Saturday 13th May
Fresh SE breeze. Bright clear weather. Preparing
Caird for pulling up to head of Bay. Clothes getting
moderately dry. Brought in 17 young albatross – 22 to date
+ 3 old birds. Observed Alt of Q at Noon to be 17° 17’
Ht of eye 12 feet 9’20”
This lat corresponds with that of the chart for S. side of ent to K. Haakon Z.D. 72° 33’ 40”
Bay to within 1’. My position should Dec 18° 22’ 53”
therefore correct the drawing of the chart Lat 54°10’ 47 S
here 1’ to N°
Taken from “Chart” in Nordenskjold’s Book.

Mt Percy
63°14’S
55°38’W
= 10 ½ ≈ 23’W of Chron:
not
(Clarence or Elephant if seen soon will give better bearings + a good “fix”)
but I will ^ allow any change to chron in meantime ^ as had we been 10 ½ m. West we wd have passed within 18 m. of the NE Danger in moderately clear weather, in wh: case we should almost certainly have seen it distinctly; whereas we only thought we saw it (It may have been hidden at times by grounded bergs. I do not know its height). Added to not having seen the Dangers or Darwin I, is the fact that the “chart” from Nds book is evidently only intended for the general public thus not the close accuracy of pos^n for Mt Percy necessary to correct chron – our great distance, small change of angle, + a certain amount of doubt as to whether we have got the right point for Mt Percy.
Appendix B

The calculations performed in the original log book of the *James Caird* are replicated here. An attempt has been made to closely mimic the operations Worsley would have performed. When logarithms are calculated they are rounded to 5 decimal places before using them in arithmetic operations. Hour angles are rounded to the nearest second in time before being used to calculate longitude. Occasionally differences in the least significant digit remain. Some numbers given in the log come from table look ups or reverse look ups that require interpolation, which may again lead to small differences. This is particularly the case for D. Lon. used in DR where interpolation has been done. For definiteness, D. Lat. and Dep. are rounded to one decimal place and D. Lon. to the nearest integer before being used in DR calculations.

In a few places where convenient the modern practice of denoting positions in degrees and minutes to the nearest tenth of a minute is adopted.

Underlined noon DR positions and OP’s remain exactly as they were recorded in the log even when the calculations undertaken here yield a slightly different result.

**Initial Distance Calculation**

An initial calculation of the distance and course from Cape Belsham to a point 46' West of Wallis Island is made using equations (3) evaluated by means of logarithms. It is further noted that there are an additional 27 nautical miles (50 km) to Wallis Island itself and thence 62 nautical miles (115 km) to Leith Harbour. This is the only instance in the log where there is evidence of a long hand calculation of this type being performed. Intermediate values were carefully labelled. During the voyage, course and distance to destination were obtained from traverse tables.
<table>
<thead>
<tr>
<th>Location</th>
<th>D. Lat.</th>
<th>D. Lon.</th>
<th>Middle Latitude, M</th>
<th>Course, C</th>
<th>Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cape Belsham</td>
<td>61° 4' S</td>
<td>54° 50' W</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>46' West of Wallis</td>
<td>54° 4'</td>
<td>39° 0'</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D. Lat.</td>
<td>420°</td>
<td>D. Lon.</td>
<td>950°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Middle Latitude, M</td>
<td>57° 34'</td>
<td>log cos M 9.72942</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>log D. Lon. 2.97772</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>log Dep. 12.70714</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>log D. Lat. 2.62325</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Course, C</td>
<td>50° 30'</td>
<td>log tan C 10.08392</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>N50°30'E</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>log D. Lat. 2.62325</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>log sec C 0.19649</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distance</td>
<td>660 miles</td>
<td>log Distance 2.81974</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>To Wallis Island</td>
<td>27</td>
<td>(46° longitude = 27 miles at Wallis Island's latitude)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>687 miles</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>To Leith Harbour</td>
<td>62</td>
<td>749 miles</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Monday, 24th April (Day 1)

Time Sight
For rating chronometer 192/262 at Wild Camp

Chronometer Error  Slow 10 m 51 s
Mean time at Greenwich 24 h 40 m 1 s Sun's true altitude 8° 21.5’ AM
Equation of Time + 1 53 Latitude 61 4.0 sec. 0.31534
Apparent time at Greenwich 24 41 54 Polar distance 102 51.5 cosec. 0.01103
Sum 172 17.0
Apparent time at ship 21 4 35 Half-sum 86 8.5 cos. 8.82795
Longitude in time 3 37 19 W Remainder 77 47.0 sin. 9.99005
Longitude 50° 19 ’ 45 “

Adjustment + 16’ Adjusted Longitude 50° 48 ’ 30 “

Tuesday, 25th April (Day 2)

Noon Position
DR 64 miles north of Cape Wild (61°4’S, 54°50’W):  60°0’S, 54°50’W

Anticipated Chronometer Errors
Chronometer  192  April 25th  12m 0” slow losing 5 seconds per day
262  26th  12  5
27th  12  10
28th  12  15
29th  12  20
30th  12  25

Wednesday, 26th April (Day 3)

Noon Positions
DR N45°E 110 miles from 60°0’S, 54°50’W:  58°42’S, 52°17’W
D. Lat. 77.8  Dep. 77.8 = D. Lon. 153

OP from time and noon sights:  59°46’S, 50°48’W
Navigation of the James Caird on the Shackleton Expedition

Monday, 24th April (Day 1)

Time Sight

<table>
<thead>
<tr>
<th>Sight times</th>
<th>2 h 23 m 29 s</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>26 7</td>
</tr>
<tr>
<td></td>
<td>30 10</td>
</tr>
<tr>
<td>Sum</td>
<td>79 46</td>
</tr>
<tr>
<td>Average</td>
<td>2 26 35</td>
</tr>
<tr>
<td>Chronometer Error</td>
<td>Fast 29 s</td>
</tr>
</tbody>
</table>

Mean time at Greenwich 2 h 26 m 6 s
Sun's true altitude 15° 50.0′ AM
Equation of Time + 2 15
Latitude 59 50.0 sec. 0.29885
Apparent time at Greenwich 2 28 21
Polar distance 103 32.0 cosec. 0.01223
Sum 179 12.0
Apparent time at ship 23 6 11
Half-sum 89 36.0 cos. 7.84393
Longitude in time 3 22 10 W
Remainder 73 46.0 sin. 9.98233
Longitude 50° 32′ 30″
Adjustment + 16′
Adjusted Longitude 50° 48′ 30″

Thursday, 27th April (Day 4)

Noon Sight

Observed altitude of Sun's lower limb 16° 28′
True altitude of Sun's centre 16° 39′ 30″
Sun's true zenith distance 73 20 30
Sun's declination 13 32 46
Latitude 59° 47′ 44″ S

Noon Position

DR: 59°46′S, 50°48′W

Friday, 28th April (Day 5)

Noon Position

DR: 59°52′S, 50°0′W
Alternative DR: 59°52′S, 50°16′W
Assuming the chronometer is running 1′4′ (= 16′ longitude) slow from rating at Cape Wild.
Saturday, 29th April (Day 6)

Noon Positions

DR N35°E 85 miles from 59°52'S, 50°16'W:

58°42'S, 48°40'W

OP from time and noon sights:

58°38'S, 50°0'W

(Null: Noon longitude of 50°18' not transferred to the OP)

Time Sight

Mean time at Greenwich  24 h 59 m 5 s  
Sun's true altitude  11° 21.0 ’ AM
Equation of Time  + 2 42  
Latitude  58° 48.0 sec.  0.28565
Apparent time at Greenwich  25 1 47  
Polar distance  104° 28.0 cosec.  0.01399
Sum  174° 37.0
Apparent time at ship  21 39 41  
Half-sum  87° 18.5 cos.  8.67174
Longitude in time  3 22 6 W  
Remainder  75° 57.5 sin.  9.98683
Longitude  50° 31’ 30”  
  hav.  8.95821

Noon Sight

Observed altitude of Sun's lower limb  16° 43’
True altitude of Sun's centre  16° 52’ 30”
Sun's true zenith distance  73 ° 7 30
Sun's declination  14° 29’ 45”
Latitude  58° 37’ 45” S
### Distance to Destination

<table>
<thead>
<tr>
<th>Date</th>
<th>Distance</th>
<th>Lat.</th>
<th>Long.</th>
</tr>
</thead>
<tbody>
<tr>
<td>OP 29th April</td>
<td>27 miles</td>
<td>West of Wallis</td>
<td>54 4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>D. Lat. 274</td>
<td>D. Lon. 660 =</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Leith Harbour 90

Total 547 miles

Middle Latitude, \( M \) 56° 21’

\( \frac{1}{2} \) D. Lon. 330

\( \frac{1}{2} \) Dep., \( M = 56° \) 184.5

\( \frac{1}{2} \) Dep., \( M = 57° \) 179.7

Difference 4.8

Interpolation for 20’ 1.6

Interpolated \( \frac{1}{2} \) Dep. 182.9

Interpolated Dep. 365.8

### Traverse Table

<table>
<thead>
<tr>
<th>Dist.</th>
<th>D.Lat.</th>
<th>Dep.</th>
</tr>
</thead>
<tbody>
<tr>
<td>330</td>
<td>184.5</td>
<td></td>
</tr>
</tbody>
</table>

Reverse look up for \( \frac{1}{2} \)Distance and Course

\( \frac{1}{2} \)D. Lat. 137.0 \( \frac{1}{2} \)Dep. 182.9

<table>
<thead>
<tr>
<th>Dist.</th>
<th>D.Lat.</th>
<th>Dep.</th>
</tr>
</thead>
<tbody>
<tr>
<td>227</td>
<td>136.6</td>
<td>181.3</td>
</tr>
<tr>
<td>228</td>
<td>137.2</td>
<td>182.1</td>
</tr>
<tr>
<td>229</td>
<td>137.8</td>
<td>182.9</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Dist.</th>
<th>D.Lat.</th>
<th>Dep.</th>
</tr>
</thead>
<tbody>
<tr>
<td>229</td>
<td>137.8</td>
<td>182.9</td>
</tr>
</tbody>
</table>
Sunday, 30th April (Day 7)

Noon Position
DR N35° E 78 miles from 58°38’S, 50°0’W: 57°34’S, 48°36’W
D. Lat. 63.9  Dep. 44.7 = D. Lon. 85

Monday, 1st May (Day 8)

Noon Position
DR N40° E 30 miles from 57°34’S, 48°36’W: 57°11’S, 48°1’W
D. Lat. 23  Dep. 19.3 = D. Lon. 36

Tuesday, 2nd May (Day 9)

Noon Position
DR N50° E 45 miles from 57°11’S, 48°1’W: 56°42’S, 46°58’W
D. Lat. 28.9  Dep. 34.5 = D. Lon. 63

Wednesday, 3rd May (Day 10)

Noon Position
DR N55° E 85 miles from 56°42’S, 46°58’W: 55°53’S, 44°53’W
D. Lat. 48.8  Dep. 69.6 = D. Lon. 125

OP from time sight: 56°13’S, 45°38’W

Position at time sight  56 ° 23 ’ S 45 ° 50 ’ 30 ” W
Run to noon N33°E 12 miles   D. Lat. 10.1  Dep. 6.5 = D. Lon. 12
Noon position  56 ° 13 ’ S 45 ° 38 ’ W

Time Sight

Chronometer Time 24 h 27 m 9 s
Chronometer Error Slow 46 s

Mean time at Greenwich 24 h 27 m 55 s Sun’s true altitude 11 ° 14.0 ’ AM
Equation of Time + 3 11 Latitude 56 23.0 sec. 0.25678
Apparent time at Greenwich 24 31 6 Polar distance 105 40.0 cosec. 0.01644
Sum 173 17.0

Apparent time at ship 21 27 44 Half-sum 86 38.5 cos. 8.76775
Longitude in time 3 3 22 W Remainder 75 24.5 sin. 9.98576
Longitude 45 ° 50 ’ 30 ”

Adjusting longitude 12.5° E gives 45°38’W
### Distance to Destination

<table>
<thead>
<tr>
<th></th>
<th>OP 3rd May</th>
<th>Bird Island</th>
</tr>
</thead>
<tbody>
<tr>
<td>D. Lat.</td>
<td>56° 13′ S</td>
<td>54° 0′</td>
</tr>
<tr>
<td>D. Lon.</td>
<td>45° 38′ W</td>
<td>38° 0′</td>
</tr>
<tr>
<td>Dep.</td>
<td>262</td>
<td>294</td>
</tr>
<tr>
<td>N63°E</td>
<td></td>
<td></td>
</tr>
<tr>
<td>294 miles</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leith Harbour</td>
<td>53°</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>347 miles</td>
<td></td>
</tr>
</tbody>
</table>

#### Thursday, 4th May (Day 11)

### Noon Position

DR N45°E 70 miles from 56°13′S, 45°38′W:

- D. Lat. 49.5
- Dep. 49.5 = D. Lon. 88

OP from time sight:

- 55°31′S, 44°10′W

Day’s Run from 56°13′S, 45°38′W

- N36°E 52 miles
- D. Lat. 42
- D. Lon. 55
- Dep. 30.8

Position at time sight

- 55° 34′ S
- 44° 50′ 15″ W

Run to noon N50°E 5 miles

- D. Lat. 3.2
- Dep. 3.8 = D. Lon. 7

Noon position

- 55° 31′ S
- 44° 43′ W

### Time Sight

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Chronometer Time</td>
<td>25 h 6 m 26 s</td>
<td>Height of Eye</td>
</tr>
<tr>
<td>Chronometer Error</td>
<td>Slow 12 m 45 s</td>
<td>Sun’s lower limb</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Altitude correction</td>
</tr>
<tr>
<td>Mean time at Greenwich</td>
<td>25 h 19 m 11 s</td>
<td>Sun’s true altitude</td>
</tr>
<tr>
<td>Equation of Time</td>
<td>+ 3 18</td>
<td>Latitude</td>
</tr>
<tr>
<td>Apparent time at Greenwich</td>
<td>25 22 29</td>
<td>Polar distance</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sum</td>
</tr>
<tr>
<td>Apparent time at ship</td>
<td>22 23 8</td>
<td>Half-sum</td>
</tr>
<tr>
<td>Longitude in time</td>
<td>2 59 21 W</td>
<td>Remainder</td>
</tr>
<tr>
<td>Longitude</td>
<td>44° 50′ 15″</td>
<td>hav.</td>
</tr>
</tbody>
</table>
Sextant Preset for Noon Sight

| DR Latitude | 55°23′0″ S |
| Sun's declination | 15°59′16″ |
| Sun's true zenith distance | 71°22′16″ |
| True altitude of Sun's centre | 18°37′44″ |
| Altitude correction | 10°44′ |
| Estimated altitude of Sun's lower limb | 18°27′0″ |

Distance to Destination

| OP 4th May | 55°31′S | 44°43′W |
| Bird Island | 54°0′D | 38°0′ |
| D. Lat. 91′ | D. Lon. 403′ = Dep. 233° N69°E 250 miles |
| Leith Harbour | 53° Total 303 miles |

Friday, 5th May (Day 12)

Noon Position

DR N50°E 95 miles from 55°31′S, 44°43′W: 54°30′S, 42°36′W
D. Lat. 61.1° Dep. 72.8° = D. Lon. 127°

Distance to Destination

| DR 5th May | 54°30′S | 42°36′W |
| Bird Island | 54°0′D | 38°0′ |
| Wallis Island | 54°4′D | 38°14′ |
| D. Lat. 26′ | D. Lon. 262′ = Dep. 153° N79°E 164 miles |

Saturday, 6th May (Day 13)

Noon Position

DR from 54°30′S, 42°36′W to 1pm: 54°26′S, 40°44′W

N30°E 16 miles 13.9 8.0
S 80°E 58 miles 10.1 57.1
| D. Lat. 3.8 N | Dep. 65.1 E | D. Lon. 112° |

Distance to Destination

| DR 6th May | 54°26′S | 40°44′W |
| Wallis Island | 54°4′D | 38°14′ |
| D. Lat. 22′ | D. Lon. 150′ = Dep. 88° N76°E 90 miles |
Sunday, 7th May (Day 14)

Noon Position

DR from 54°26′S, 40°44′W: 54°23′S, 39°40′W

S60°E 12 miles  6.0 S  10.4 E
N70°E 28 miles  9.6 N  26.3

D. Lat.  3.6 N  Dep.  36.7 E  D. Lon.  63

OP from time and noon sights:

Position at P.M. time sight  54 ° 33 ′ S  39 ° 11 ′ 0 ″ W
Run from noon N68°E14 miles  D. Lat.  5.2  Dep.  13.0 = D. Lon.  22
Noon position  54 ° 38 ′ S  39 ° 33 ′ W

Time Sights

Mean time at Greenwich  25 h 24 m 51 s  Sun’s true altitude  16 ° 55.0 ′ AM
Equation of Time  + 3 32  Latitude  54 39.0 sec.  0.23764
Apparent time at Greenwich  25 28 23  Polar distance  106 49.0 cosec.  0.01898
Sum  178 23.0
Apparent time at ship  22 48 19  Half-sum  89 11.5 cos.  8.14945
Longitude in time  2 40 4 W  Remainder  72 16.5 sin.  9.97888
Longitude  40 ° 1 ′ 0 ″  hav.  8.38495

Mean time at Greenwich  23 h 19 m 38 s  Sun’s true altitude  7 ° 21.0 ′ AM
Equation of Time  + 3 32  Latitude  54 41.5 sec.  0.23809
Apparent time at Greenwich  23 23 10  Polar distance  106 47.5 cosec.  0.01892
Sum  168 50.0
Apparent time at ship  20 44 22  Half-sum  84 25.0 cos.  8.98808
Longitude in time  2 38 48 W  Remainder  77 4.0 sin.  9.98884
Longitude  39 ° 42 ′ 0 ″  hav.  9.23393
Chronometer Time \(5^h\ 10^m\ 14^s\)
Chronometer Error \(\text{Slow } 13^m\)
Mean time at Greenwich \(5^h\ 23^m\ 14^s\)
Sun's true altitude \(9^\circ\ 57.0'\ PM\)
Equation of Time \(+\ 3\ 33\)
Latitude \(54^\circ\ 33.0\ \text{sec.}\ \ 0.23658\)
Apparent time at Greenwich \(5\ 26\ 47\)
Polar distance \(106\ 52.0\ \text{cosec.}\ 0.01910\)
Sum \(171\ 22.0\)
Apparent time at ship \(2\ 50\ 3\)
Half-sum \(85\ 41.0\ \text{cos.}\ 8.87661\)
Longitude in time \(2\ 36\ 44\ W\)
Remainder \(75\ 44.0\ \text{sin.}\ 9.98640\)
Longitude \(39^\circ\ 11'\ 0''\ h\av.\ 9.11869\)
Correction to Noon \(22\)
Longitude at Noon \(39^\circ\ 33'\)

**Distance to Destination**

<table>
<thead>
<tr>
<th>OP 7\text{th} May</th>
<th>Bird Island</th>
</tr>
</thead>
<tbody>
<tr>
<td>(54^\circ\ 38'\ S)</td>
<td>(39^\circ\ 36'\ W)</td>
</tr>
<tr>
<td>(54\ 0)</td>
<td>(38\ 0)</td>
</tr>
</tbody>
</table>

D. Lat. \(38'\) D. Lon. \(96'\ =\ Dep. \(56\ N56^\circ\ E\) 68 miles

Leith Harbour \(53\)

Total \(121\) miles

**Monday, 8\text{th} May (Day 15)**

Noon Position

DR N78\textdegree E 90 miles from 54°38'S, 39°34'W: \(54^\circ 19'\ S, 37^\circ 2' W\)
D. Lat. 18.7 Dep. 88.0 = D. Lon. 151

**Saturday, 13\text{th} May**

Noon Sight

Observed altitude of Sun's lower limb \(17^\circ\ 17'\)
Corrections (height of eye 12ft) \(9'\ 20''\)
True altitude of Sun's centre \(17^\circ\ 26'\ 20''\)
Sun's true zenith distance \(72\ 33\ 40\)
Sun's declination \(18\ 22\ 53\)
Latitude \(54^\circ\ 10'\ 47''\ S\)