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helped ourselves to rum and limes, and prepared for our first night's solid sleep. Since we had left the Western Escarpment of the Depression the night before, we had done an 80-mile night drive, and during the day we had travelled another 100 miles.

When I awoke the next morning I found my head resting against the rear wheel of my jeep, my bedding roll untouched in the back, and my mess tin full of last night's bully stew. Later in the day we crossed the Bahariya track, and after many more miles, as the sun began to cast long black shadows, we topped the last ridge. Below us lay a wide luxurious belt of palms; through the palm trees and paddy fields ran the Nile. We picked up our glasses and recognized the familiar minarets of the citadel just visible against the blue cliffs. Wearily we dismounted our guns and turned towards the pyramids. We parked the jeeps outside the Mena Camp Naafi, and three bearded officers slunk into the Mena House Hotel and ate, not out of dusty mess-tins, but off clean white plates.

THE OBSERVATIONS OF AMUNDSEN AND SCOTT AT THE SOUTH POLE

ARTHUR R. HINKS, C.B.E., F.R.S.

SOME seven years ago, in reviewing a book on the life of Peary, I had occasion to calculate by the position line method his four observations at the Pole, that had been calculated elaborately, but, as it seemed to me unsuitably, by methods of spherical trigonometry more proper to lower latitudes (*Geogr. J.* 89 (March 1937) 255 and 90 (August 1937) 167). I was interested to see how simply and conclusively these position lines illustrated and confirmed Peary's narrative of what he did to fix his position at the North Pole, and I resolved to apply one day the same method to the observations of Amundsen and of Scott's navigator, Bowers, at the South Pole. Other matters intervened, and it was only last winter that I found opportunity to collect the material, and time in long evenings on duty to study the observations made by the Norwegians and the British in December 1911 and January 1912.

The Norwegian and English editions of Amundsen's book, published in the autumn of 1912, contain certain figures in the narrative, a few pages of facsimiles from his observation books as illustrations, and a brief appendix dealing in a curiously incomplete and unsatisfactory way with his final observations at the Pole. But so far as I can discover, the bulk of his results have never been printed, and if the original observation books survive, they are unfortunately now inaccessible. One map in the narrative shows the Norwegians marching poleward along meridian 169° W., and another map shows them as on the meridian of Framheim about 163½° W. So the route of the expedition is not too well documented.

The surveys of the British expedition produced fourteen maps, which were

published in 1923 in a volume 'British (*Terra Nova*) Antarctic Expedition 1910–13: Report on Maps and Surveys.' The Preface says that Colonel H. G. Lyons, F.R.S., as Honorary Editor of the Physical Reports of the Expedition, had originally planned a Memoir which was to contain a critical discussion of the more precise work, to be written by himself, as well as full reports of the various officers concerned with the survey work. Lieutenants H. L. Pennell, R.N., and H. de P. Rennick, R.N., Commander and First Officer of the *Terra Nova*, had reduced all the primary positions and drawn some of the maps, but both lost their lives in the war of 1914–18. Colonel Lyons was never able to write the proposed Memoir, and he entrusted the whole publication to other hands.

The Meteorological results of the *Terra Nova* expedition are published in three large volumes, one of discussion, one of charts, and the third tables of observations. We shall refer to these as Meteorology.

Scott's march to the South Pole

The only account of the astronomical positions determined on Scott's march to the South Pole is contained in Chapter V of eight pages in the 'Report' above mentioned. It begins when the last supporting party turned back on 4 January 1912 in 87° 32′ S. 160° 41′ E., not W. as is printed on page 25. From this point Bowers took over the principal part of the observations, making on most days circum-meridian sights for latitude during the lunch-time halt, and sights for longitude at the evening camp: all in the best tradition of the conservative naval officer. Scott had been present at a meeting of the R.G.S. in 1909 when the simple method of graphical determination by position lines when near the Pole had been described (*Geogr. J.* 35 (March 1910) 299), and he had taken part in the discussion, but was unconverted. So Bowers persisted with his circum-meridian latitudes near noon until January 15, though he had in fact been making a mistake in his reduction to the meridian, which was of small effect only because he was so near to the Pole. On June 15 he gave up this reduction, and his evening sight on that day was the last which he worked up as a longitude. On January 17 and 18 all his sights were worked as if they were meridian altitudes, and the Report has treated them as if they were, with the strange remark "there being, of course, no such thing as a circum-meridian sight at the Pole."

At this point it becomes evident that there is something seriously wrong, not with Bowers, but with the Report's exposition of what he did; and as the Report gives none of the original figures, except one facsimile page from the observation book of the last observation near the Pole about noon on January 18, it was necessary to seek the original observation book, preserved at the Scott Polar Research Institute at Cambridge. With great kindness the Director of the S.P.R.I. first copied all the figures for the last five observations and their reduction, and later deposited the original at the R.G.S. for my use. Each observation had been worked on the original page of the observation book, a thin sketch-book of blank detachable pages, with nothing to keep the record in a standard form, so that the figures of the calculation are all over the place, and require some identification. But they are beautifully written, and there is no serious difficulty in disentangling them.

The book begins with the departure position on the return of the Supporting Party under Lieut. Evans on 4 January 1912:

Lat. 87° 32′·3 S. Long. 160° 41′ E. Var. 180°
Watches at 8 p.m. 3rd
S. $0^h\ 2^m\ 11^s{\cdot}4$ fast on G.M.T. losing ·76 secs daily
T. 2 7 59·1 fast on G.M.T. losing 4·23 secs daily

Watch S soon became irregular, and T was used in all the observations.

The combined parties had reached the head of the Beardmore Glacier and emerged onto the polar plateau in longitude 160°; they kept as close to this meridian as possible all the way to the Pole, determining the variation of the compass by observations which are a little difficult to interpret, and checking their meridian by longitude observations and calculations which necessarily became less effective as the latitude became extreme. Instead of re-examining these calculations in detail I propose to plot them all afresh as giving position lines.

The method is the simplest possible; with our approximate knowledge of the Greenwich Apparent Time of the observation we can lay off the bearing of the Sun. Having corrected the observed altitude of the Sun for refraction and parallax, one compares the corrected altitude with the Sun's declination interpolated from the Nautical Almanac. If the altitude is greater than the declination, the observer is somewhere on a line which is at right angles to the direction of the Sun, and displaced from the Pole towards the Sun by the amount of the difference Altitude minus Declination. If the declination is numerically greater than the altitude, the line is displaced away from the Sun by the amount of the difference. It matters not whether one is observing near local noon or at the evening camp or anywhere in between; the method is exactly the same, of the most direct and engaging simplicity, and the resulting position line gives the whole of the information that the observation provides.

The lines in Fig. 1 more or less at right angles to the meridian 160° East of Greenwich are derived from the observations made during the halts for lunch; those lying more or less along the meridian are from the observations at the evening camps; observation number 3 was made at a temporary halt on a morning march. To get the complete position of the evening camp one moves the lunch-time line towards the pole by the distance shown by the sledge meter during the afternoon march. The intersection of the lunch-time line thus shifted by dead-reckoning to the evening camp is shown in figure 1. The navigation was first-rate; no camp is as much as a mile right or left of the meridian along which they were trying to march, and the graphical solution (Fig. 5, p. 174; the scale of Fig. 1 is too small) shows camp 68 a little left of the meridian, as Bowers' observation worked up by him for longitude made it; not several miles to the right, as the diagram on page 29 of the Report plots it (Fig. 6, p. 175). The 'miles' throughout this discussion are geographical miles or minutes of arc.

This figure 1 brings us to the evening of January 16, the day of the great disappointment. On page 543 of 'Scott's Last Expedition' his journal reads:

> We marched well in the morning and covered 7½ miles. Noon sight showed us in Lat. 89° 42′ S., and we started off in high spirits in the after-

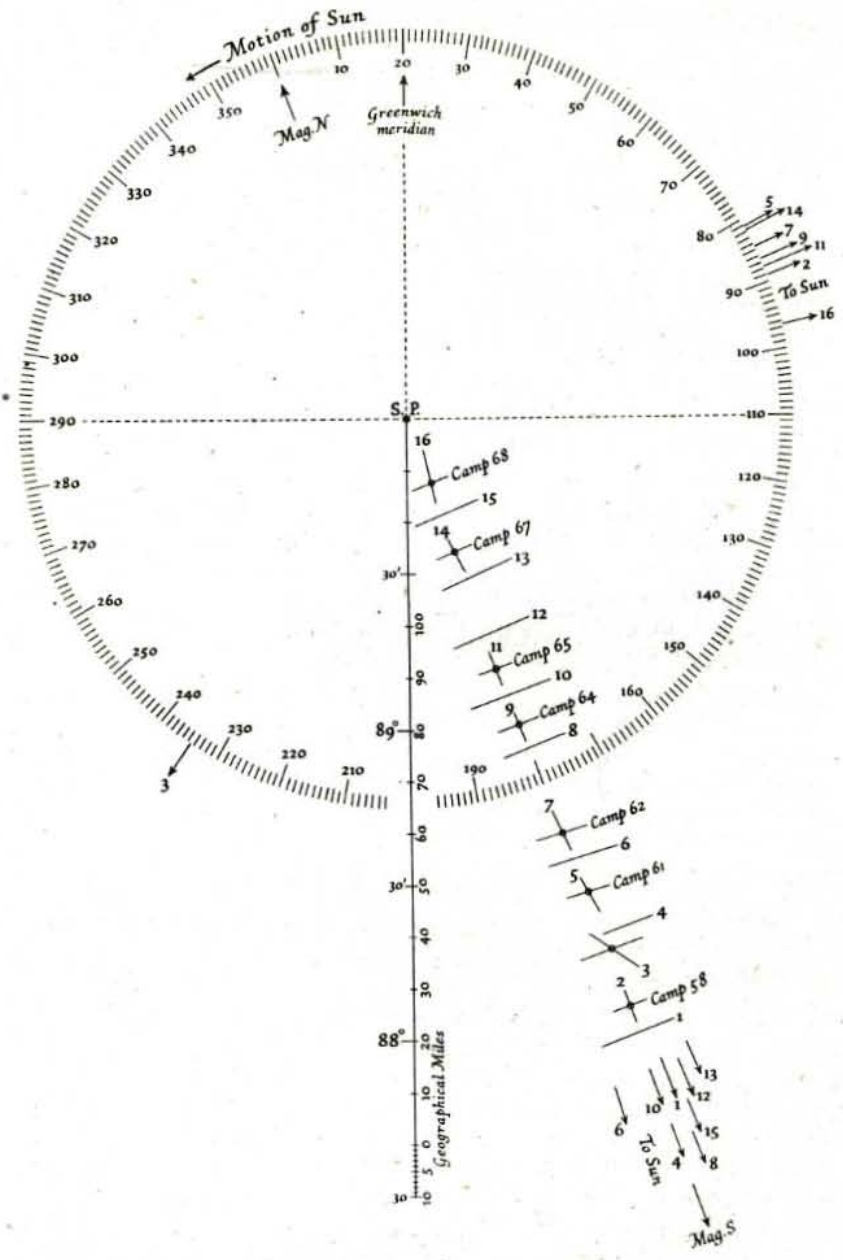


Fig. 1. Position lines from Bowers' observations, Camp 58 to Camp 68

noon, feeling that tomorrow would see us at our destination. About the second hour of the march Bowers' sharp eyes detected what he thought was a cairn; he was uneasy about it, but argued it must be a sastrugus. Half an hour later he detected a black speck ahead. Soon we knew that this could not be a natural snow feature. We marched on, found that it was a black flag tied to a sledge bearer; near by the remains of a camp; sledge tracks and ski tracks

> going and coming and the clear trace of dogs' paws—many dogs. This told us the whole story. The Norwegians have forestalled us and are first at the Pole.

Wilson's account, quoted from his journal by Seaver in 'Edward Wilson of the Antarctic,' p. 278, is:

> *Jan.* 16. We got away at 8 a.m. and made 7·5 miles by 1.15, lunched, and then in 5·3 miles came on a black flag and the Norwegians' sledge, ski, and dog tracks running about N.E. and S.W. both ways. The flag was of black bunting tied with string to a fore and after which had evidently been taken off a finished-up sledge. The age of the tracks was hard to guess, but probably a couple of weeks—or three or more—the flag was fairly well frayed at the edges. We camped here and examined the tracks and discussed things.

It is fortunate that Wilson records "we camped here" and that Scott has "nearby the remains of a camp," which was evidently the Norwegian camp of the evening of December 13: its latitude by account, 89° 45′, agrees well with Bowers' 89° 45′.6 for Camp 68. We shall see that the coincidence of these two camps is an essential factor in the solution of the problem: What did each do on the following day?

Up to that point Scott had been heading straight for the Pole; but on January 17 he writes:

> "We started at 7.30, none of us having slept much after the shock of our discovery. We followed the Norwegian sledge tracks for some way; as far as we can make out there are only two men. In about three miles we passed two small cairns. Then the weather overcast, and the tracks being increasingly drifted up and obviously going too far to the west, we decided to make straight for the Pole according to our calculations."

Wilson says:

> "In the morning we were up at 5 a.m. and got away on Amundsen's tracks, going S.S.W. for 3 hours, passing two small snow cairns, and then, finding his tracks too snowed up to follow, we made our own bee-line for the Pole."

Amundsen's track cut Scott's obliquely. The diagram in Report (Fig. 6) makes it nearly parallel to the meridian of Framheim 163° 37′ W.; but in getting up from the barrier to the plateau the Norwegians had borne to the right, and the head of the ascent is in about 169°. If on the plateau they steered on this meridian they would have been marching on about N. 32° E. Magn. at the point where they intersected the meridian 160° E. The diagram illustrating the Appendix IV of Amundsen's second volume (English) makes the bearing about N. 51° E. but this will be found inconsistent with other observations; it must have been in the neighbourhood of N. 30° E. if in the neighbourhood of the Pole the Magnetic Meridian is as shown in our plotting. Why Scott, who had been marching so straight to the Pole, was hypnotized into following Amundsen's trail when it cut across his own is hard to understand; but he did so for some three hours, and put himself several miles off his course. When they realized that this was a mistake they reverted, I think, to their former compass course, Magnetic North, and after a halt for lunch they marched $6\frac{1}{2}$ miles more on what Scott calls due south

and then made Camp 69. Here Bowers made several observations at intervals during the night.

All these, with the lunch observation that day, and that at the Pole lunch-camp the next, were worked up by Bowers as if they were meridian sights for latitude, and have been treated as such in the Report, which goes so far as to deduce a probable error for Bowers' latitudes from the divergences from the mean of the various sights at Camp 69. But it is clear that Scott and Bowers on the morning of January 18 realized that these were not all latitudes: had they been, they would have given no indication on which side of the Pole they were. Scott's journal says: "Decided after summing up all observations that we were 3·5 miles away from the Pole—one mile beyond it and 3 to the right. More or less in this direction Bowers saw a cairn or tent." One may easily reconstruct their summing up.

The observations at the Pole

The observed altitude, corrected for level, refraction, and parallax, is the corrected altitude, and 90° minus this is the corrected zenith distance. In the southern hemisphere, when the Sun is on the meridian at local noon the sum of the zenith distance and the southern declination of the Sun is the Latitude south. When the Sun is on the meridian at local midnight the sum of the zenith distance and the declination comes out greater than 90°, and the latitude is 180° minus this sum. At intermediate hours the sum of the zenith distance and the declination is nearer to 90°, and passes through 90° when the Sun is about six hours from the meridian.

Bowers worked up the six observations at the Pole, five at Camp 69 and one at the lunch camp on the following morning, in this way, and the following figures are extracted from his observation book:

Obs.		18	19	20
G.M.T.	.. Jan. 16	19 18 27	19 30 11	21 4 44
Corr. alt.	..	21° 2′25″	21° 2′51″	21° 1′36″
Zen. dist.	..	68 57 35	68 57 9	68 58 24
S. Decl.	..	20 59 28	20 59 23	20 58 37
Sum ..	..	89 57 3S	89 56 32	89 57 1S
	Mean 18, 19	89 56 48S		

Obs.		21	22	23
G.M.T.	.. Jan. 17	4 29 3	7 3 31	13 14 3
Corr. alt.	..	20°55′31″	20°50′48″	20°51′43″
Zen. dist.	..	69 4 29	69 9 12	69 8 17
S. Decl.	..	20 54 25	20 53 54	20 50 57
Sum ..	..	89 58 54	90 3 6	89 59 15S

The four sights in No. 18 are all on face right, and in No. 19 all on face left. Bowers has correctly taken the mean of 18 and 19 and treated this mean as one observation. The Report treats them as two, considering this "of course quite sound in the unique position of the observer in this case," as if being 3 miles from the Pole somehow eliminated the collimation error of the theodolite and the index error of the level.

The Report rightly observes, on p. 26, that in calculating 21 Bowers had

made some mistakes (which had been corrected in Scott's writing) but that the correction to the watch had been omitted (so that the declination was wrong). But Report does not remark that owing to an error in multiplication the declination was wrong anyhow. Scott made the sum 89° 58′ 54″ as above; Report "on re-working with all corrections" makes it 89° 59′ 12″; my calculation is 90° 0′ 34″ with Bowers' refraction tables, or 90° 0′ 50″ with those in 'Hints,' vol. I. (See below, p. 167: *Recalculation*).

Scott calculated No. 22 himself, and when he arrived at the sum 90° 3′ 6″ he subtracted it from 180° and wrote underneath it 89° 56′ 54″ without remark. But he must very soon have seen the significance of this sum greater than 90°; it was no doubt the key which led to the correct summing up.

The Report remarks on No. 23 that "The observed figures are in Captain Scott's handwriting; in fact he has initialled a correction, so that Bowers was probably observing, though he usually booked his own observations." Now it is easy to distinguish between the numerals of Scott and Bowers; the former wrote 9 with a straight tail, and the latter wrote it with a strong curl. A glance at the observation book shows that Scott recorded all the observations 18 to 23; that Bowers worked up 18 to 21; that Scott corrected Bowers' calculation of 21 and calculated 22 himself. They both worked up 23.

No. 23 was reduced first by Scott and then by Bowers; they agreed within a second of arc, but accidentally. The Report points out that Scott "applies the wrong sign to the bubble correction, uses the refraction correction from a computation made in the morning of that day and does not apply the correction for parallax." The first and third objections are just, but the second was no mistake; the refractions for the five preceding observations had been the same within a second or so. It was Bowers' refraction that might have been criticized; he either made an error or used a different refraction table, which made a difference of 14″. As it is, I think, a more accurate value I have given Bowers result in the above table.

Now when Scott and Bowers "summed up" their observations at Camp 69 they must have seen that at about 7.30 p.m. of the time they were keeping the sum of zen.dist. and S.decl. was about 89° 57′; about twelve hours later, at 7 a.m., it was about 90° 3′; and at 2 a.m. it had been, according to their calculation, about 89° 59′. They rightly concluded that the observation at 7.30 p.m. must have been within an hour or two of local noon, and at 7 a.m. within the same range of local midnight. They were therefore about 3 miles from the Pole, and to the right of it as seen from the way they had come. How they concluded they were a mile beyond it is not so clear; the wrong result for the 2 a.m. sight would have seemed more appropriate to 11 p.m.

However they did it, 'twas a good estimate. The greater is the pity that the Report, failing to understand what Scott and Bowers certainly did comprehend, if perhaps a little vaguely in their fatigue after a night broken with observations, has treated all the observations of this group as meridian altitudes, in spite of the fact that they were made at about 7.30 and 10 p.m., 2 and 7 a.m., and has calculated from their divergences a probable error for Bowers' observations which is about three times as great as it really was. What the Report calls "the bad observation taken at 2 in the morning, which has a residual of 106 seconds" is No. 21, which, as we shall see when we plot the position lines, is bad only because it was as far as possible from being a latitude.

Recalculation of these observations

For plotting the position lines I have recalculated these six observations: we require the Greenwich Apparent Time, the Corrected Altitude, and the Declination of the Sun. The difference between the two latter is the "intercept," and as it is to be plotted in minutes and decimals, or geographical miles, I have calculated these to two places of decimals. The G.A.T. is expressed in degrees and one place of decimals. A tenth of a degree is 24 seconds of time, and the Greenwich mean time carried by watch T may very well have been accurate to within 24^s.

The Report says nothing of the Refraction Tables used by Bowers, except that Sledging Tables, a booklet of 150 pages, were chiefly reprints or adaptations of the tables given in the then current edition of 'Hints to Travellers,' but that the Refraction Tables were differently arranged, which they certainly should have been for these extreme conditions. I cannot find that any copy of these sledging tables has been preserved; even Dr. Mill's collection of polar literature does not contain one. I have myself used the graph provided in the 11th edition of 'Hints' for refraction in extreme conditions, and this makes the refraction correction about 14 or 15 seconds of arc greater than those calculated by Bowers, except in No. 23, where we agree precisely. Bowers had for that one observation multiplied the mean refraction by 0·8 instead of by 0·7. The Meteorological Tables in vol. III, p. 633, make the barometer 0·03 higher than it was at 7.30 a.m.; the temperature was not recorded at the Lunch camp. There are no records of barometer or thermometer in the Observation book, but they are generally given in the Tables just mentioned.

The declinations have been interpolated with second differences, which is just worth while.

Bowers' observations recalculated by A.R.H.

		18	19	20
G.A.T.	.. Jan. 16	287°2	290°1	313°7
Corr. Alt.	..	21° 2′19	21° 2′62	21° 1′38
Decl.	..	20 59·46	20 59.36	20 58.62
Diff. ..	..	+ 2.73	+ 3.26	+ 2.76

		21	22	23
G.A.T.	.. Jan. 17	33°0	103°4	196°0
Corr. Alt.	..	20° 55′30	20° 50′51	20° 51′71
Decl.	..	20 56.10	20 53.85	20 50.96
Diff. ..	..	− 0.80	− 3.34	+ 0.75

To plot the position line, draw a line from the Pole to the point on the divided circle which marks Greenwich Apparent Time; this is the direction of the Sun at observation. Lay off along this line a distance equal to the difference Altitude minus Latitude, towards the Sun if it is positive, and away from it if negative. A line through this plotted point at right angles to the radial line is the position line on which the observer must be. The intersection of two position lines more or less at right angles gives the observer's place. This is the simple graphical method of finding position within a few degrees of the Pole. It has been objected that a man cannot use geometrical instruments in a sleeping-bag; the precision of Bowers' diagram

of camps and positions about the Pole refutes this opinion. But in any case, if the observation book could have alternate pages with a divided circle and a scale of miles one may sketch the position lines freehand with sufficient accuracy for the immediate purpose, if one can make such good and clear calculations in a sleeping-bag.

The five complete observations made near the Pole are plotted as position lines on Fig. 5, p. 174. They show that the conclusion drawn by Scott and Bowers when they thought over the observations at Camp 69 was near the truth; they were a little more than 3 miles to the right, but not a mile beyond it.

We turn now to the Norwegian observations a month before. These have never, so far as can be ascertained, been published in detail. A plate in the English edition of 'The South Pole' gives a few of the sights made at the camp named Polheim, photographed from the observation book; the Norwegian edition, 'Sydpolen,' gives the full twenty-four. Both editions contain an appendix of a few pages with a very inadequate discussion of them. I am much indebted to Dr. Hugh Robert Mill for lending me his copy of the Norwegian, probably the only copy in England, and to Dr. Olaf Devik for translating the relevant passages. Before the observations are discussed there is a curious confusion of dates to be disentangled.

Amundsen's dates

The *Fram* left Christiansand on 9 August 1910 and Funchal on September 9, passed south of the Cape of Good Hope two months later, was off Kerguelen on November 28, crossed the 180th meridian on 6 January 1911, and moored in the Bay of Whales on January 14, having touched nowhere since leaving Funchal. These dates are from 'The South Pole,' by Roald Amundsen, translated from the Norwegian by A. G. Chater, London, John Murray, 1912. They agree with the dates in the original Norwegian edition, Roald Amundsen, 'Sydpolen,' Gyldendanske Bokhandel, København, 1912. For brevity we will refer to these as English and Norwegian respectively.

A note on page 384 of volume II, Appendix II, Meteorology (English, not in Norwegian) says: The date was not changed on crossing the 180th meridian. This might be read as applying only to the Meteorological Record at Framheim. But the page 33 of an observation book, reproduced on II.85 of Norwegian (not in English), gives a latitude observation at noon on 15 November 1911; the reduction shows, in the value taken for the Sun's declination, that local noon was in advance of Greenwich by about 13^h; that is, they had not changed their date on passing into the western hemisphere, but were keeping Australian date.

The account of the journey to the Pole is covered by chapters X, XI, and XII of vol. II, English, and in a long single chapter "Mot Polen" of vol. II, Norwegian. Both say that the party of five left their base at Framheim on the Bay of Whales on 20 October 1911, but from that point the Norwegian dates are a day later than the English; the twenty-four hours of observation at their polar camp Polheim are from noon to noon of December 17–18, Norwegian, and December 16–17, English. A note at the end of the Norwegian chapter

says that as date was not changed at the passage of the 180th meridian on the voyage of the *Fram* to the Bay of Whales, all dates in this chapter will have to be corrected one day back. Some pedant seems to have persuaded Amundsen to make this very unnecessary change before the *Fram* reached Hobart and despatched to the newspapers the long message which is reprinted in "The First Account" (English I, vii–xix) and in "Den første Beretning" (Norwegian I, 9–26); except that he forgot to change the day of the start for the Pole, which appears in both as October 20 when it should be 19. The change was forgotten also in printing the main text of Norwegian, vol. II, but was made in the English; and it was made in the report on the Astronomical Observations in both Norwegian and English, though neither mentions the change. We may be allowed to call the change pedantic because it makes a discontinuity between the dates of the Norwegian and the simultaneous British expedition: both keeping the Australian date in the field, but the former changing to the American date, except in the principal Norwegian chapter, and in the facsimile reproductions of observation books and reductions which illustrate that chapter. To sum up:

The Australian date, and approximate Framheim Civil Time, about 13 hours in advance of Greenwich Civil Time, or 25 hours in advance of Greenwich Mean Time beginning at Noon, are used in

Norwegian Volume II, pages 1 to 172, Sjette Kapitel, 'Mot Polen,' and on facsimile reproductions of observations in this chapter.

English Volume II, Appendix II, pages 372 to 394, 'Meteorology.'

The American date and approximate Framheim Time about 11 hours slow on Greenwich Civil Time, or one hour fast on Greenwich Mean Time, are used in

Norwegian Volume I, pages 9 to 26: 'Den første Beretning.'
Volume II, pages 408 to 412: 'Overlaerer Alexanders Erklaering om undersøkelsene av observationsmaterialet.'

English Volume I, pages vii to xix: 'The first Account.'
Volume II, Chapters X to XIII, pages 1 to 175.
Volume II, Appendix IV, pages 399 to 403, 'The astronomical observations at the Pole.'

In my discussion I have retained the original Australian date.

The observations at Polheim

The Appendix IV, pp. 399–403 of the English, contains a Note by Professor H. Geelmuuyden, Director of the University Observatory at Christiana (Oslo) which is not found in the Norwegian. He says that having been requested to receive the astronomical observations for the purpose of working them out he had handed them over to a schoolmaster who had so full an insight into the theoretical basis that he was capable of working without being bound down by instructions. This note is a preface; there is no indication that the astronomer ever looked at the results of his action, and his must be the responsibility for the very unsatisfactory treatment that these observations received at the hands of the schoolmaster.

After working up the observations made from 6 a.m. to 7 p.m. the day before at the first polar camp (Sledge camp) which are nowhere published,

Amundsen and his four companions sledged down on the morning of December 17 (Australian date) a distance of 5½ geographical miles on compass bearing N.W.1/4W. and set up the small spare tent, which they named Polheim, about an hour before noon; and here they took altitudes of the Sun every hour from noon on the 17th to noon on the 18th. These observations are reproduced in facsimile from pages 168 and 169 of the observation book, on the double-page plate between pages 136 and 137 of the Norwegian, vol. II. Only the second half of this plate is published in the English, and the date December 17 there shown does not belong to this half, which is for the morning of the 18th. The observations were made with No. 1 of the two sextants, and with watch No. 3. The index error is given as minus one minute of arc, but there is no indication of the assumed watch error on Framheim time; the appendix has no trace of barometer or thermometer readings required for calculating the refraction, though these must have been somewhere in the observation books. The published material is therefore insufficient for a complete solution.

I have plotted the observed altitudes corrected for semi-diameter, parallax, and refraction, in the upper line of Fig. 2. It will be seen that the figures

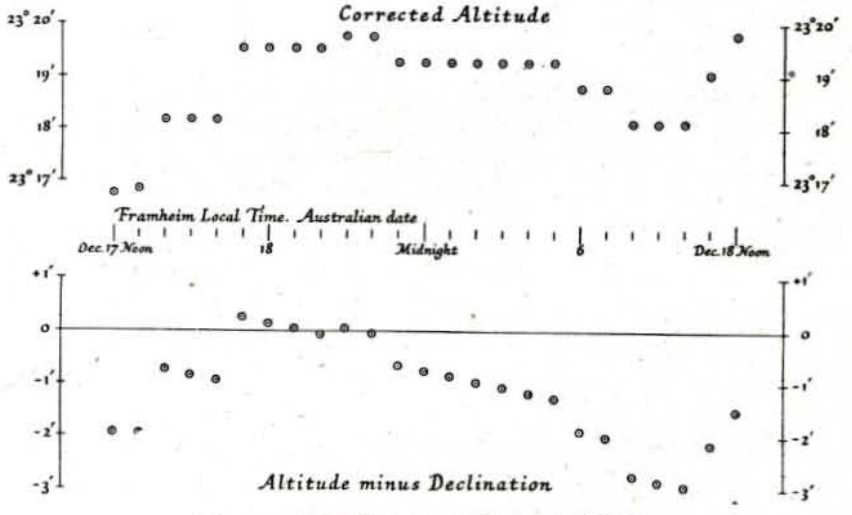
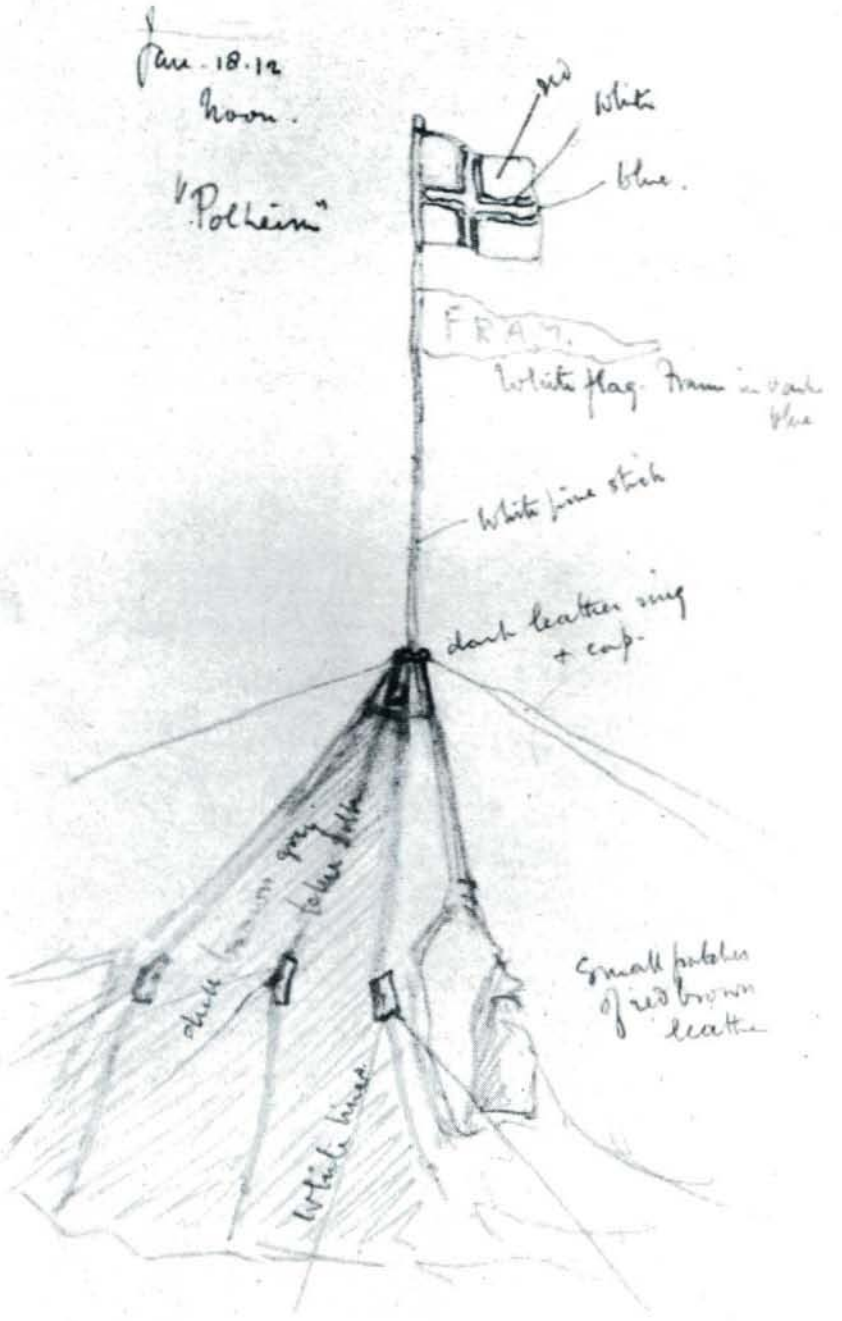


Fig. 2. Norwegian observations at Polheim

tend to repeat themselves for several hours together; thus for seven consecutive hours, from 11 p.m. to 5 a.m. the corrected altitude is 23° 19′.27, immediately following two of 19′.77, which are my highest. The calculator deduces an upper culmination altitude of 23° 19′.2, and a lower of 23° 17′.4, which are "one or two minutes of arc too low," perhaps because he has not applied the index correction. But neither had I, preferring to deduce it, as will be seen. From these two figures he derives a latitude 89° 58′.6, which is "confirmed by the considerable displacement of the periods of culmination . . . caused by the change in the Sun's declination." He concludes from this that Polheim must lie south of 89° 57′ but north of 89° 59′, and on a



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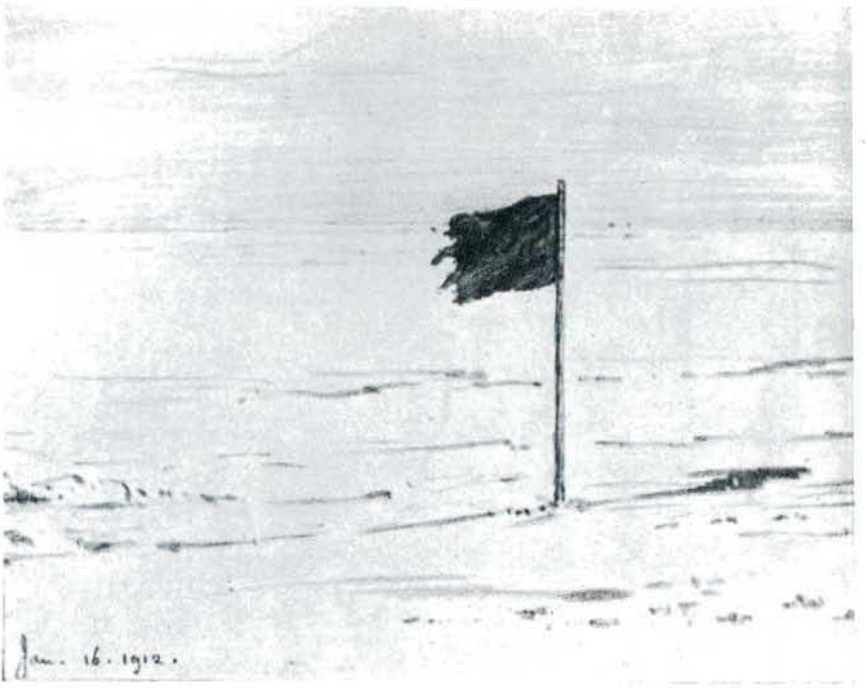
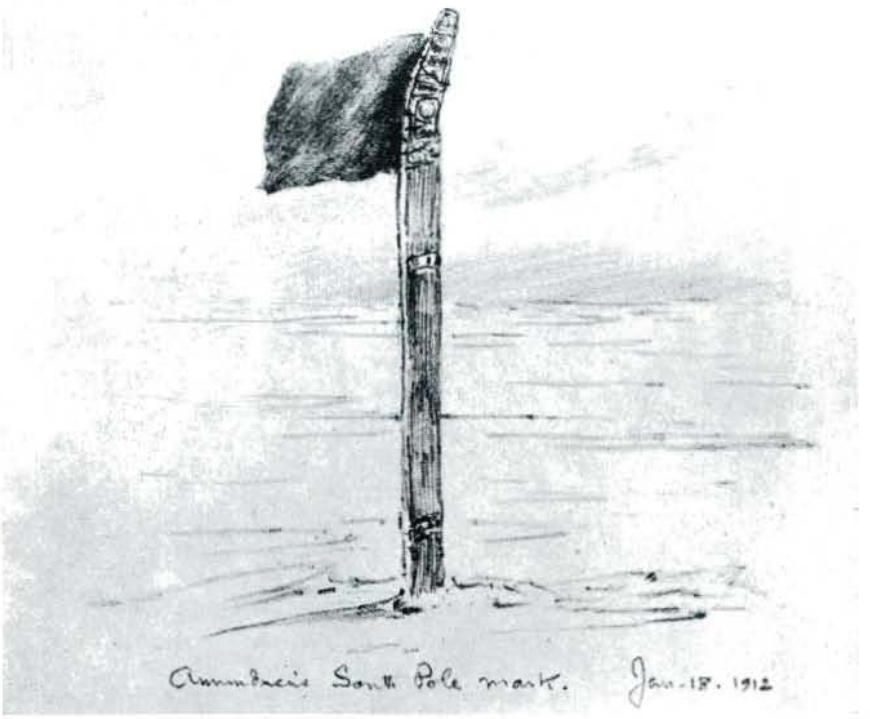
Amundsen's tent 'Polheim' at the South Pole



Norwegian Flag 1, close to Scott's Camp 68



Norwegian Flag 2, where Dr. E. A. Wilson found Amundsen's note discussed in the text

diagram he actually shows the limits of uncertainty in latitude as above and between 30° and 75° E. in longitude: area EFGH in Fig. 3.

A glance at the plotted observations, upper line, shows how vain it must be to look for displacements of the time of culmination due to the motion of the Sun in declination, at this epoch, only a few days from the solstice, and only a mile or two from the Pole. If instead one plots in the lower line the differences between the corrected altitudes and the declination of the Sun, which latter would be the altitude of the Sun at the Pole, it is easy to see that the range of difference is about three minutes, so that the latitude is about 89° 58½′; that the maximum is somewhere between 5 and 10 p.m. and the minimum between 8 and 10 a.m., so that Polheim was displaced from the Pole in the direction of the Sun within an hour or two of 9 p.m. But if the observations are worked up as position lines they give a much more definite result and do more justice to the skill and determination of the observers. Amundsen and his men took the trouble to observe the Sun every hour for twenty-four hours, and every observation of such a series, if properly reduced, can contribute equally to the result: not only those which are near a maximum or minimum.

The observation books give the time of each observation as a round hour: Noon, 1 p.m., 2 p.m., etc., and in default of any knowledge of the watch error we must assume that watch No. 3 was keeping Civil Time of the Framheim meridian, which is 163° 37′ West or 196° 23′, that is, $13^h\ 5^m.6$ East of Greenwich. Thus Framheim Civil Time of the Australian date was $25^h\ 6^m$ in advance of Greenwich Mean Time of the same date, reckoned from noon as in the Nautical Almanac of that epoch. The observation books give also the compass bearing of the Sun at the observation, to quarters of a point (one quarter-point is 2°.8). The differences between the compass bearings at successive observations show that they were only roughly at the intended hours. It has seemed best to calculate the declination, refraction, etc., for the stipulated hours, but to plot the position lines from the compass bearings, assuming that Magnetic North at the South Pole is along the meridian 20° West of Greenwich. There are no published figures of Amundsen's, and it will be well anyhow to use the same figure as we have used for Scott's magnetic bearings.

We have no sufficient data for calculating accurately the refraction correction. On December 11 the temperature, probably at the noon observation, was minus 13° F. On the afternoon they left the Pole it was minus 2°.2, and there are no records in between, nor any barometer heights. Assuming thermometer minus 5° F. and barometer 19½ inches, and using the graph for correction in extreme conditions given in 'Hints to Travellers,' I.256, 7, we have for apparent altitude 23° 20′ a refraction correction −1′.64, and this can hardly be more than a few hundredths of a minute of arc wrong at the worst. It has been applied to all the observations.

The quantities Corrected Altitude minus Sun's Declination are plotted in the lower line of Fig. 2 against the intended time in hours from Framheim noon. In Fig. 3 these numbers from noon are set out on the corresponding compass bearings of the Sun. The position line, with its current number, is set off at right angles to the Sun's bearing, towards the Sun if the altitude is

greater than the declination, away from it if less, and at a distance from the Pole corresponding to altitude minus declination. If the observations were all exact, and there was no index error, these position lines would all intersect at the position of Polheim; but the lines are displaced away from the Sun by a negative index error of about a minute of arc, so that they leave a blank space round about the place of observation, and one can estimate within a few tenths of a minute where Polheim must be. To get a closer determination

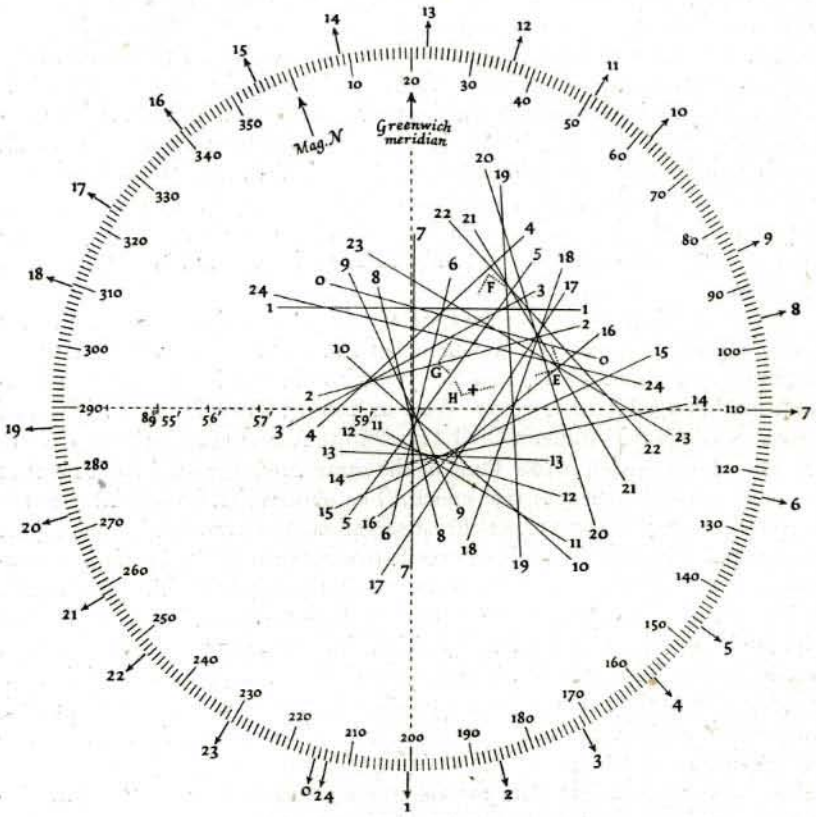


Fig. 3. Position lines from Norwegian observations at Polheim

I think that the best method is to take the observations in fours: 0.6.12.18; 1,7,13,19; and so on, treating the sun by the quadrantal method used for stars.

On each quadrilateral of Fig. 4 describe a circle which will as nearly as possible touch the four position lines. The centre of the circle is the position derived from the four lines, and the radius of the circle is a measure of the sextant's index error. The mean of the seven radii is 1·2 minutes of arc, which confirms the Norwegian figure of one minute. If the seven centres are transferred to a single plotting, it is evident that the latitude of Polheim is about a minute and a quarter less than 90°, and its longitude about 72° East

of Greenwich. If the coordinates of the seven centres are scaled off and the means taken, one finds the latitude 89° 58′·75 and the longitude 71°·6. The graphical method is good enough, and it is evident from the concentration of the quadrilateral centres that the derived position of Polheim must be right within ten seconds of arc or say 320 metres.

The twenty-four-hour programme of observations, performed by Amundsen, Hanssen, Wisting, and Hassel at Polheim, gave then a very much better result than was made to appear in the brief and inadequate report made by the calculator to whom Professor Geelmuyden turned over the task which he had been asked to perform himself. It is a pleasure to demonstrate, more than thirty years after the event, by this simple and obvious graphical discussion, how good those observations were.

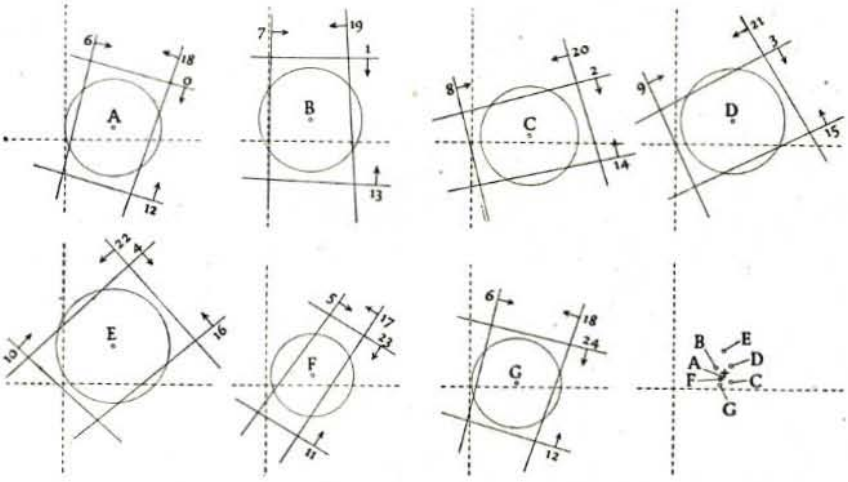


Fig. 4. Polheim position lines in groups of four

The Norwegians and British at the Pole

To make a combined plot of the two parties' movements at the Pole we have as a basis for Fig. 5 three astronomical positions:

The British Camp 68 of the night of January 16, from our plot of the British approach; this is also the Norwegian camp of December 14.

The British Camp 69, determined by four position lines during the night of January 17–18.

The Norwegian camp Polheim, determined by 24 position lines at hourly intervals from noon on December 17.

We have also single position lines for the British lunch camps of January 17 and 18, the latter to be called by Scott the Pole Camp.

The Norwegians set up a sledge at their camp of December 15–17 and left it there as a mark. They had made twelve observations there which have never been published, but they have given the position of Sledge camp as $5\frac{1}{2}$ geographical miles S.E.1/4E. from Polheim.

We must assume that the Norwegians marched straight from Camp 68 to

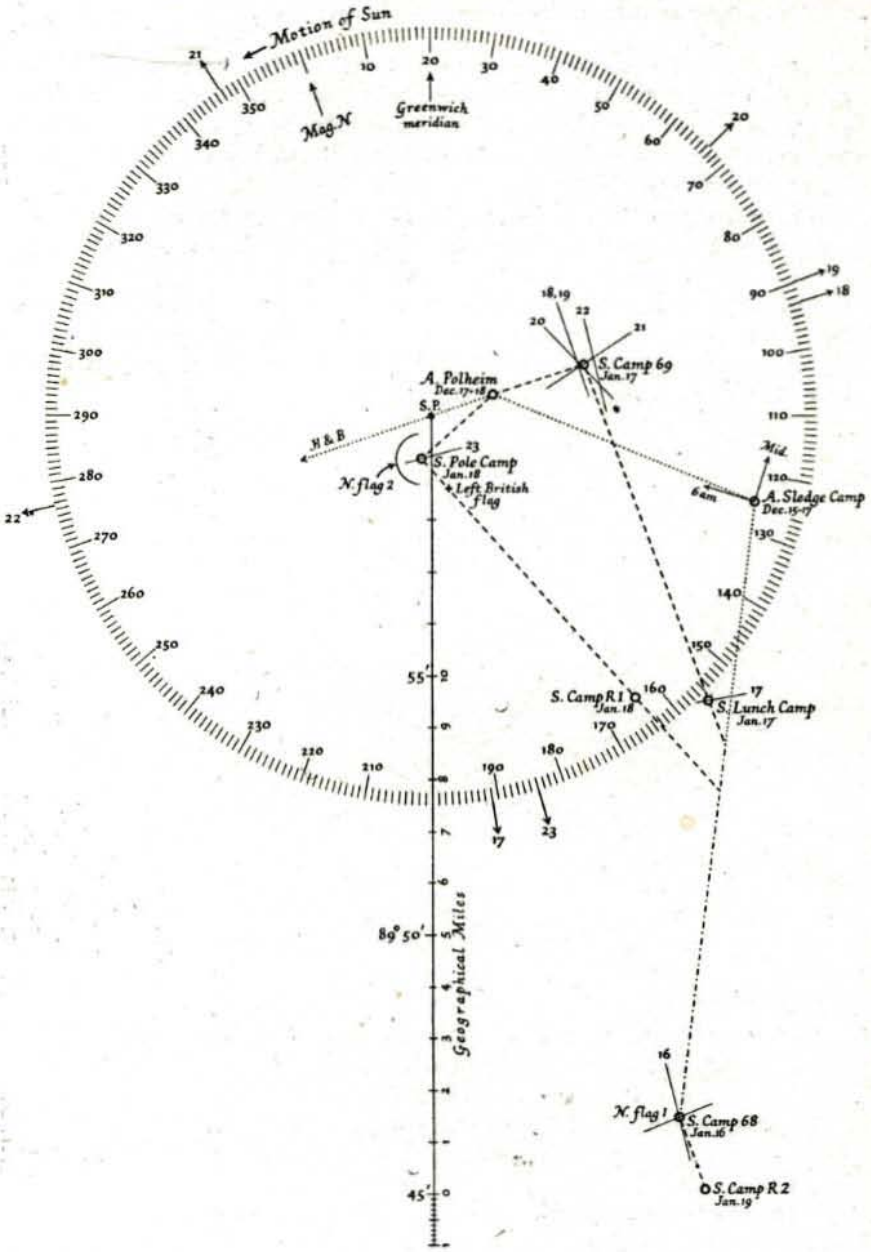


Fig. 5. British and Norwegian positions near the Pole: S British, A Norwegian

Sledge camp. Scott marched along their tracks for several hours, and in about three hours passed two small cairns, but then struck off "on a bee line for the Pole" (Wilson), or "due South" (Scott), meaning presumably the compass course on which they had been marching up the meridian 160° E., that is, magnetic north. Setting off this line back from Camp 69 we find approxi-

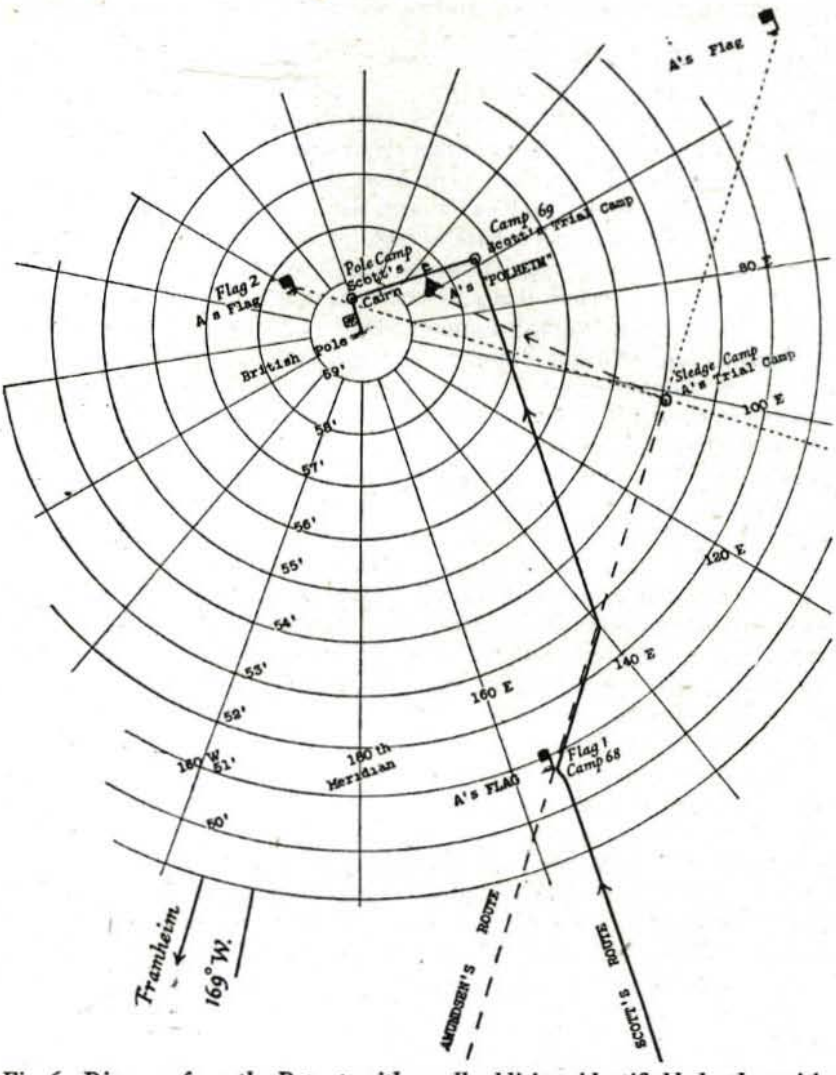


Fig. 6. Diagram from the Report, with small additions identifiable by the writing

mately where the British turned off from the Norwegian tracks, and the intersection of this line with position line 17 gives the position of the lunch camp of January 17.

Scott says that they marched 7·4 miles in the morning and 6·5 after lunch: 13·9 for the day. Wilson gives only incomplete times: over 3 hours and $3\frac{1}{2}$. Bowers' diagram in the observation book makes it 8·1 in the morning and 6·4 in the afternoon: total 14·5. My plot of camps 68 and 69 from a re-reduction of the observations makes the direct distance between the two 14·6 miles, and the two legs of the traverse 8·1 and 7·9, giving 16·0. The astronomical observations seem to make it impossible that Scott's figures for the length of the march can be right, and Bowers' plot does not fit much better, probably because Camp 68 shown on the lower edge of the page should be

beyond it. I think that our plot is as nearly correct as the rather vague data allow, for the marches of January 17.

We have seen how Scott and Bowers, after the early morning observation of January 18 at Camp 69, decided that they were 3·5 miles from the Pole—1 mile beyond it and 3 to the right. More or less in this direction, says Scott, meaning towards the Pole, Bowers saw a cairn or tent, which was Polheim. "We have just arrived at this tent," writes Scott, "2 miles from our camp, therefore about $1\frac{1}{2}$ miles from the Pole," which implies that it was so nearly in the line of march that a diversion to visit it did not add anything much to the distance. Wilson's account: "During the forenoon we passed the Norwegians' last S.^{ly} camp" implies the same, and Polheim is by our plot slightly less than half a mile from the direct line, from Camp 69, not to the Pole, but to Scott's Pole Camp; it was exactly on the line to the Pole.

Page 26 of the Report says that the most probable distance and bearing was worked out to be a little over 3 miles S. 80° W. by compass, with the extraordinary comment "Variation being 180° naturally." What is the authority for the figure 80° W. is not known; our astronomical position for Camp 69 makes the Pole S. 92° W. magnetic. Neither Scott nor Wilson gives the course on which they marched, $3\frac{1}{2}$ miles according to Scott, $3\frac{3}{4}$ by Wilson. Taking 3·6 as the mean, and striking an arc of this radius from Camp 69 to cut the position line from Bowers' single sight at the Pole Camp, we make it 0·85 geographical miles from the Pole on the meridian about 167° West of Greenwich. They had passed the Pole on their right hand half a mile away, and gone a little too far.

At this Pole Camp Scott writes: "We built a cairn, put up our poor slighted Union Jack and photographed ourselves. . . . We carried the Union Jack about $\frac{3}{4}$ of a mile north with us and left it on a piece of stick as near as we could fix it." Wilson (p. 280) says: "Here we lunched—camp—built a cairn—took photos—flew the Queen-Mother's Union Jack and all our own flags. We call this the Pole—though as a matter of fact we went half a mile further on in a S.E.^{ly} direction, after taking further sights, to the actual final spot, and here we left the Union Jack flying." Bowers says in the observation book: "From this position ran down exact distance to Pole by sledge metre and left British flag." Table 73 of the Meteorology, Vol. III, has the note: "18th. Lunch $\frac{3}{4}$ mile N of Pole left British flag on Pole."

All four accounts are consistent with the idea that when they started from the Pole Camp on the homeward march they imagined they were on the far side of the Pole, and would cross it on the way home. Bowers' diagram in the observation book, and the diagram in the Report, page 29, based upon Bowers, though not very carefully, are drawn to agree with this interpretation. But they are all wrong. The observation 23 at the Pole Camp was made when the Sun was bearing South 4° West, Magnetic, as plotted in Fig. 5. Bowers' Corrected Altitude of the Sun was 20° 51′ 43″; the interpolated Declination was 20° 50′ 57″; and my own calculations agree closely with Bowers'. The difference between the altitude and the declination is 46 seconds, which is Bowers' 1500 yards; but the altitude is greater than the declination, and therefore the position line is displaced from the Pole towards the Sun by 1500 yards. When they sledged another 1500 yards in the same

general direction, they were sledging away from the Pole, not towards it: an unhappy mistake, and not easy to explain when they had interpreted so successfully the observations made at Camp 69.

Their compass course when they started for home on the afternoon of January 18 is not recorded by Scott. Wilson says in a S.E.^{ly} direction. "After lunch we made 6·2 miles from the Pole Camp to the North again—and here we are camped for the night." Of the following morning Scott says: "Early in the march we picked up a Norwegian cairn and our outward tracks. We followed these to the ominous black flag." South-easterly would have taken them across to their tracks of the afternoon of January 17. I think the natural interpretation of Scott's narrative is that they intersected their Poleward tracks somewhere between Camp 68 and the place where they turned away from the Norwegian tracks soon after they had passed a Norwegian cairn. They marched 1 ½ miles beyond Camp 68 and made Camp R.2 on the evening of January 18. As plotted the day's march is 10·3 miles, which is reasonable enough when the morning's march was only 3 ½ miles and they had had much to do at the Pole Camp.

I am disposed to think that there is not much more to be made from the available material. My plot differs a good deal from that of Bowers and more from that of the Report (Fig. 6), but both of these are spoiled by the mistake of putting the Pole Camp on the Greenwich side of the Pole, and making the second position of the Union Jack as at the Pole instead of 1 ½ miles away. Apart from this one mistake by an overtired man, the observations and deductions made by Bowers were excellent: far better than was allowed in the official account of them.

The Norwegian Black Flags

Certain black flags set up by the Norwegians play a conspicuous yet obscure part in the British narrative.

Flag 1 is the black flag close to Camp 68 which showed the British that they were not first in the field; it has been described on pages 163, 164. There is no word about it in Amundsen's narrative.

Flag 2 is the flag about half a mile from Scott's Pole Camp. He says of it (I.546):

> "Less than ½ a mile south we saw stuck up an old underrunner of a sledge. This we commandeered as a yard for a floorcloth sail. I imagine it was intended to mark the exact spot of the Pole as near as the Norwegians could fix it. (Height 9500.) A note attached talked of the tent as being 2 miles from the Pole. Wilson keeps the note."

Wilson says (page 280):

> "At our lunch South Pole Camp we saw a sledge-runner with a black flag about ½ a mile away blowing from it. Scott sent me on ski to fetch it and I found a note tied to it showing that this was the Norskies actual final Pole position. I was given the flag and the note with Amundsen's signature, and I got a piece of the sledge-runner as well. The small chart of our wanderings shows best how all these things lie."

Bowers' small chart in his observation book shows Flag 2 a little less than half a mile from the cairn at the Pole camp, magnetic bearing about N. 35° W.

The diagram in Report does not agree very well with Bowers, and both are so much wrong in placing the Pole camp on the wrong side of the Pole that this evidence is of no weight.

But it is hard to see why Scott and Wilson believed that this flag marked the Norwegian Pole. Wilson brought home the note attached; it is now at the Polar Research Institute, and I have been permitted to study it. On a small sheet of thin yellowish paper is written with pencil in a fine formal hand: "The Norwegian home Polheim / is situated in 89° 58′ S. Lat. / SE by E (comp) 8 miles / 15 Decbr 1911 / Roald Amundsen." Whatever this may mean in itself, it certainly does not mean that the flag to which it was attached was planted to mark the Norwegians' Pole.

There is one indication that Scott found a message from the Norwegians that has not been recorded. They had marked their camp of December 15–17 with an upturned sledge. Scott passed more than 2 miles away from that camp on the afternoon of January 17, but does not mention it and probably did not see it. Wilson, describing Polheim, says "We found no sledge there, though they said there was one." Where can the Norwegians have said there was a sledge, that Wilson expected to see at Polheim? Was it an unrecorded note at Polheim, misunderstood; or another unmentioned note at Flag 2?

Now for the Norwegian accounts of their flag-planting. Having arrived at Sledge camp in the evening of their Framheim time, and started about 11 p.m. to get a meridian sub-polar altitude of the Sun,

> "at 12.30 a.m. we put our instruments away, well satisfied with our work, and quite convinced that it was the midnight altitude we had observed. The calculations which were carried out immediately afterwards gave us 89° 56′ S. We were all well pleased with this result. The arrangement now was that we should encircle this camp with a radius of about twelve and a half miles. . . . Three men went out in different directions, two at right angles to the course we had been steering, and one in continuation of that course. . . . Three small bags of light windproof stuff were made, and in each of these was placed a paper, giving the position of our camp. In addition, each of them carried a large square flag of the same dark brown material, which could be easily seen at a distance. As flag-poles we elected to use our spare sledge-runners, which were both long—12 feet—and strong."

These men set out at 2.30 a.m., carrying three papers of which one has been recovered and is described above. It speaks of Polheim, which had not then been established; one must suppose that they started by calling the Sledge camp by that name. It stated that this Polheim was 8 miles from the place where the flag was to be planted, which suggests that the original programme of marching 12½ miles in each direction had been modified. And it gave the compass-bearing of Polheim from the place where the flag was to be planted: presumably the reverse of the course on which the bearer of the flag was directed. But they had no compasses they could carry, nor any means of estimating distance except by time. They all three came back some time after 10 a.m., to learn that a second observation at 6 a.m. "instead of giving us a greater altitude than the midnight observation, gave us a smaller one, and it was then clear that we had gone out of the meridian we thought we were following. . . . We measured the Sun's altitude at every hour from

6 a.m. to 7 p.m., and from these observations found, with some degree of certainty, our latitude and the direction of the meridian." But the flags were already planted, and it is evident that the compass-bearings inscribed upon the papers they bore cannot be relied upon.

Unfortunately neither Scott nor Wilson gives the bearing of Flag 2 from their Pole camp. Taking it as on a circle of half a mile radius from the Pole camp, the bearing of Sledge camp from the Flag 2 must lie between 122° and 113° E. of N. The bearing S.E. by E. written on the paper is 124°; the magnetic bearing of the line of Amundsen's march, as plotted in Fig. 5 is N. 27° E., or by chance exactly at right angles to the bearing of Scott's Pole camp from Amundsen's Sledge camp. All these figures show that as nearly as can be expected Flag 2 is on a line from Sledge camp at right angles to the direction of approach, and the distance may be as much as 7·6 miles, not so far from the 8 miles of the paper. I think that we may say, then, that Flag 2 may very well be the flag at right angles leftward of the trail, set out by one of Amundsen's "encircling" party, but it cannot possibly be, as Scott and Wilson thought, what the Norwegians took to be the Pole.

The English edition has a plate preceding page 121, entitled "Chart of the immediate surroundings of the South Pole, copyright 1912 Roald Amundsen," which shows a highly idealized plot of the Norwegian route: straight up to the Sledge camp on the meridian of Framheim, and straight on again to Polheim exactly at the Pole. This is a somewhat reduced version of a similar plate in the Norwegian, the first of a batch of unnumbered plates following page 2 of Vol. II; it is signed Tho. Nilsen 6 Februar 1912, which is not on the English version. Nilsen was First Officer and afterwards Commander of the *Fram*; his chart is a fantasy drawn after the return of the polar party to the ship; it is flatly contradicted by the narrative and by the figure in the astronomical appendix. But it shows one thing of interest: a fourth encircling flag something less than 12 miles in rear of Sledge camp, that is to say, about Scott's Camp 68. The narrative says nothing of leaving a flag at this point, still less of anyone going back there with a flag, or planting one there on the way back. But if setting out the flags right and left and forward had been planned before reaching their Pole it would have been natural to begin by leaving one at 68, which is 12 miles from the Sledge camp. This may be the explanation of Flag 1, which gave the first sign to the British party that the Norwegian had preceded them: I can find no other.

Nilsen's drawing shows a similar set of flags disposed about Polheim at a lesser distance, about 8 kilometres, and the Report accepts them, saying that "as at the last camp, three men went out in different directions and set up marks at . . . four miles." The narrative however says that two men went out in the same direction, towards the Pole as determined by the twenty-four hours observations at Polheim, and the narrative must be preferred to the imagination of the *Fram's* first officer. We may then write off the second set of flags as imaginary, and consider Flag 2 as certainly one of the first set, with Flag 1 as the fourth if there were four and not three.

One can but regret that the published results and discussion of the astronomical positions determined on these two historic expeditions are so meagre

and incomplete. Observations made within a few miles of the Pole are so rare and have such special interest that every figure of the records and reductions should have been published. The whole could have been contained in a dozen pages: not very much compared with the 823 pages of figures in the third volume of the Meteorology and the two volumes of discussion. In contrast with the Meteorology, nothing of the astronomical determinations has been printed except some few of the concluded results; and the brief discussion is quite unworthy of their importance, as I have been compelled to indicate. The agreeable feature of the present paper is its main conclusion, that the observations of both parties were very much better than has ever before been represented, and deserve praise that has been long delayed.

Perhaps no one will ever go to the Pole again on foot, and take a twenty-four-hour round of sights to fix his camp. But men may from time to time go by air, and need a convenient method of finding the Pole and confirming it on landing. The method used in this paper works sufficiently well to about 5 degrees from the Pole, and further if one remembers that the position line is really an arc of a circle with concavity towards the Sun, and allows accordingly. If one is equipped with a set of templates to draw arcs of large radius, the method may be extended to 20 or more degrees, as was done by Wilkins in his flight from Point Barrow to Spitsbergen. And if one works with these on a polar stereographic projection it may be extended yet farther. But its prime simplicity is near the Pole, where other methods break down, and there it will from time to time be practised.

MUD VOLCANOES ON THE MAKRAN COAST

SIR AUREL STEIN'S reference in the *Journal* for November–December 1943 to the mud volcano called Chandragup, near the coast between the Phor river and Sangal, as a place of Hindu pilgrimage, suggested to Squadron-Leader A. J. Young that he should send us some photographs of this volcano taken with a miniature camera on a solo flight in June 1940. Squadron-Leader Young in a second letter describing a flight in September 1940 mentions two hills of dark red colour contrasting with the yellow sandstone of the other hills. He thinks that they were bordering the Basol river and that the western of them would be the hill with spot height 3113 feet in about 25° 45′ N., 64° 10′ E. in the sketch-map illustrating Sir Aurel Stein's paper. The photographs have been submitted to Dr. J. V. Harrison, who has kindly written the following note:

"These mud volcanoes extend all round the Makran coast from Biyaban to British Baluchistan, and three of them were mentioned in my paper on the Coastal Makran (*Geogr. J.* 97 (January 1941) 1–15). One of them discharged a watery mud which would produce a neat cone like Young's. One belched out viscous stuff to form Napag. . . . To the west of Jask there are more of them, and one is very like Young's photo. It occurs near Birz (26°; 57° 29′).

"British Baluchistan was examined by the Burma Oil people long years ago