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.

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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 of 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

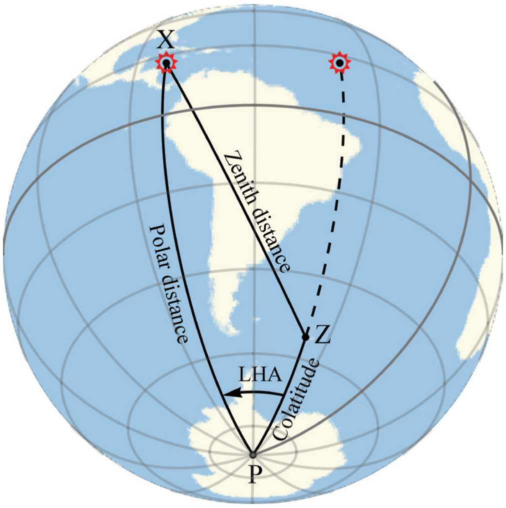

Figure 1. The navigational or PZX triangle for the time sight of 7 May 1916 when the *James Caird* was at the point Z, nearing South Georgia on its voyage from Elephant Island. The dashed line shows the triangle at Local Apparent Noon (LAN) when the Sun is on the observer's meridian and LHA = 0.

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, δ, by p.d. = 90° + δ.

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 – δ. 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 = Apparent Time – 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, δ, 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 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 $M = ½ (L_1 + L_2)$ 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*[1].

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

$$L = \mathrm{ZD} - \delta \qquad (1)$$

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	$\mathrm{ZD}=90°-H_o$
Sun's declination	δ
Latitude	$L=\mathrm{ZD}-\delta$

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 $\underline{\text{O}}$. 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 Θ. 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

$$\operatorname{hav}(\mathrm{LHA}) = \sec L \csc(\mathrm{p.d.}) \times \cos\frac{S}{2}\sin\left(\frac{S}{2}-H_o\right) \qquad (2)$$

where $S = H_o + L + \mathrm{p.d.}$

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 θ is the haversine (half versed sine) and is defined as

$$\operatorname{hav}\theta \equiv \frac{1}{2}\left(1-\cos\theta\right) = \sin^2\frac{\theta}{2}$$

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, λ_1) to position (L_2, λ_2) lying at a distance D and course direction C measured eastward from north the fundamental equations of middle-latitude sailing are:

$$\text{D.Lat.} = L_2 - L_1 = D\cos C \qquad (3a)$$

$$\text{Dep.} = D\sin C \qquad (3b)$$

$$M = ½(L_1 + L_2) \qquad (3c)$$

$$\text{D.Lon.} = \lambda_2 - \lambda_1 = \text{Dep.}\sec M \qquad (3d)$$

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.

Sun's true altitude	H_o		
Latitude	L	sec.	$\log_{10}\sec L$
Polar distance	p.d.=90°+ δ	cosec.	$\log_{10}\csc$ p.d.
Sum	$S = H_o + L$ + p.d.		
Half-sum	$½S$	cos.	$10 + \log_{10}\cos ½S$
Remainder	$½S - H_o$	sin.	$10 + \log_{10}\sin(½S - H_o)$
		hav.	$\Sigma = 10 + \log_{10}\operatorname{hav}(\text{LHA})$
			reject the 10!

Mean time at Greenwich	GMT
Equation of time	EqT
Apparent time at Greenwich	GAT = GMT + EqT
Apparent time at ship	LAT
Longitude in time	λ^{h}= GAT − LAT
Longitude	$\lambda° = 15\,\lambda^{h}$

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

Traverse	**C °**	Table
Dist.	D.Lat.	Dep.
-	-	-
-	-	-
-	-	-
$D \rightarrow$	$D \cos C$	$D \sin C$
-	-	-
-	-	-
-	-	-

From equation (3d), D.Lon. = 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.

Traverse	**M °**	Table
Dist.	D.Lat.	Dep.
-	-	-
-	-	-
-	-	-
D.Lon.	← Dep.	-
-	-	-
-	-	-
-	-	-

In practice this may require interpolation in one or both of *M* and Dep.

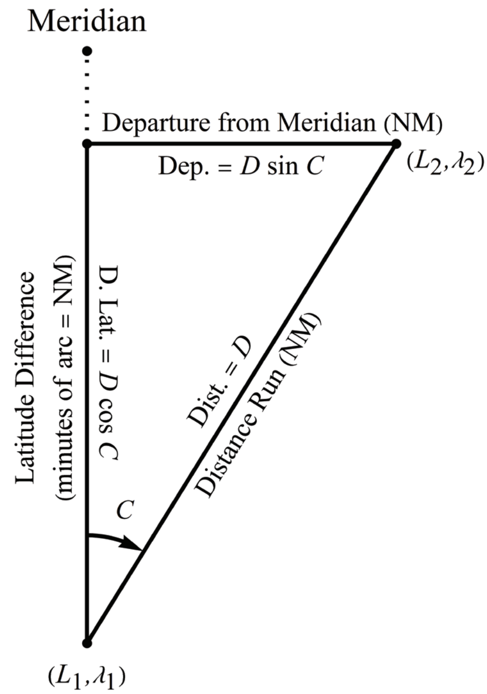

Figure 2. Graphical representation of quantities used in rhumb line course and distance calculations. NM indicates that a value is expressed in units of nautical miles

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 ½ to compute the remaining distance and course to the destination on 29 April and 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, λ_1) the middle latitude is then:

$$M = L_1 + \tfrac{1}{2}\,\text{D.Lat.} \tag{4}$$

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, λ_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, λ_1) the distance and course to the destination (L_2, λ_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), Dep. = 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 ante-meridian (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)[3]. 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)[4] 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$^{\underline{d}}$, 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^m55^s slow and a CR losing 5^s 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^m51^s 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^m51^s 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^m1^s and gives a CE of 12^m52^s. Worsley apparently rejected this result as being too large and chose instead to 'allow 1minute+4sec more slow' yielding a CE of '$\underline{11^{min}55^{sec}}$ slow' with the justification that the longitude of Cape Belsham is 'only approximately known'. The CE of 11^m55^s 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.

Longitude of Cape Belsham	54 °	50 ′	0 ″	
Longitude by Time Sight	54	19	45	
Difference		30 ′	15 ″	
Difference in time		2 ^{m}	1 ^{s}	more slow
Chronometer Error		10 ^{m}	51 ^{s}	Slow
"allow"		1	4	more slow
Adjusted CE		11 ^{m}	55 ^{s}	Slow

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 $12^{m}45^{s}$ and 13^{m} 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 2¼ 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^{m} 52^{s} 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
46' or 27^{m} West of Wallis Island	54	4	39	0
Wallis Island	54	4	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' (Worsely 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 volume[2] 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

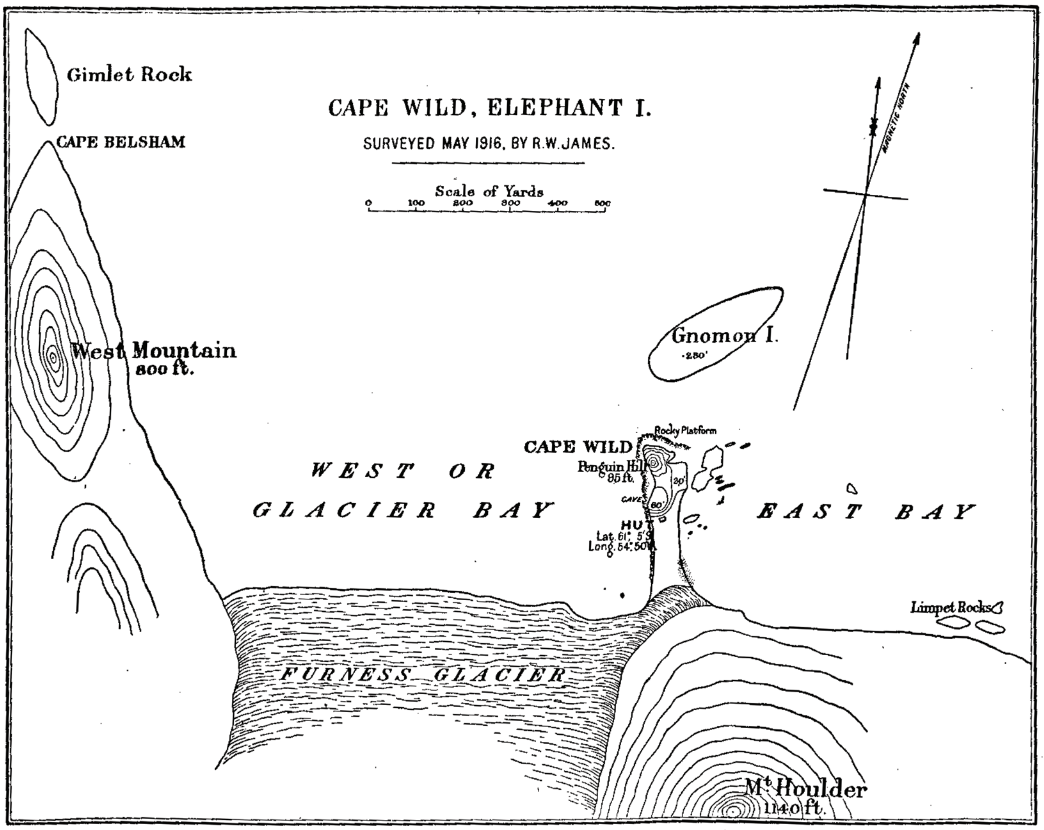

Figure 3. Survey map by Reginald James from May 1916 showing the location of and area surrounding Wild Camp where 22 members of the Shackleton Expedition spent 4½ months awaiting their eventual rescue on 30 August 1916. Reproduced by permission of The Royal Society of Edinburgh from Wordie (1921).

(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 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.

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.

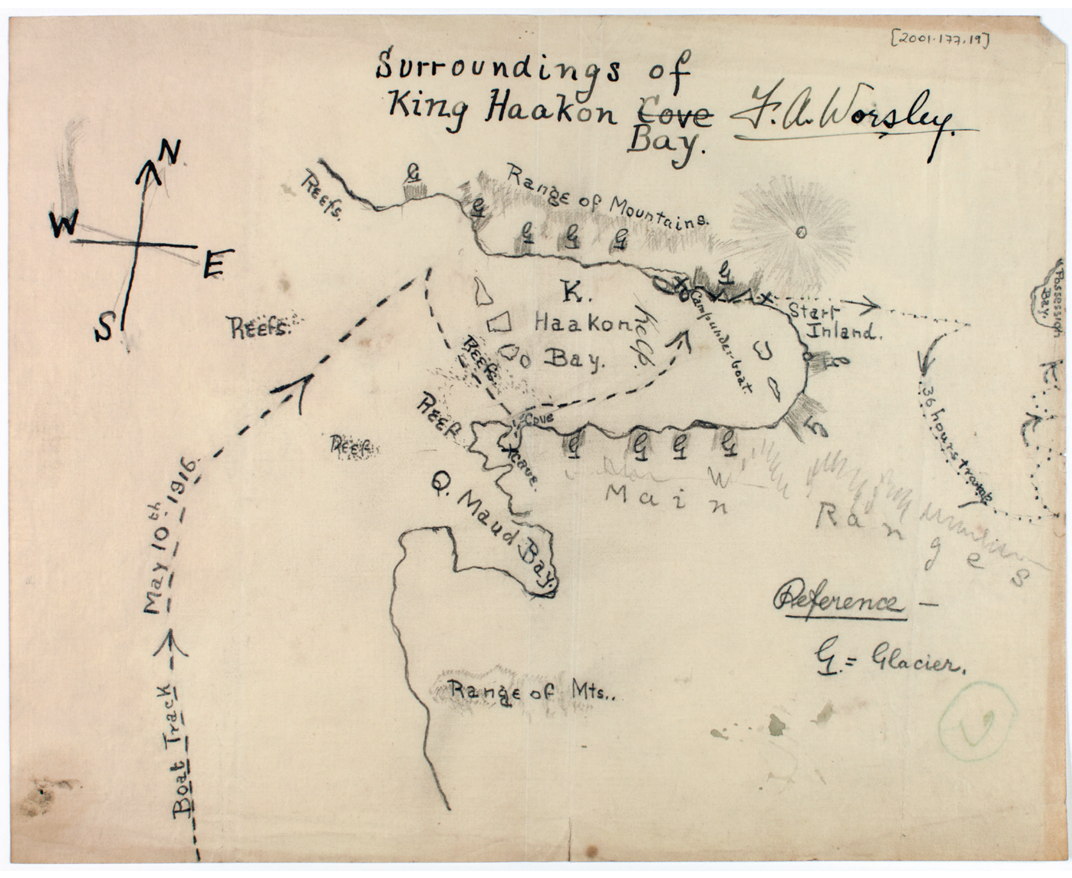

Figure 5. Frank Worsley's sketch map of King Haakon Bay and its surroundings. Canterbury Museum 2001.177.19

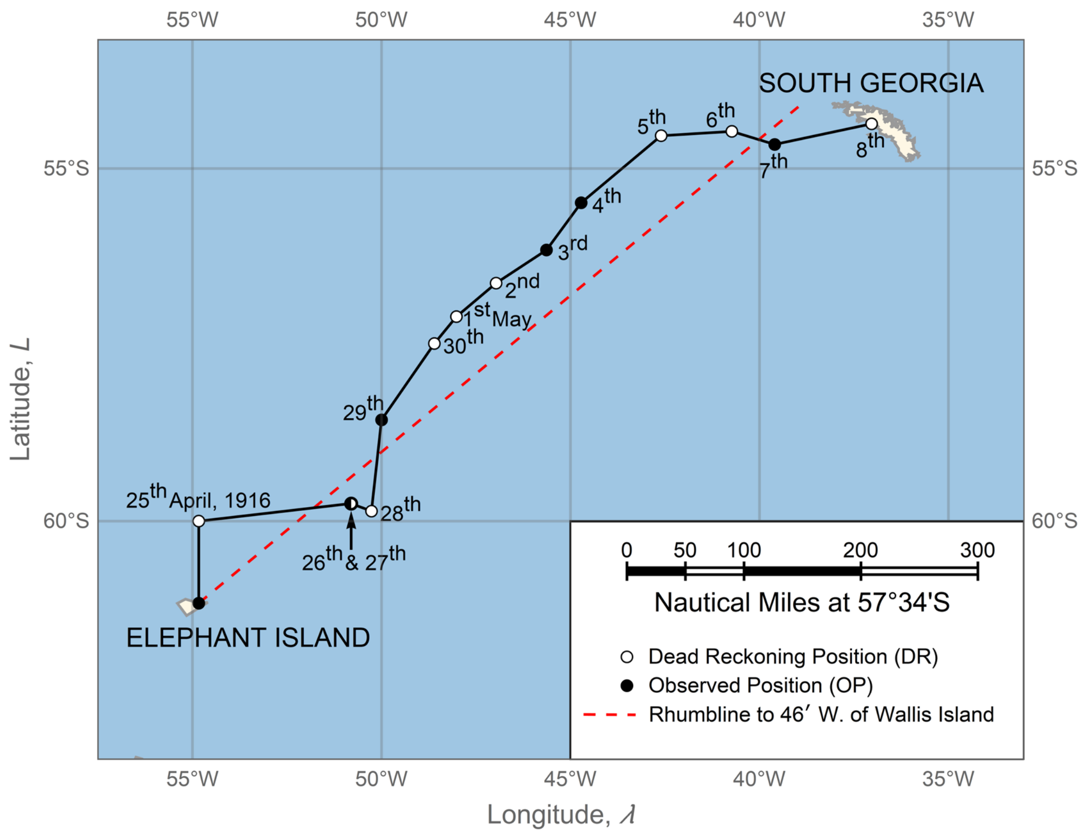

Figure 6. Track of the *James Caird* from Elephant Island to South Georgia showing positions from the log book at noon each day. Dead reckoning (DR) positions are shown as open circles, ○, and observed positions (OP) as solid dots, ●. The dotted line is the rhumb line course from Cape Belsham on Elephant 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.
3. http://www.spri.cam.ac.uk/archives/shackleton/articles/N:_999a.html
4. http://collections.rmg.co.uk/collections/objects/79134.html

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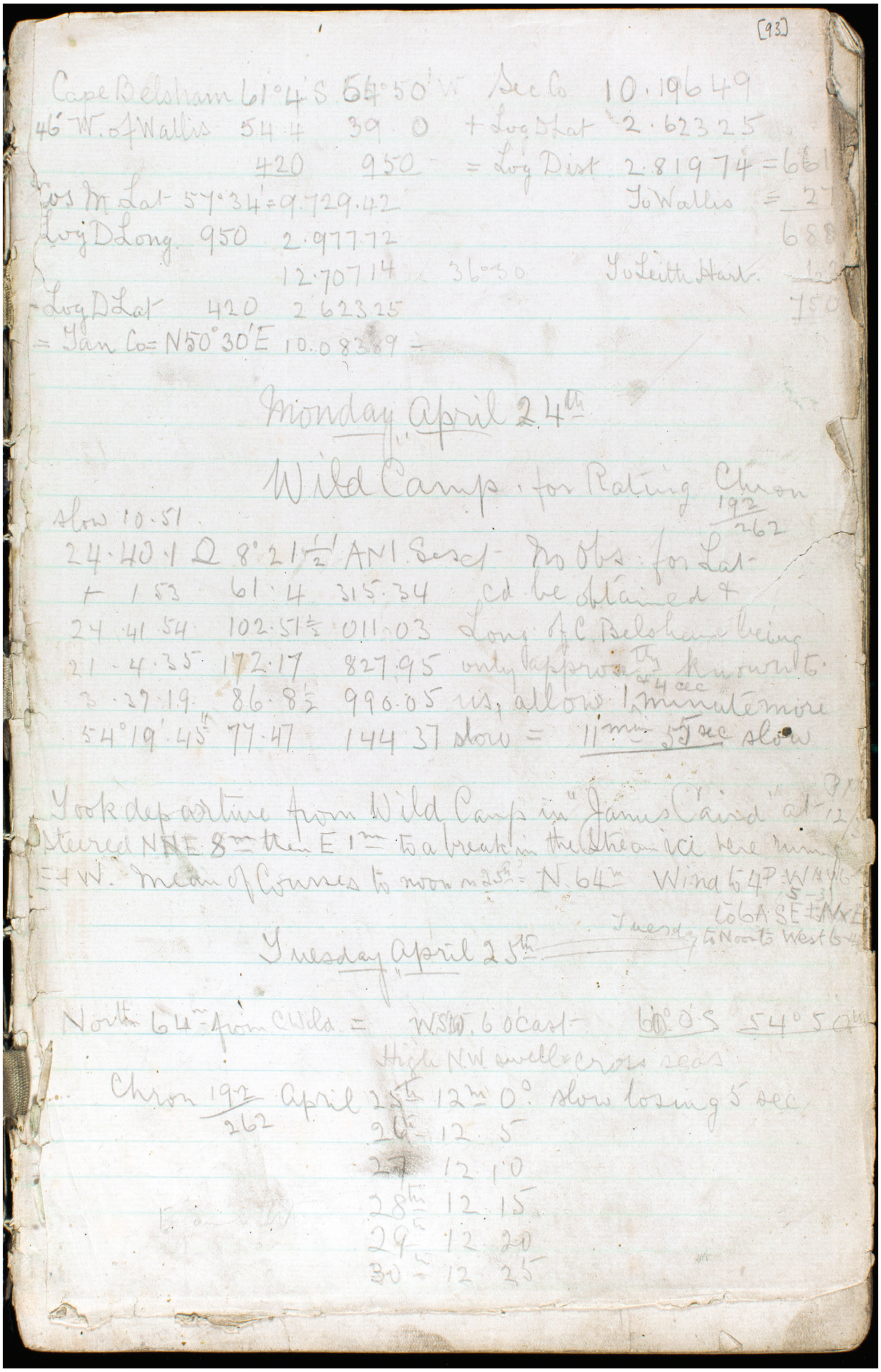
Appendix A

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.


[93]

Cape Belsham 61°4 S 54°50' W Sec Co 10.19649
46' W. of Wallis 54 4 39 0 + Log D Lat 2.62325
420 950 = Log Dist 2.81974 = 661
Cos M Lat 57°34' = 9.729.42 To Wallis = 27
Log D Long 950 2.97772 688
12.70714 36°30 To Leith Harb. 62
Log D Lat 420 2.62325 750
= Tan Co = N50°30'E 10.08389 =

Monday April 24th

Wild Camp. for Rating Chron 192/262

Slow 10.51
24.40.1 ☉ 8°21½' AM Sextant. No Obs. for Lat.
+ 1.53 61.4 315.34 cd be obtained &
24.41.54 102.51½ 011.03 Long of C. Belsham being
21.4.35 172.17 827.95 only approx.ly known to
3.37.19 86.8½ 990.05 us, allow 1 minute 4 sec more
54°19'45" 77.47 144 37 slow = 11 min 55 sec slow

Took departure from Wild Camp in "James Caird" at 12
Steered NNE 8 m then E 1 m to a break in the stream ice here running
E & W. Mean of Courses to noon on 25th = N. 64 m Wind to 4 P WNW
5–3
to 6 A SE & NXE

Tuesday April 25th Tuesday to Noon to West 6–4

North 64 m from C Wild = WSW. 6 Ocast 60°0 S 54°50
High NW swell & cross seas

Chron 192/262 April 25th 12 m 0° slow losing 5 sec
26th 12.5
27 12.10
28th 12.15
29th 12.20
30th 12.25

Cape Belsham	61°4′S 54°50′W		Sec Co	10.19649		
46′W. of Wallis	54 4	39 0	+Log Dlat	2.62325		
	<u>420</u>	<u>950</u>	= Log Dist	2.81974	= 661	
Cos M Lat 57°34′=	9.729.42			To Wallis	= <u>27</u>	
Log DLong 950	2.977 72				688	
	12.707 14	36°30		To Leith Harb	<u>62</u>	
-Log DLat 420	2.623 25				750	
=Tan Co=N50°30′E	10.083 89 -					

Mon<u>day April</u> 24$^{\underline{th}}$

Wild Camp for Rating Chron

<u>192</u>

slow 10.51				262
24.40.1	<u>O</u>	8°21 ½′ AM Sext		No Obs for Lat
+ 1 53		61 . 4	315.34	cd be obtained +
24 41 54		102.51 ½	011.03	Long. of C. Belsham being
21. 4.35		172.17	827.95	only approx^{tly} known to
3.37.19		86. 8 ½	990.05	us, allow 1minute+4sec more
54°19′.45″		77.47	144 37	slow = <u>11^{min}55^{sec}</u> slow

PM

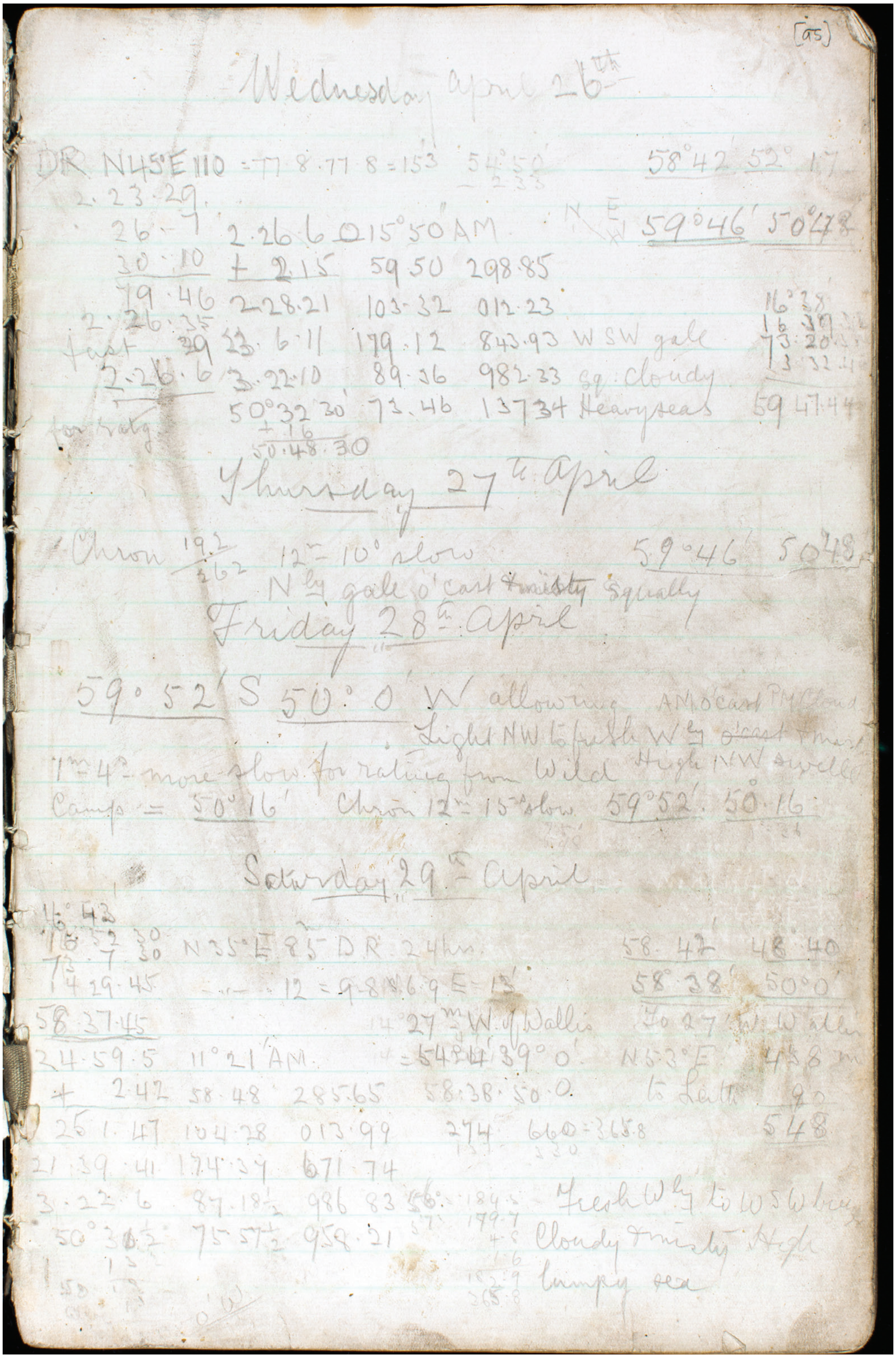
Took departure from Wild Camp in "James Caird" at 12/30
Steered NNE 8$^{\underline{m}}$ then E1$^{\underline{m}}$ to a break in the stream ice here being
E+W. Mean of Courses to noon on 25th = N64$^{\underline{m}}$ Wind to 4^{P} WNW6-
to 6A·SE to NxE
Tuesday to Noon to West 6-4

Tues<u>day April</u> 25th

North 64^{m} from CWild = WSW 6 o'cast <u>60</u>°<u>0′S</u> <u>54</u>°<u>50′W</u>

High NW swell + cross seas

Chron <u>192</u>	April 25$^{\underline{th}}$	12$^{\underline{m}}$0^{s} slow losing 5 sec
262	26$^{\underline{th}}$	12 5
	27	12 10
	28$^{\underline{th}}$	12 15
	29$^{\underline{th}}$	12 20
	30$^{\underline{th}}$	12 25


[95]

Wednesday April 26th

DR N45°E 110 = 77.8 . 77.8 = 153 54°50 58°42 52° 17
2.23.29
26.7 2.26.6 ⊙ 15°50 AM 59°46' 50°48
30.10 + 2.15 59 50 298.85
79.46 2.28.21 103.32 012.23 16°38
2.26.35
fast 29 23 6.11 179.12 843.93 WSW gale 73.20
2.26.6 3.22.10 89.36 982.33 sq. cloudy 13 32
50°32 30 73.46 13734 Heavy seas 59 47 44
+16
for rating 50.48.30

Thursday 27th April

Chron 19.2 / 26.2 12m = 10' slow 59°46' 50°48
Nly gale o'cast & misty squally

Friday 28th April

59°52' S 50°0' W allowing AM o'cast PM cloud
Light NW to fresh Wly o'cast & misty
1m = 4s more slow for rating from Wild High NW swell
Camp = 50°16' Chron 12m = 15s slow 59°52' 50°16

Saturday 29th April

16°43
16 52 30
73 7 30 N35°E 85 DR 24 hrs 58 42 48 40
14 29 45 12 = 9.8 86.9 E = 15' 58°38' 50°0'
58 37 45 14°27 m W of Wallis 50 27 W Wallis
24 59 5 11°21 AM = 54.4 39°0' N53°E 458 m
+ 2.42 58 48 285.65 58.38 50.0 to Leith 90
25 1.47 104.28 013.99 274 660 = 365.8 548
21 39 41 174.34 671.74
3.22.6 87.18½ 986 83 56 184 Fresh Wly to WSW breeze
50°36½ 75 57½ 958.21 179.7 Cloudy & misty High
lumpy sea

Wednesday April 26th

DR N45°E 110 = 77.8 77.8 = 153 54°50″ 58°42′ 52°17
2.23.29 - 2 33 N E
26 7 2.26. 6 O 15°50 AM W 59°46′ 50°48′
30 10 + 2.15 59 50 298.85
79. 46 2 28.21 103.32 012.23 16°38′
2.26. 35 16 39 30
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

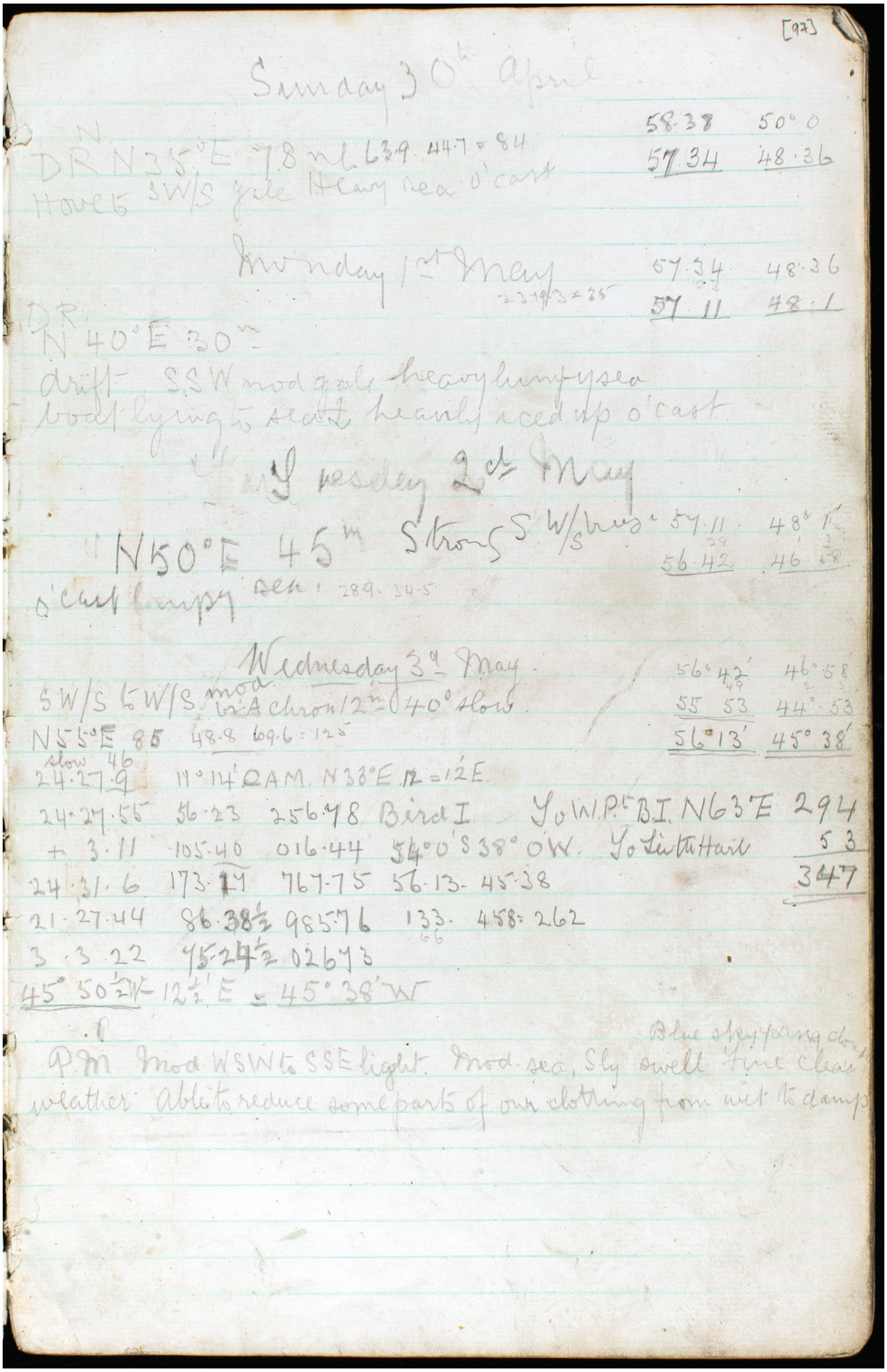
Chron 192/262 12^m 10^s slow 59°46′ 50°48′
N^{ly} gale o'cast + misty squally

Friday 28th April

59°52′S 50°0′ W allowing AM o'cast PM Cloud
Light NW to fresh W^{ly} ~~o'cast~~+mist
$1^m 4^s$ more slow for rating from Wild High NW swell
Camp = 50°16′ Chron $12^m 15^s$ slow. 59°52′ 50°16

Saturday 29th April

16° 43′
16 . 52 30
73. 7. 30 N35°E85^m DR 24hrs 58.42′ 48°40
14. 29. 45 —" — 12 =9.8N6.9E = 13′ 58°38′ 50°0′
58. 37. 45 27^mW. 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 to Leith 90
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^{ly} 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



[97]

Sunday 30th April

N. DR N35°E 78 nl. 63.9 44.7 = 84	58.38	50° 0
Hove to SW/S gale Heavy sea o'cast	57 34	48.36

Monday 1st May

23.4 19.3 = 35	57.34	48.36
D.R. N 40° E 30m	57 11	48.1

drift SSW mod gale heavy lumpy sea
boat lying to sea & heavily iced up o'cast

Tuesday 2nd May

N50°E 45m Strong S W/S breeze	57.11	48° 1
	56.42	46 58

o'cast lumpy sea 289. 34.5

Wednesday 3rd May

	56° 42'	46° 58
SW/S to W/S mod by A chron 12m 040° slow	55 53	44° 53
N55°E 85 48.8 69.6 = 125	56°13'	45° 38'

slow 46
24.27.9 11° 14' 0 AM. N38°E 12 = 12 E.
24.27.55 56.23 25678 Bird I To W.Pt B.I. N63°E 294
+ 3.11 105.40 016.44 54°0'S 38° 0'W. To Leith Hair 53
24.31.6 173.17 767.75 56.13. 45.38 347
21.27.44 86.38½ 98576 133. 458 = 262
3.3.22 75.24½ 02673
45° 50½'W - 12½'E = 45° 38' W

P.M. mod WSW to SSE light. mod. sea, Sly swell. Blue sky passing clouds fine clear weather. Able to reduce some parts of our clothing from wet to damp

Sunday 30h April

N 58.38 50° 0

DR N35°E 78 mls 63.9 44.7 = 84 57.34 48.36

Hove to SW/S gale Heavy sea o'cast

Monday 1st May

57.34 48.36

DR 23 19.3=35 57.11 48. 1

N40°E 30m

drift SSW mod gale heavy lumpy sea

boat lying to sea ⚓ heavily iced up o'cast

Tuesday 2d May

N50°E 45m Strong SW/S breeze 57.11 48° 1′

o'cast lumpy sea 28.9. 34.5 56.42 46 58

Wednesday 3d May

SW/S to W/S mod br A chron 12m40s slow 56°42′ 46°58′

N55°E 85 48.8 69.6 = 125 55 53 44°53′

slow 46 56°13′ 45°38′

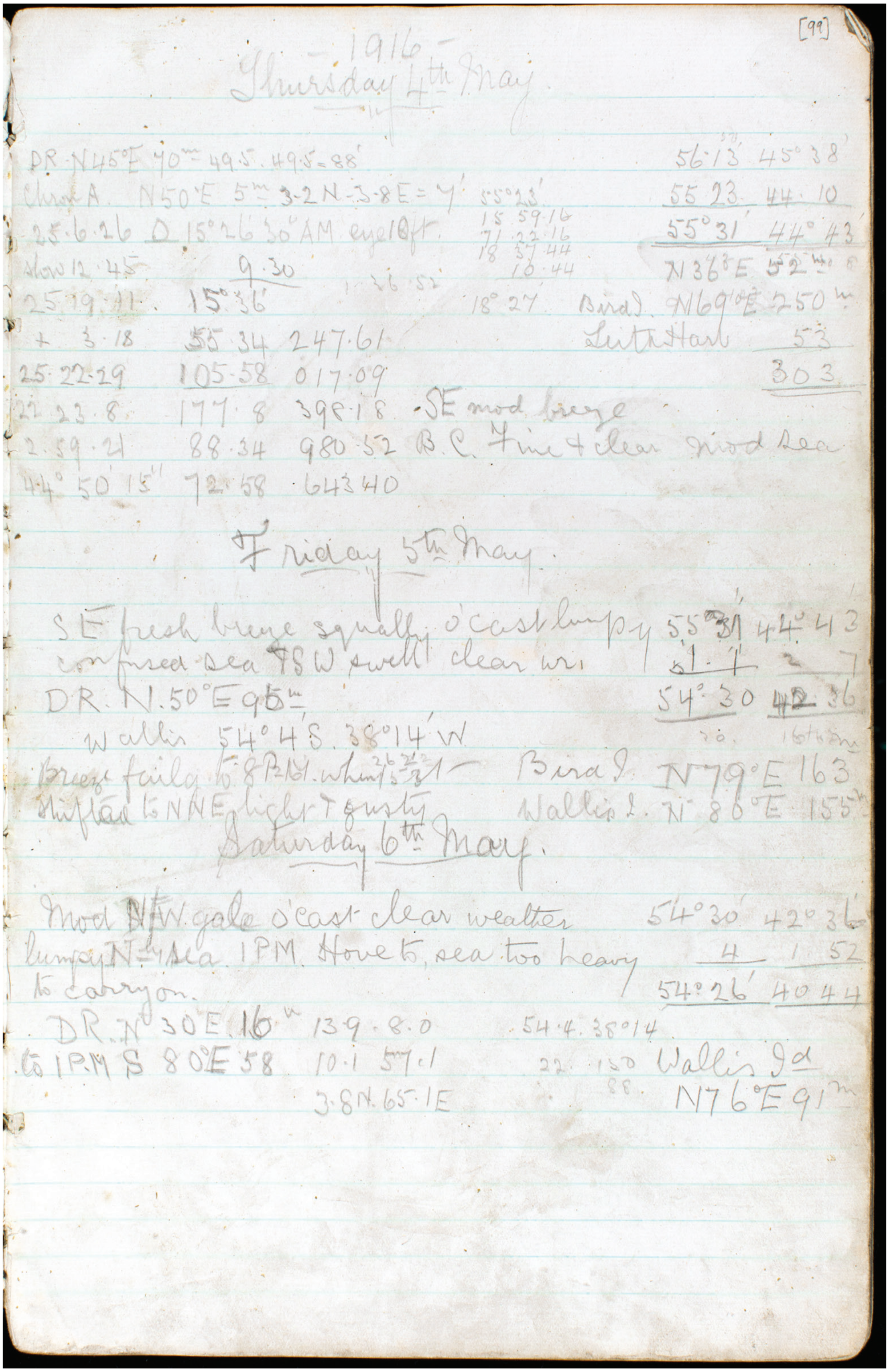
24.27.9	11°14′ O AM	N33°E 12 = 12′E		
24.27.55	56.23	256.78	Bird I To W.P.t B.I. N63°E	294
+ 3.11	105.40	016.44	54°0′S 38°0′W To Leith Harb	53
24.31. 6	173.17	767.75	56.13. 45.38	347
21.27.44	86.38 ½	985.76	133. 458=262	
3. 3.22	75.24 ½	026 73	66	

45°50½ W -12½′ E = 45°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


[99]

1916
Thursday 4th May

DR N45°E 70m 49.5 . 49.5 = 88' 56.13 45°38
Chron A. N50°E 5m 3.2 N 3.8 E = 4' 55 23 44 10
25.6.26 ☉ 15°26 30" AM eye 10ft 55°31 44°43
slow 12 45 9.30 N36½°E 52m
25 19 41 . 15°36 18°27 Bird I. N69°E 250m
+ 3.18 55 34 247.61 Leith Harb 53
25.22.29 105.58 017.09 303
22 23.8 177.8 398.18 SE mod breeze
2.59.21 88.34 980.52 B.C. Fine + clear Mod sea
44°50'15" 72.58 64340

Friday 5th May

SE fresh breeze squally o'cast lumpy 55°31 44°43
confused sea + SW swell clear wr. 1 1 2 7
DR N.50°E 95m 54°30 42 36
Wallis 54°4 S. 38°14' W
Breeze failing to 8 PM. when it shifted to NNE light + gusty Bird I. N79°E 163
Wallis I. N 80°E 155m

Saturday 6th May

Mod NW gale o'cast clear weather 54°30' 42°36
lumpy N'ly sea. 1PM. Hove to, sea too heavy to carry on. 4 1 52
54°26' 40 44
DR N 30 E 16m 13.9 8.0 54.4. 38°14
to 1PM S 80°E 58 10.1 57.1 Wallis Id
3.8 N. 65.1 E N76°E 91m

-1916 -

Thursday 4^{th} May

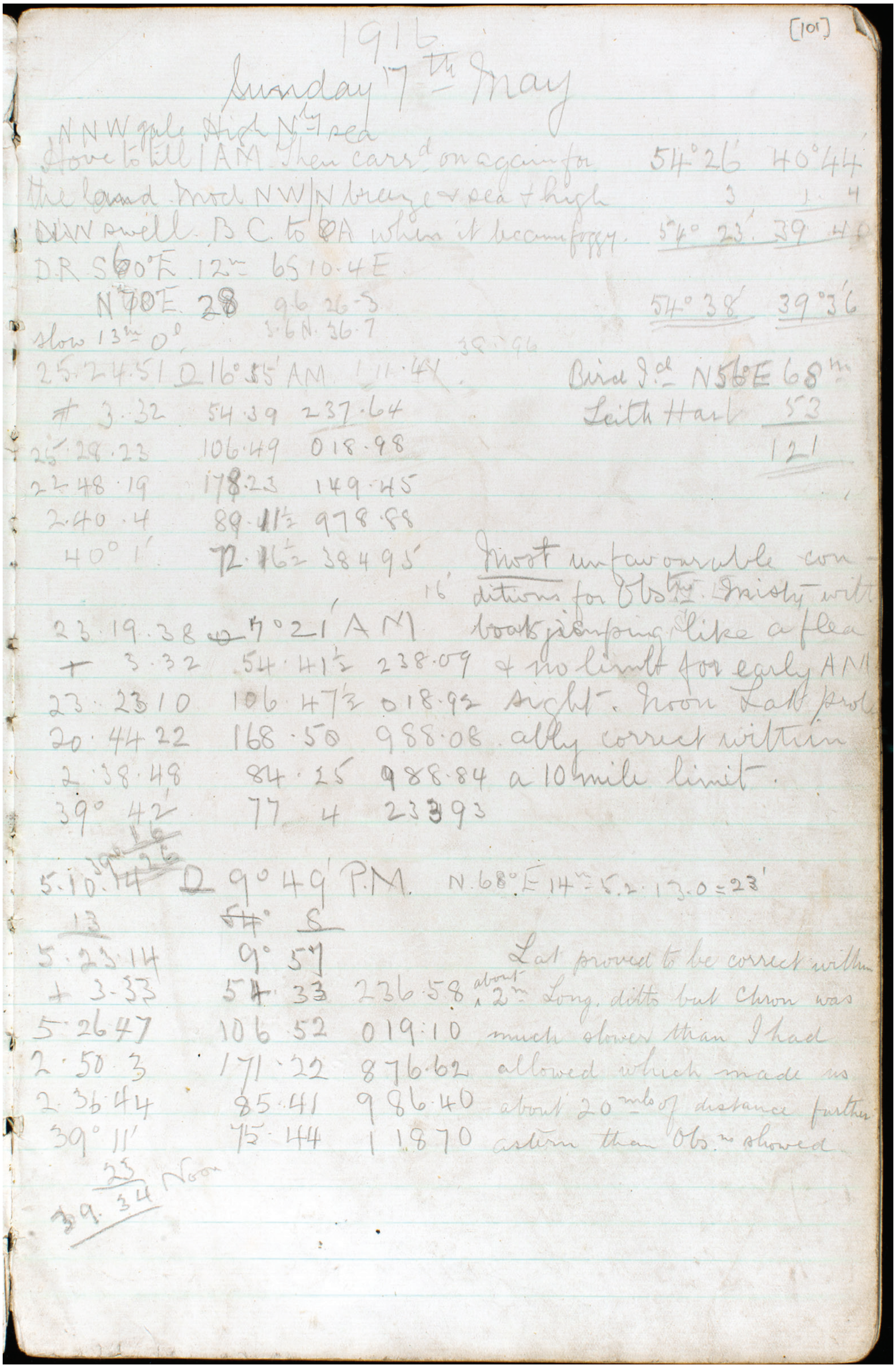
DR N45°E 70^{m} 49.5 49.5 = 88′ 56°13′ 45°38′
Chron A N50°E 5^{m} 3.2N 3.8E = 7′ 55°23′ 55.23 44.10
25.6.26 O 15°26′30″AM eye 10ft 15 59 16 55°31′44°43′
slow 12.45 9.30 71.22.16 42 55 30 8
25.19.11 15°36′ 1.36.52 18.37.44 91 403
\+ 3.18 55.34 247.61 10 44 N36°E 52^{m}
25.22.29 105.58 017.09 18° 27′
22.23. 8 177. 8 398.18 Bird I^{s} N69°E 250^{m}
2.59.21 88.34 980.52 Leith Harb. 53
44°50′15″ 72.58 643.40 SE mod breeze 303
B.C. Fine+clear mod sea

Friday 5^{th} May

SE fresh breeze squally o'cast lumpy 55°31′44°.43′
confused sea + SW swell clear wr 1. 1′ 2. 7
DR N50°E 95^{m} 54°30 42.36
Wallis 54°4′S 38°14′W
26 262′
153
Breeze failg to 8PM when Bird I N79°E 163^{m}
shifted to NNE light and gusty Wallis I. N80°E 155^{m}

Saturday 6^{th} May

Mod N/W gale o'cast clear weather 54° 30′ 42°36′
lumpy N^{ly} sea 1PM. Hove to, sea too heavy 4 1 52
to carry on. 54° 26′ 40 44
DR N 30 E 16^{m} 13.9 8.0 54.4. 38°14
to 1PM S 80°E 58 10.1 57.1 22. 150 Wallis I^{d}
3.8N.65.1E 88 . N76°E 91^{m}



[101]

1916

Sunday 17th May

NNW gale High N'ly sea
Hove to till 1 AM Then carr.d on again for the land. Mod NW/N breeze & sea & high NW swell. B.C. to BA when it became foggy.
54°26' 40°44'
3 1.4
54°23' 39 40
D.R. S60°E 12m 6S 10.4E
N70E 28 9.6 26.3
3.6N 36.7
54°38' 39°36'
slow 13m 0°

39 46

25.24.51 ☉ 16°55' AM 111.41
+ 3.32 54.39 237.64
25 28.23 106.49 018.98
22 48.19 178.23 149.45
2.40.4 89.11½ 978.88
40°1' 72.16½ 38495

Bird Id N56E 68m
Leith Harb 53
121

16'
23.19.38 ☉ 7°21' AM
+ 3.32 54.41½ 238.09
23.23.10 106.47½ 018.92
20.44.22 168.50 988.08
2.38.48 84.25 988.84
39° 42' 77.4 23393

Most unfavourable conditions for Obs.ns Misty with boat jumping like a flea & no limit for early AM sight. Noon Lat probably correct within a 10 mile limit.

16
39°26
5.10.14 ☉ 9°49' P.M. N.68°E 14m = 5.2.13.0 = 23'
13 54° S
5.23.14 9° 57
+ 3.33 54.33 236.58
5.26.47 106.52 019.10
2.50.3 171.22 876.62
2.36.44 85.41 986.40
39°11' 75.44 11870

Lat proved to be correct within about 2m Long. ditto but Chron was much slower than I had allowed which made us about 20 mls of distance further astern than Obs.n showed

23
39.34 Noon

1916
Sunday 7$^{\underline{th}}$ May

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

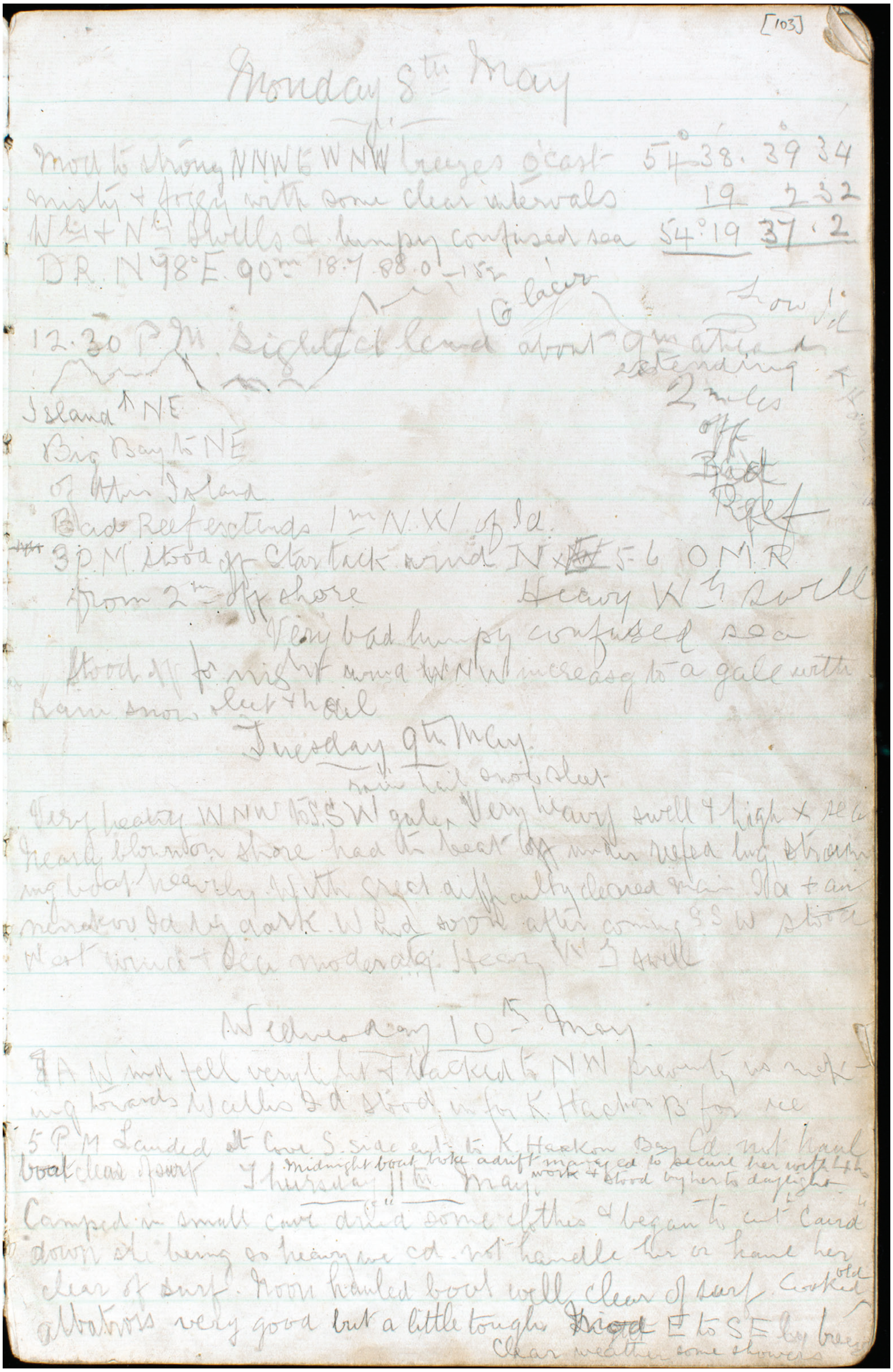
54°26′ 40°44′
3 <u>1 4</u>
<u>54°23′</u> <u>39 40</u>

DR S60° E 12$^{\underline{m}}$ 6S 10.4E
N70° E 28 9.6 26.3
Slow 13$^{\underline{m}}$0^{s} 3.6N 36.7 38 96

<u>54°38′</u> <u>39°36′</u>

25.24.51 <u>O</u>	16°55′ AM	1 11 41	Bird I$^{\underline{d}}$ N56°E 68^{m}
+ 3.32	54.39	237.64	Leith Harb <u>53</u>
25.28.23	106.49	018.98	<u>121</u>
22.48.19	178.23	149.45	
2.40. 4	89.11½	978.88	
40° 1′	72.16½	384 95	<u>Most</u> unfavourable con-
		16′	ditions for obs$^{\underline{tns}}$. Misty with
23.19.38 ~~O~~	7°21′ AM		boat jumping like a flea
+ 3.32	54.41½	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	
<u>16</u>			
<u>39°26′</u>			

5.10.14 <u>O</u>	9°49′P.M.	N68°E 14$^{\underline{m}}$ 5.2 13.0 = 23′	
<u>13</u>	~~54~~° <u>8</u>		
5.23.14	9°57		Lat proved to be correct within
+ 3.33	54.33	236.58	about 2$^{\underline{m}}$ 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 $^{\underline{mls}}$ of distance further
39°11′	75.44	118 70	astern than Obs^{ns} showed
<u>23</u>			
<u>39.34</u> Noon			



[103]

Monday 8th May

Mod to strong NNW to WNW breezes o'cast 54° 38. 39 34
misty & foggy with some clear intervals 19 2 32
W'ly & N'ly Swells & lumpy confused sea 54° 19 37 . 2
D.R. N 98° E. 90m 18.7 88.0 -152

Glacier

Low Isld

12.30 P.M. Sighted land about 9m ahead extending 2 miles off

Island ↑ NE
Big Bay to NE
of this Island
Bad Reef extends 1m N.W. of Id.

Bad Reef

3 P.M. Stood off Star tack wind N x ~~E~~ 5-6 O.M.R
from 2m off shore Heavy W'ly 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 SSW gale. Very heavy swell & high x sea
nearly blown on shore had to beat off under reefed lug strain
ing boat heavily. With great difficulty cleared main Id & an
[illegible] Id by dark. Wind soon after coming SSW stood
W'est wind & sea moderatg. Heavy W'ly swell

Wednesday 10th May

8 A Wind fell very light & backed to NW presently we mak-
ing towards Wallis Id. stood in for K. Haakon B for ice
5 P.M Landed at Cove S. side ent. to K. Haakon Bay Cd. not haul
boat clear of surf

Thursday 11th May

midnight boat broke adrift managed to secure her with 4 hrs work & stood by her to daylight

Camped in small cove 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 ~~Wind~~ E to SE by breeze
Clear weather some showers

Monday 8th May

Mod to strong NNW to WNW breezes o'cast	54° 38′	39°34′
misty + foggy with some clear intervals	19	2 32
W^{ly} + N^{ly} swells + lumpy confused sea	54°.19	37. 2
DR N78°E 90^{m} 18.7 88.0 =152		

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

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

Tuesday 9th May

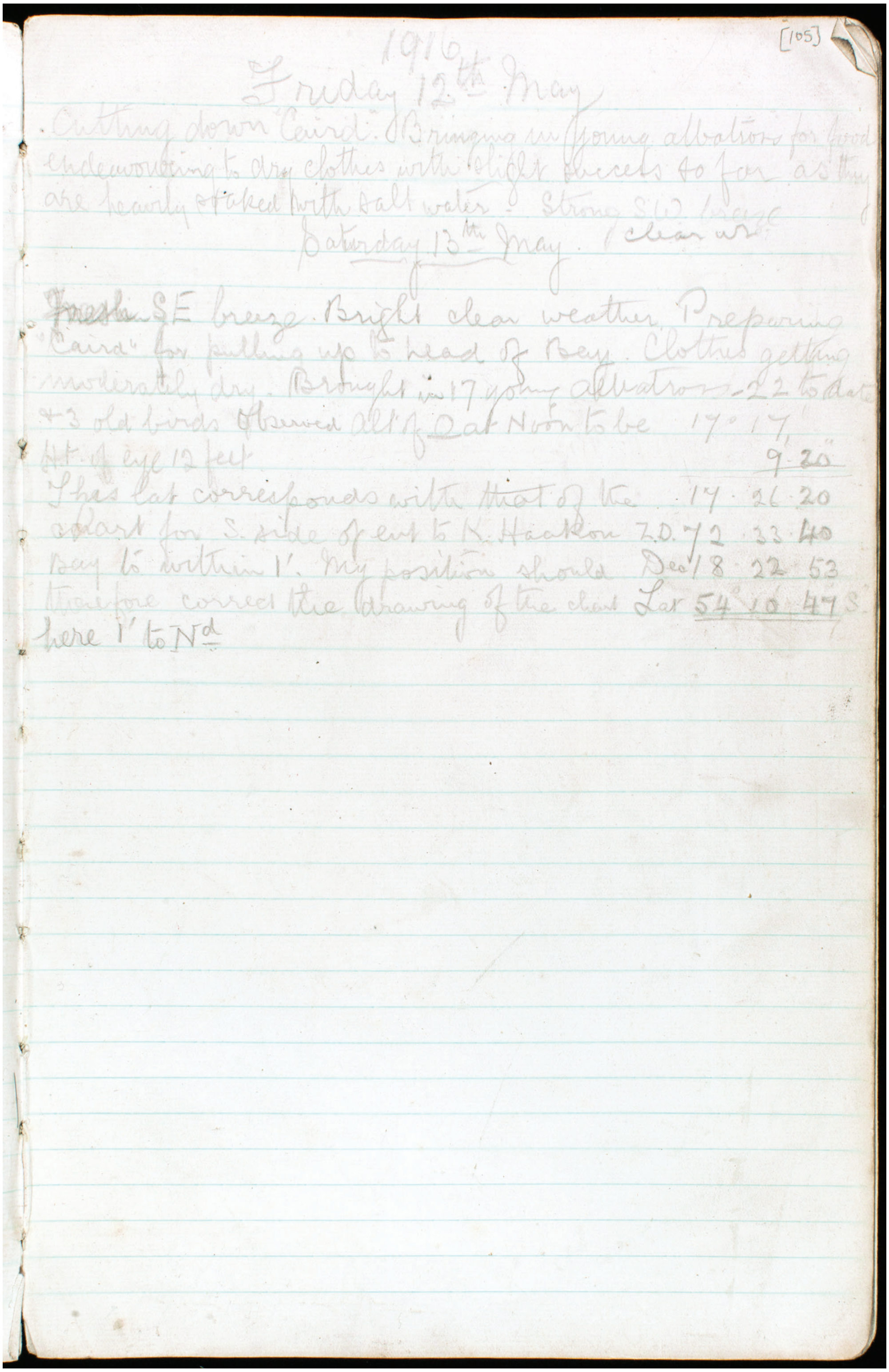
rain hail snow sleet
Very heavy WNW to S.SW gale ^ Very heavy swell + high x sea
Nearly blown on shore had to beat under reefed lug, strain
ing boat heavily. With great difficulty cleared main Id + An
nenekov Id by dark. Wind soon after S.SW stood
West wind + sea moderatg. Heavy W^{ly} swell

Wednesday 10 th 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



[105]

1916

Friday 12th May

Cutting down "Caird". Bringing in young albatross for food
endeavouring to dry clothes with slight success so far as they
are heavily soaked with salt water. Strong S.W. 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 ☉ at Noon to be 17° 17′
Ht of eye 12 feet 9 20″

This lat corresponds with that of the 17 26 20
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 Nd

1916

Friday 12th May

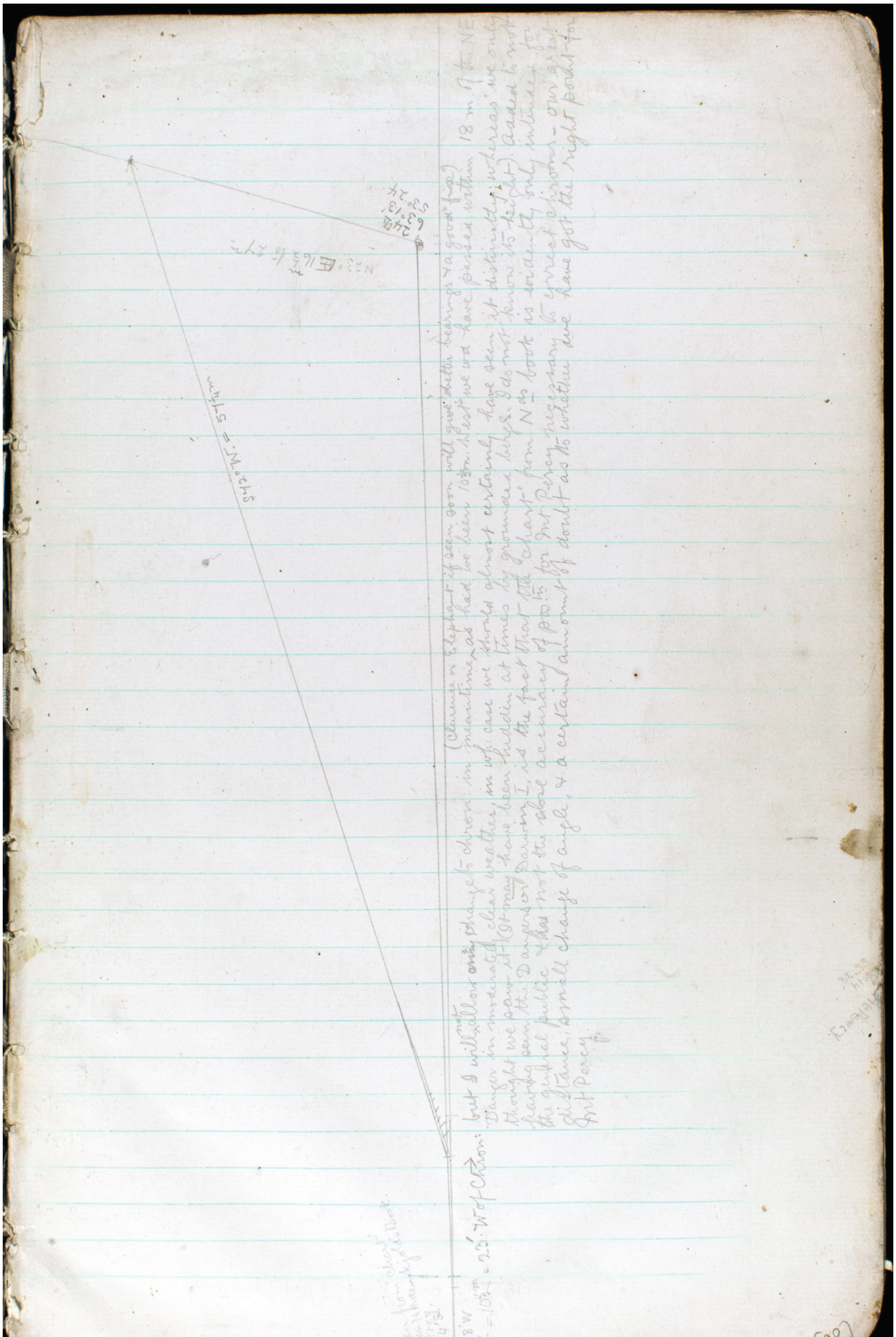
Cutting down Caird. Bringing in young albatross for food endeavouring to dry clothes with slight success so far as they are heavily soaked with saltwater. Strong SW breeze

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 O at Noon to be

+ 3 old birds. Observed Alt of O at Noon to be		17° 17′
Ht of eye 12 feet		9′·20″
This lat corresponds with that of the		17· 26 ·20
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 Nd		


S42° W. = 57¼ m
N23° E 16¾ to 27
24th
63°13'
53°24
Taken from "chart" in Nordenskjolds Book.
Mt Percy
63°14'S.
55°38'W
← = 10½m = 23' W of Chron:
(Clarence or Elephant if seen soon will give better bearings & a good "fix")
but I will not allow any change to chron: in meantime, as had we been 10½m. 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 & has not the close accuracy of posn for Mt Percy necessary to correct chrons. – our great
distance, small change of angle, & a certain amount of doubt as to whether we have got the right point for
Mt Percy.
[98]

Taken from "Chart" in Nordenskjold's Book.
Mt Percy
63°14′S
55°38′W
= 10 ½ m=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 <u>may</u> 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 postn for Mt Percy necessary to correct chrons – 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.

Cape Belsham	61° 4′ S		54° 50′ W
46′ West of Wallis	54 4		39 0
D. Lat.	420′	D. Lon.	950′
Middle Latitude, *M*	57° 34′	log cos M	9.72942
		log D. Lon.	2.97772
		log Dep.	12.70714
		log D. Lat.	2.62325
Course, *C*	50° 30′	log tan C	10.08389
	N50°30′E		
		log D. Lat.	2.62325
		log sec C	0.19649
Distance	660 miles	log Distance	2.81974
	660		
To Wallis Island	27	(46′ longitude = 27 miles at Wallis Island's latitude)	
	687 miles		
To Leith Harbour	62		
	749 miles		

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	54 °	19 ′	45 ″				hav.	9.14437

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	192/262	April	25th	12m	0″	slow losing 5 seconds per day
			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

Time Sight

Sight times	2 h	23 m	29 s
		26	7
		30	10
Sum		79	46
Average	2	26	35
Chronometer Error		Fast	29 s

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 ″				hav.	8.13734
Adjustment	+	16 ′						
Adjusted Longitude	50 °	48 ′	30 ″					

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

Thursday, 27th April (Day 4)

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^m4^s (= 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

Position at time sight		58 °	48 ′	S					50 °	31 ′	30 ″	W
Run to noon N35°E12 miles	D. Lat.		9.8		Dep.	6.9	=	D. Lon.		13	30	
Noon position		58 °	38 ′	S					50 °	18 ′		W

(Note: 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

OP 29th April	58 ° 38 ′ S		50 ° 0 ′ W				
27 miles West of Wallis	54 4		39 0				
D. Lat.	274 ′	D. Lon.	660 ′ =	Dep.	365.7	N53°E	457 miles
					Leith Harbour		90
					Total		547 miles

Middle Latitude, M	56 ° 21 ′
½ D. Lon.	330
½ Dep., M = 56°	184.5
½ Dep., M = 57°	179.7
Difference	4.8
Interpolation for 20′	1.6
Interpolated ½ Dep.	182.9
Interpolated Dep.	365.8

Traverse **56 °** Table

Dist.	D.Lat.	Dep.
.	.	.
.	.	.
.	.	.
330	184.5	-
.	.	.
.	.	.
.	.	.

Traverse **57 °** Table

Dist.	D.Lat.	Dep.
.	.	.
.	.	.
.	.	.
330	179.7	-
.	.	.
.	.	.
.	.	.

Reverse look up for ½Distance and Course
½D. Lat. 137.0 ½Dep. 182.9

Traverse **53 °** Table

Dist.	D.Lat.	Dep.
.	.	.
.	.	.
227	136.6	181.3
228	137.2	182.1
229	137.8	182.9
.	.	.

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°E12 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 ″				hav.	9.02673

Adjusting longitude 12.5′ E gives 45°38′W

Distance to Destination

OP 3rd May		56 ° 13 ′ S		45 ° 38 ′ W				
Bird Island		54 0		38 0				
	D. Lat.	133 ′	D. Lon.	458 ′	= Dep.	262	N63°E	294 miles
	½ D. Lat.	66				Leith Harbour		53
						Total		347 miles

<u>Thursday, 4th May (Day 11)</u>

Noon Position

DR N45°E 70 miles from 56°13′S, 45°38′W: <u>55°23′S, 44°10′W</u>

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

OP from time sight: <u>55°31′S, 44°43′W</u>

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°E5 miles	D. Lat.	3.2	Dep. 3.8	=	D. Lon.	7
Noon position		55 ° 31 ′ S				44 ° 43 ′ W

Time Sight

Chronometer Time	25 h	6 m	26 s	Height of Eye	10 ft			
Chronometer Error	Slow	12 m	45 s	Sun's lower limb	15 °	26.5 ′		
				Altitude correction		9.5 ′		
Mean time at Greenwich	25 h	19 m	11 s	Sun's true altitude	15 °	36.0 ′	AM	
Equation of Time	+	3	18	Latitude	55	34.0	sec.	0.24761
Apparent time at Greenwich	25	22	29	Polar distance	105	58.0	cosec.	0.01709
				Sum	177	8.0		
Apparent time at ship	22	23	8	Half-sum	88	34.0	cos.	8.39818
Longitude in time	2	59	21 W	Remainder	72	58.0	sin.	9.98052
Longitude	44 °	50 ′	15 ″				hav.	8.64340

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		38 0					
	D. Lat.	91 ′	D. Lon.	403 ′ =	Dep.	233	N69°E	250	miles
					Leith Harbour			53	
					Total			303	miles

<u>**Friday, 5th May (Day 12)**</u>

Noon Position

DR N50°E 95 miles from 55°31′S, 44°43′W: <u>54°30′S, 42°36′W</u>

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		38 0		153	N79°E	164	miles
Wallis Island		54 4		38 14					
	D. Lat.	26 ′	D. Lon.	262 ′ =	Dep.	153	N80°E	155	miles

<u>**Saturday, 6th May (Day 13)**</u>

Noon Position

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

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		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		26.3				
	D. Lat.	3.6 N	Dep.	36.7 E	D. Lon.	63		

OP from time and noon sights: 54°38′S, 39°36′W

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	Slow	13 m							
Mean time at Greenwich	5 h	23 m	14 s		Sun's true altitude	9 °	57.0 ′	PM	
Equation of Time	+	3	33		Latitude	54	33.0	sec.	0.23658
Apparent time at Greenwich	5	26	47		Polar distance	106	52.0	cosec.	0.01910
					Sum	171	22.0		
Apparent time at ship	2	50	3		Half-sum	85	41.0	cos.	8.87661
Longitude in time	2	36	44	W	Remainder	75	44.0	sin.	9.98640
Longitude	39 °	11 ′	0 ″					hav.	9.11869
Correction to Noon		22							
Longitude at Noon	39 °	33 ′							

Distance to Destination

OP 7th May		54 ° 38 ′ S		39 ° 36 ′ W					
Bird Island		54 0		38 0					
	D. Lat.	38 ′	D. Lon.	96 ′	=	Dep.	56	N56°E	68 miles
						Leith Harbour			53
						Total			121 miles

Monday, 8th May (Day 15)

Noon Position

DR N78°E 90 miles from 54°38′S, 39°34′W: 54°19′S, 37°2′W

D. Lat. 18.7 Dep. 88.0 = D. Lon. 151

Saturday, 13th May

Noon Sight

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