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Roald Amundsen's route across the polar plateau in 1911–1912

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Research Article

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Abstract

Roald Amundsen's exact route from the top of the Axel Heiberg glacier to the South Pole and back in 1911–1912 has always been somewhat unclear because he never observed his longitude during his southern journey. His approach was simply to steer approximately in a true southerly direction by magnetic compass as long as obstacles did not force him to deviate. The fact that he only knew approximately where he was most of the time on the polar plateau never caused any severe problems for him, but it complicated the search for a depot during the return journey. Based on Amundsen's bearings of some peaks in the Transantarctic Mountains, in combination with his compass courses adjusted with accurate values for the magnetic declination at the time, this paper elucidates Amundsen's actual route across the polar plateau in 1911–1912. The main result is that Amundsen must have taken a more easterly route than what previously has been assumed.

Introduction

Navigation without access to landmarks was often a demanding task for past time explorers, both at sea and on the ice in the polar regions. It could be difficult to get the required clear observations of the solar altitude at noon with sufficient precision, and the following calculations to obtain values for latitude and longitude were relatively complex and time-consuming (Hinks, 1910). However, in some situations, shortcuts that saved time and energy for the travellers could be applied. For example, if the destination was one of the two geographical poles on the earth, one possible shortcut was to simply ignore the longitude observations, with the idea that if you are travelling in a general northerly (or southerly) direction, you will theoretically reach the North Pole (or the South Pole) sooner or later because all meridians coincide at the poles. While that shortcut obviously is theoretically efficient, there is at least one practical disadvantage with it; you will only know approximately where you are during the journey.

During the race for the South Pole in 1911–1912 between the Norwegian Roald Amundsen and the Englishman Captain Robert Falcon Scott, Amundsen used the aforementioned shortcut. While Scott's party observed both latitudes and longitudes many times during the march, thereby spending a lot of time and mental energy to calculate exact positions, Amundsen used the simple strategy to steer southwards by magnetic compass, to keep record of his daily distances through dead reckoning, and to measure his latitude every now and then to verify his dead reckoning (Amundsen, 1912; Scott, 2008). In fact, the only place where Amundsen took detailed observations related to longitude during his southern journey was at the South Pole in the middle of December 1911, although those observations were all the more meticulous. They were afterwards examined by mathematician Anton Alexander and presented as an appendix in Amundsen's published narrative from the expedition *The South Pole* (Amundsen, 1912, pp.399–403), with the main conclusion that the probable position of Amundsen's most southerly camp Polheim was 89°58'30" S, 60° E, and that two of his men, Helmer Hanssen and Olav Bjaaland, probably passed the actual Pole point at a distance of a few hundred metres, perhaps even less, when Amundsen sent them out to plant a flag about 5 miles (note that the unit "miles" refer to nautical or geographical miles, that is, 1,852 metres, throughout in this paper) in what they believed was a southerly direction from Polheim on 17 December 1911 before they started their return journey northwards (Hanssen, 1941, p.95).

Amundsen's detailed observations at the South Pole were re-examined by astronomer and geographer Arthur R. Hinks (1944), who concluded that the location of Polheim probably was 89°58'45" S, 72° E, that is, slightly closer to the actual Pole point than what Alexander's analyses in 1912 revealed. Hinks, who served as Chief Assistant at the Cambridge Observatory and then Secretary of the Royal Geographical Society (RGS), in 1909 had presented to the RGS his paper "Notes on Determination of Position Near the Poles" (which was later published in *The Geographical Journal*, see Hinks, 1910). In this paper, he advocated a quick and simple graphical method to fix one's position near the North Pole or near the South Pole where local time and thus also longitude tend to become indeterminate. Somewhat simplified, Hinks' core idea was to disregard the laborious standard methods to calculate longitude, and instead rely on a sequence of several simple observations of solar altitudes for the determination of an approximate position. Captain Scott attended at that RGS seminar but chose to rely on traditional and time-consuming calculations during his march to the South Pole 2 years later, instead of taking advantage of Hinks' method or some other shortcut. As mentioned above, Amundsen used a simple method of his own, that is, just steering as close to south as possible by an adjusted magnetic compass course without bothering about longitude at all until he reached the South Pole. The only major deviation he had to make occurred when he climbed the Transantarctic Mountains by way of the Axel Heiberg glacier in order to reach the polar plateau, which put him and his four men about six degrees of longitude further west than his route across the Ross Ice Shelf.

According to the route map Amundsen published in his narrative from the expedition (see Fig. 1), he seems to have assumed that his march from the top of the Axel Heiberg glacier across the polar plateau to the South Pole took place approximately along meridian 169° E, although Amundsen never explicitly mentioned an assumed meridian in the running text or elsewhere in his book. In fact, a careful inspection of a high-resolution version of the route map in Figure 1 shows that the route across the plateau is implied slightly *west* of meridian 169° E; hence, despite its sketchy and indicative nature, it cannot be used as evidence that Amundsen actually believed that he at any time during his journey across the plateau travelled east of meridian 169° E.

That Amundsen travelled approximately along meridian 169°E is an interpretation also made, but not questioned, by Hinks (1944, p.160). Drewry and Huntford (1979, p.331), suggested that Amundsen rather journeyed along a meridian 168° E, at least across the Mohn basin. Alberts (1995, p.186) states that Amundsen seems to have travelled across the plateau between the 168th and the 169th meridian. However, the prior conjecture, or even consensus, that Amundsen travelled southwards to the South Pole approximately between the 168th and the 169th meridian gives rise to several anomalies regarding observations of topographic features made by Amundsen and his men. As this paper will show, Amundsen actually seems to have travelled east of meridian 166° E on 1 December while he still was in the Mohn Basin, east of meridian 162° E on 8 December when he broke Shackleton's farthest south record, and close to meridian 153° E when he passed the 89th parallel four days later.

In a paper published in *Polar Record*, Drewry and Huntford (1979) reconstructed Amundsen's route from the top of the Axel Heiberg glacier and southwards during a period of 1.5 weeks in late November and early December 1911. There does not seem to exist any later scientific analyses of any other part of Amundsen's route across the polar plateau in the literature. The analysis by Drewry and Huntford (1979) was primarily based on the various bearings of mountain peaks Amundsen took during his journey, and the estimations of longitudes seem to have been derived through manual plots on a map (the authors do not indicate anywhere in their paper that spherical trigonometry or any similar mathematical method was in fact used, instead, they mention explicitly, e.g. on page 331, that bearings were "plotted on the map"). In addition, they utilised only Amundsen's and Bjaaland's diary notes to make further interpretations. Finally, Drewry and Huntford (1979) relied on Amundsen's own somewhat erratic measurements of magnetic declination (or "compass variation" as it was denoted in the past) while reconstructing his route.

In this paper, spherical trigonometry (Todhunter, 1886) is used to calculate the most accurate estimation possible of Amundsen's route based on his own observed bearings of mountain peaks and other features together with his assumed locations and heights of those features. In addition, the analysis here covers Amundsen's entire journey on the plateau, from the top of the Axel Heiberg glacier to the vicinity of the South Pole, and to some extent also back to the top of the Axel Heiberg glacier. Furthermore, the route will be reconstructed based on the actual magnetic declination in late 1911 according to the International Geomagnetic Reference Field (IGRF) 2020 model (Alken et al., 2021). Finally, this study relies on all available diaries from the journey for interpretations, that is, in addition to Amundsen's and Bjaaland's, Sverre Hassel's and Oscar Wisting's diaries will also be utilised.

Because Hanssen did not have access to any diary notes of his own from the journey in later life (Kløver, 2011; Michaelsen, 2011), we will utilise some of Hanssen's thoughts about the South Pole expedition that appeared in his autobiographical book *Gjennom isbaksen* (In English: "Through the ice box") that was published three decades later (Hanssen, 1941) and in English as *Voyages of a Modern Viking* a couple of years before the Norwegian version (Hanssen, 1936). One could note that Hanssen's book basically consists of three sections that coincide with Amundsen's three major expeditions (i.e. with *Gjøa*, *Fram* and *Maud*, respectively) where Hanssen participated. Interestingly, the three sections are written in a very different manner. The *Gjøa* section is a broad narrative that focuses on the crew's interaction with the Indigenous people and includes detailed descriptions of their behaviour. The *Fram* section consists mostly of disconnected anecdotes from the journey to the South Pole. The *Maud* section, in particular regarding Hanssen's long sledge journey along the Siberian coast, reads largely like a classical continuous narrative based on detailed diary notes. This sharp discrepancy is a strong indication that Hanssen did not have access to any diary notes of his from the journey to the South Pole when he wrote the book.

The remainder of this paper is structured as follows. The next section introduces the general problem with magnetic declination when a magnetic compass course is followed and demonstrates that Amundsen systematically overestimated the magnetic declination during his southern journey. After that, the materials and methods used in the paper are discussed more in detail. Then, Amundsen's journey across the polar plateau is reconstructed based on his reported distances and compass courses adjusted for the actual magnetic declination at the time, in combination with calculated positions derived from observed bearings of mountain peaks and other features as well as qualitative analyses of all available diaries. Finally, the paper ends with the overall conclusion that Amundsen and his men must have followed a more easterly route across the polar plateau to the South Pole in 1911 than what previously has been assumed – a fact that explains some previous anomalies regarding observations of mountain peaks in the Transantarctic Mountains.

Magnetic declination

One of the pillars for this paper is the magnetic declination on the polar plateau in 1911. Magnetic declination is primarily caused by the fact that the magnetic North Pole does not coincide with the geographic North Pole; hence, it is the major reason why regular magnetic compasses generally do not show the true cardinal directions (Dawson & Newitt, 1982). The size of the magnetic declination varies substantially among different locations on earth and

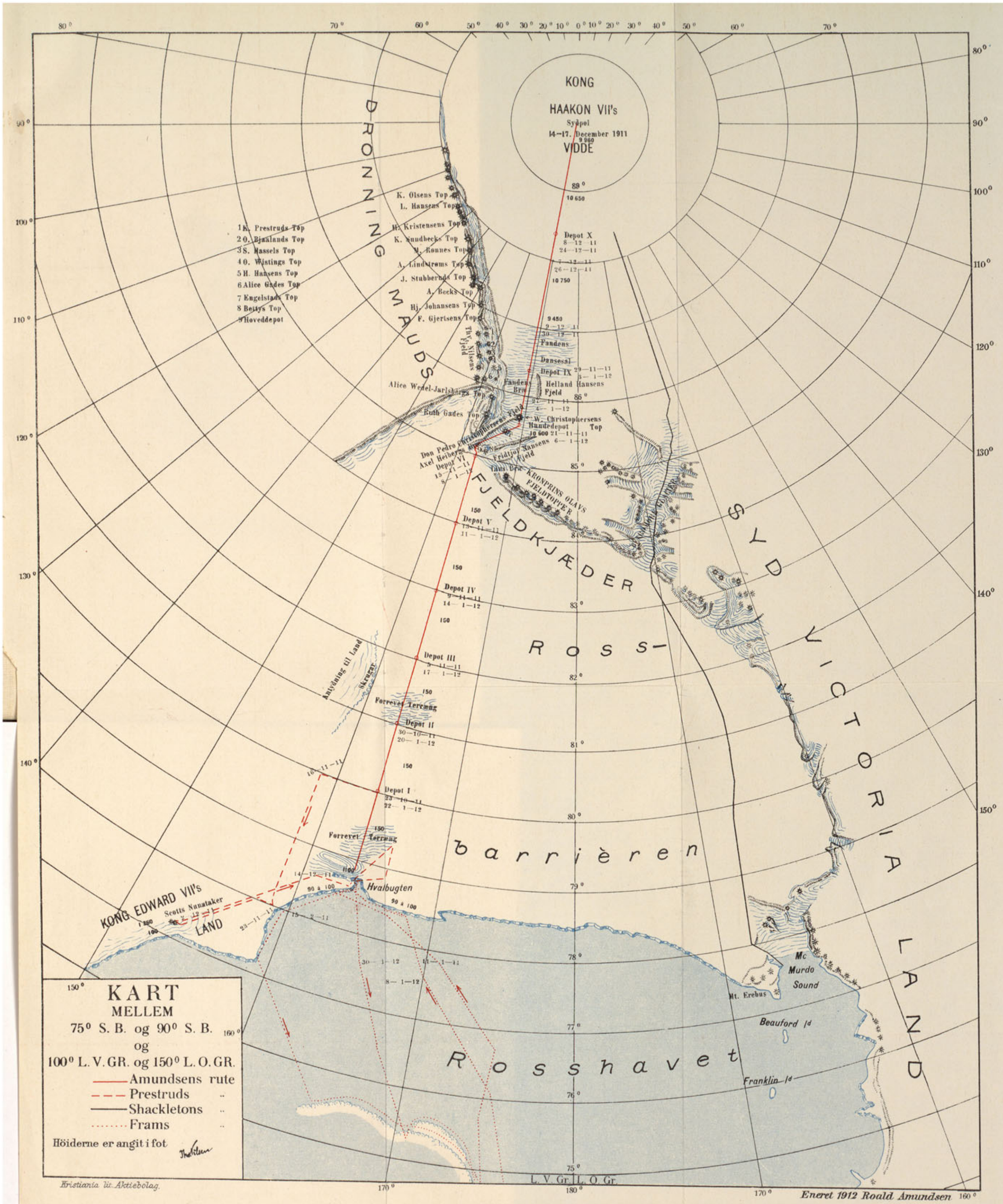

Figure 1. Amundsen's route map of his southern journey. Source: Amundsen, 1912, p.439.

changes (albeit slowly) over time. Because an observed course from a magnetic compass must be adjusted for magnetic declination to obtain the true course, the observer needs accurate information about the magnetic declination at the current location and time. The mathematics itself behind such adjustments is rather simple because magnetic declination is essentially just the angle between

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magnetic north and true north at your current location. For example, if you know that the current magnetic declination where you are is 135° E (a level Amundsen faced during his South Pole journey), and you, like Amundsen, wish to travel in a true southerly (180°) direction, you must steer towards the northeast (45°) by your magnetic compass because 180–135 = 45. This conceptual problem has been understood by naval explorers for many centuries (e.g. Halley, 1683).

Obtaining the magnetic declination at a certain location is rather easy nowadays, but it could be a challenging task in the past. Amundsen measured the magnetic declination at several points during his southern journey and used the results to adjust his compass course in order to travel as closely as possible due south. Amundsen's general method for making estimations of the magnetic declination was described by Mohn (1915, p.41): "During the journey to the Pole the variation of the compass was determined by means of the altitude and compass-bearing of the Sun. From the altitude and declination of the Sun, and the latitude, was computed the azimuth of the Sun; and this, compared with the compass-bearing, gave the error or variation of the compass.". Table 1 shows the results from the compass variation estimations Amundsen made during his southern journey, that is, the values he used to adjust his compass course. For each such estimate, the table also shows the actual magnetic declination values for each approximate position and date according to the IGRF 2020 model (Alken et al., 2021). Although the correlation between Amundsen's measurements and the declination according to the IGRF model is high ($r = 0.957$), Amundsen consequently overestimated the declination.

The estimation of the magnetic declination used while ascending the Axel Heiberg Glacier to the Butcher's Shop was made on 15 November while Amundsen and his men were still on the Ross Ice Shelf, while the remaining four estimations *en route* to the South Pole were made after they had reached the polar plateau. Hence, the data in Table 1 show that Amundsen overestimated the easterly magnetic declination in his measurements by on average almost 10° while travelling on the plateau. Consequently, when Amundsen believed he travelled in a true 180° course (i.e. true south) by compass adjusted for magnetic declination across the plateau, his actual course was about 170°. Hence, he unknowingly trended slightly but systematically to the east from his intended meridian. Of course, a deviation of that magnitude does not necessarily pose a serious problem if your goal is to reach the South Pole where all meridians converge anyway – your journey only becomes somewhat longer. But if you think you are somewhere else than where you actually are on your outward journey, there may be potential for trouble on your return journey due to error propagation if, for example, you need to find a previously laid down depot of supplies without being able to take advantage of your own outward tracks. Furthermore, the fact that Amundsen travelled on a more easterly route across the polar plateau than what previously has been assumed explains some of his otherwise quite anomalous observations of peaks in the Queen Maud Mountains and other features. We will examine this more in detail later in this paper.

Table 1. Estimations of magnetic declination made by Roald Amundsen during his southern journey (from Mohn, 1915) and corresponding real magnetic declinations.

Date in 1911	Approx. latitude	Approx. longitude	Declination (Amundsen)	Declination (IGRF 2020)
30 October	81°00' S	163° W	119° E	115.6° E
5 November	82°00' S	163° W	129° E	119.9° E
9 November	83°00' S	163° W	133° E	123.7° E
13 November	84°00' S	163° W	140° E	127.1° E
15 November	84°30' S	163° W	140° E	128.7° E
27 November	86°00' S	167° W	145° E	136.8° E
4 December	87°00' S	164° W	143° E	136.8° E
8 December	88°20' S	162° W	147° E	136.6° E
10 December	88°40' S	160° W	146° E	135.2° E

Materials and methods

All magnetic declination estimates in this study were derived from the IGRF model, generation 13 (Alken et al., 2021) which was released in 2020. The IGRF 2020 constitutes a model of the Earth's magnetic field at a specific time. Because it is a mathematical model, albeit a rather complicated one, it is not perfectly aligned with the real magnetic field. However, it has achieved worldwide acceptability as a standard and has proved valuable for many applications, and its results are typically accurate to 30 min of arc, which corresponds with an error margin of 0.5°. Hence, compared to the estimates of magnetic declination made by Roald Amundsen during his South Pole journey, results from the IGRF 2020 should be regarded as very reliable.

All Amundsen's data regarding daily distances, compass courses and magnetic declination estimates were obtained from Mohn (1915). The same data set was used by Drewry and Huntford (1979) in their attempt to analyse Amundsen's route through Mohn basin during the period 26 November to 4 December 1911, however, seemingly without using exact mathematical methods to estimate positions, and definitely without adjustment of compass courses based on reliable estimates of magnetic declination. To reconstruct Amundsen's route over the polar plateau based on the data from Mohn (1915), spherical trigonometry (Todhunter, 1886) was used to estimate new positions based on previous positions, distances and compass courses adjusted for magnetic declination. The trigonometric formulas and a detailed numerical example can be found in Appendix A. Spherical trigonometry was also used in a similar manner to calculate some positions based on bearings of mountain peaks, for example, the location for the Devil's glacier depot.

Amundsen used dead reckoning to approximate his daily distances. As expected, because Amundsen frequently had to travel in a zig zag pattern or make other types of detours to avoid crevasses and other difficult areas, especially when he crossed Devil's glacier, the sum of distances between the two points as measured by him through dead reckoning do typically not agree perfectly with the corresponding straight-line distance. To compensate, the dead reckoning distances between each pair of points were adjusted proportionally to make the sum of them equal to the straight-line distance. For example, when Amundsen travelled from the Butcher's Shop to 86°21' S, he noted a total of 50 miles by dead reckoning in his log. The straight-line distance is about 46.5 miles. Hence, his estimated daily distances during this section were reduced by about 7% to align them with the actual distance. The same type of adjustment was made for each section until Amundsen reached 89°06' S. After that, Amundsen and his crew were so close to the South Pole that local time and thus also meridians began to lose meaning. Hence, for the purpose of this study, there is no point to try to

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analyse Amundsen's exact route in the vicinity of the pole. Furthermore, Hinks (1944) provides an excellent overview and analysis of Amundsen's movements in this area.

Amundsen's journey

To the Butcher's shop

The first major obstacle that Amundsen encountered, after having crossed the Ross Ice Shelf, was the Queen Maud Mountains, where he chose to continue straight southwards from Mount Betty – a route which forced him to climb several mountains before he could descend onto the Axel Heiberg glacier (Amundsen, 1912). From there, he realised that the best or even only route up to the polar plateau probably was westwards via the glacier (Amundsen, 1912), even though most explorers would probably deem the Axel Heiberg glacier basically impossible to climb with heavily laden dog sledges such as those Amundsen used. But Amundsen found a way up, after substantial reconnaissance and gruesome toil. His route there was the only possible one according to Wally Herbert (1962) who was the first after Amundsen to travel down the Axel Heiberg glacier during a dog sledge expedition in 1961–1962 (Herbert went up onto the plateau by way of the Beardmore Glacier further westwards). Monica Kristensen (1987), who is the only one except Roald Amundsen to have travelled both up and down the Axel Heiberg glacier with dog sledges, also established that the route Amundsen used was the only possible one. As long as the current ban of dogs in Antarctica is maintained, the feat can obviously not be repeated. Interestingly, both Herbert (1962, p.687) and Kristensen (1987, p.119) recognised some of Amundsen's camp sites during their own treks on the glacier based on his photographs and descriptions.

As soon as Amundsen had cleared the Axel Heiberg glacier and reached the polar plateau, he turned southwards around Mount Engelstad, at the southeastern side of the top of the glacier and eventually established on 21 November a camp called the Butcher's Shop on a ridge (Amundsen, 2010, p.305). The name of the camp is derived from the fact that he slaughtered 24 of his 42 remaining dogs there, based on the idea that the South Pole almost certainly was located on the plateau where he now was; hence, he did not need as many dogs for the rest of his journey (Amundsen, 1912). Amundsen and his crew also took the opportunity to rest the remaining dogs as well as themselves in the Butcher's Shop. A blizzard extended their stay there for another couple of days.

The ridge on which the Butcher's Shop camp was located is nowadays called Butcher's Spur (Alberts, 1995). It is the only ridge in the neighbourhood that fits the descriptions given by Amundsen and his men (Amundsen, 2010, p.305; Bjaaland, 2011, p.127; Wisting, 2011, p.141). The ridge is ice-covered and descends from Mount Don Pedro Christophersen to the polar plateau. The section of the ridge where Amundsen passed is located approximately on latitude 85°35' S and extends in an east-west direction (USGS, 1968). Amundsen himself reported that the latitude of the Butcher's Shop was 85°36' S (Amundsen, 2010, p.305), but the diaries are not in full agreement. Bjaaland (2011, p.127) agreed with Amundsen that the latitude in fact was 85°36' S, but Hassel (2011, p.135) stated that the observed latitude of this camp was 85°35.6' S, that is, slightly further north. Wisting (2011, p.141) said that the observation showed a latitude even slightly further north than in Hassel's report; 85°35' S. We do not know why they disagree somewhat, but Hanssen, Wisting, Hassel and Amundsen himself were all skilled navigators, and Hassel (2011, p.135) mentioned that "we" measured the solar altitude that resulted in the estimated latitude of the camp, so it was probably an average of measurements made by two or more of the men. Hence, given the imperfect reliability in Amundsen's solar observations, it seems safe to conclude that 85°35' S, that is, on the Butcher's Spur, in fact was the exact latitude of the Butcher's Shop.

The longitude of the Butcher's Shop was estimated by Mohn (1915, p.45) as 167°40' W, based on Amundsen's own dead reckoning. However, Drewry and Huntford (1979) discovered a previously unpublished bearing taken on Mount Fridtjof Nansen of 5° (true) from the Butcher's Shop in Amundsen's navigation notebook and estimated the longitude of the Butcher's Shop to 167° 52' W based on the bearing. However, the actual magnetic declination in that area at that time according to IGRF 2020 was 136.6° E, whereas Amundsen's current estimation from 15 November was 140° E. Hence, his current overestimation of the magnetic declination at that time was 3.4°, and the true bearing of Mount Fridtjof Nansen was therefore 1.6° rather than 5°. Because we now know that the peak of Mount Fridtjof Nansen is located at 85°21' S, 167°33' W (Alberts, 1995, p.260), we can use spherical trigonometry to compute the actual location of the Butchers Shop. Through the application of such mathematical methods, one can show that a 26-km straight line in a 1.6° direction from 85°35' S, 167°38' W ends at 85°21' S, 167°33' W, that is, at the peak of Mount Fridtjof Nansen (the mathematical details regarding this calculation can be found in Appendix A). In other words, given that the Butcher's Shop was located on Butcher's Spur at 85° 35' S, and that his observed bearing of Mount Fridtjof Nansen was accurate based on his previously estimated magnetic declination, the exact longitude for the Butcher's Shop seems to have been 167°38' W, that is, 2 km further east on the ridge compared to the estimation by Drewry and Huntford (1979). Note that the altitude at this point, correctly estimated by Amundsen (2010) to have been almost 3,300 metres, is higher than the peak of Mount Wilhelm Christophersen and about the same as the peak of Mount Engelstad, hence, Mount Fridtjof Nansen, which is much higher, would have been observable behind the other two mountains from the Butcher's Shop as long as fog or other meteorological phenomena did not reduce visibility.

Across the polar plateau to the South Pole

Even though the blizzard was still active on 26 November 1911, Amundsen could not wait any longer, hence, he and his men set out southwards from the Butcher's Shop with their remaining dogs and three sledges. His strategy was still to travel due south on an adjusted compass course until he reached the South Pole, however, because he overestimated the magnetic declination (see Table 1), he trended unknowingly but systematically to the east during his entire journey southwards across the plateau. In this section, that deviation will be analysed in detail.

Using Amundsen's occasionally observed latitudes, his adjusted daily distances, and his daily compass courses adjusted for the actual magnetic declination, his approximate route from the Butcher's Shop across the polar plateau until he reached the vicinity of the South Pole was reconstructed based on spherical trigonometry (see Appendix A). The detailed results are displayed in Table 2 below, where the tendency of eastward deviation becomes apparent. The reason why there is more than one note for some days is simply that Amundsen reported stages that way in his notebook. Also, there is no note at all for 9 December, because they stayed in camp and rested that day.

Table 2. Roald Amundsen's reconstructed approximate route across the Antarctic plateau.

Day	Compass course (degrees)	Declination IGRF 2020 (degrees E)	True course (degrees)	Adjusted distance (miles)	Latitude	Longitude
25 November					85°35' S	167°38' W
26 November	39.375	136.7	176.075	17.0	85°44' S	167°30' W
27 November	39.375	136.8	176.175	25.9	85°58' S	167°16' W
28 November	33.75	137.1	170.85	27.5	86°13' S	166°41' W
29 November	33.75	137.4	171.15	15.5	86°21' S	166°20' W
30 November	33.75	137.3	171.05	8.2	86°25' S	166°09' W
01 December	33.75	137.3	171.05	16.2	86°34' S	165°47' W
02 December	33.75	137.2	170.95	21.4	86°45' S	165°15' W
03 December	33.75	137.0	170.75	3.1	86°47' S	165°10' W
04 December	33.75	136.9	170.65	20.9	86°58' S	164°35' W
04 December	33.75	136.8	170.55	17.1	87°07' S	164°05' W
05 December	39.375	136.8	176.175	38.1	87°28' S	163°34' W
06 December	39.375	136.7	176.075	38.1	87°48' S	162°57' W
07 December	39.375	136.7	176.075	20.9	87°59' S	162°35' W
07 December	39.375	136.7	176.075	17.3	88°09' S	162°15' W
08 December	39.375	136.6	175.975	13.3	88°16' S	161°59' W
08 December	33.75	136.6	170.35	17.1	88°25' S	161°03' W
10 December	33.75	136.0	169.75	11.4	88°31' S	160°20' W
10 December	33.75	135.2	168.95	19.0	88°41' S	158°54' W
10 December	33.75	134.0	167.75	15.2	88°49' S	157°30' W
11 December	33.75	132.8	166.55	17.1	88°58' S	155°31' W
12 December	33.75	130.8	164.55	15.2	89°06' S	153°11' W

Despite the extreme blizzard conditions with storm and snowdrift, Amundsen made good distances during 26–27 November after having marched out from the Butcher's Shop, almost reaching the 86th parallel. On 27 November, he was able to obtain a new observation of the magnetic declination, this time in terms of an overestimation of 8.2° (see Table 1). Hence, unbeknownst to him, he began to trend slowly but systematically to the east on his way southwards over the plateau.

During the march on 28 November, approximately on latitude 86°9' S, Amundsen (2010, p.307) observed two rather long snow-clad ridges about 4 miles to the west of him that he later named the Helland Hansen Mountains. Hassel (2011, p.137) also assumed that these features were land and thought that they were about 3 miles away. Bjaaland (2011, p.128) imagined that the ridges were about 5–6 miles away. Wisting too mentioned the features in his diary (Wisting, 2011, p.143) but did not provide an estimation of how far away they were. However, there are no such ridges in the aforementioned area. The illusion can be explained by the fact that there is a rather steep slope upwards in the ice cap about 5 miles to the west from where they were at the time. The slope, which may resemble snow-covered ridges when seen from the east, is part of the feature that nowadays is referred to as the Helland Hansen Shoulder, which also is generally regarded as the western boundary of the Mohn Basin (Alberts, 1995, p.325).

Earlier on 28 November, when he was approximately on latitude 86°3' S according to his dead reckoning, Amundsen saw a mountain peak in an ESE direction for a short while when the mist temporarily cleared (Amundsen, 2010, p.307). At the time, he was slightly to the east of longitude 167° W. Amundsen estimated that the peak may have been about 10 miles away. There is however no physical feature in the area that fits his description perfectly. A seemingly reasonable explanation is that they saw the feature that is nowadays known as Olsen Crags, that surmounts a small but conspicuous mountain block that projects into the east side of the Amundsen Glacier at 86°12' S, 160°48' W, which fits in terms of bearing although the distance to it was much longer – almost 30 miles. Drewry and Huntford (1979) do not mention this observation in their running text at all, but a plotted bearing on the map in their Figure 2 implies that Olsen Crags may have been the feature that Amundsen saw. However, a closer investigation reveals that the height of the peak of Olsen Crags is about the same as the altitude of Amundsen's location when he made his observation; hence, it would have been entirely below the horizon and thereby hidden from Amundsen's view. A more realistic explanation, therefore, is that Amundsen saw the peak in the ice cap that rises several hundred metres above the surrounding area in about 86°3' S, 165°10' W. That feature is about 8–9 miles from where Amundsen was at the time, however, in an almost due easterly direction rather than ESE. Wisting remarked the same day in his diary about "high mountain peaks" (in plural) in an ESE direction about 5 miles away but stressed that the mist might have been deceiving (Wisting, 2011, p.143). Hassel did not mention any similar sight at all in his diary note for the day, but Bjaaland mentioned the peak in his diary, however, he said that it was in an easterly direction and covered in snow (Bjaaland, 2011, p.128). Hence, it was most likely the peak in the ice cap at 86°3' S, 165°10' W they saw after all. This explanation becomes even more credible when considering their overestimated magnetic declination, which led them to believe that the bearing of an observed feature to the east of them was in a somewhat more southerly direction than it actually was.

On 29 November, after having travelled two miles (Hassel 2011, p.137, thought it was 3–4 miles) from the camp site, a mountain suddenly appeared to the southeast. It was the cluster of peaks that surrounded the Norway Glacier at the head of the Amundsen Glacier. Although the four major peaks in this cluster on modern maps are called Mount Wisting, Mount Bjaaland, Mount Hassel and Mount Prestrud, after Amundsen's men, the cluster itself does not seem to have an established name. Amundsen himself used the temporary label "F chain" in his diary, but Drewry and Huntford (1979) suggested that it could be called the "Helge Massif" after Helge, one of Helmer Hanssen's sledge dogs who had to be put down at the South Pole after having collapsed there. For simplicity and in the honour of Helge, we will use the name "Helge Massif" here for that cluster of peaks.

The same day, Amundsen also saw another huge mountain with some adjacent peaks running in a north-south direction to the northeast of the Helge Massif, which he tentatively called the "G chain", even though fog hid the northern part of it. The main mountain Amundsen saw in the "G chain" was probably the most prominent one in the Nilsen Plateau mountains, that is, one that today is known as Mount Kristensen. Another discovery Amundsen made 29 November was the heavily crevassed area ahead of him immediately to the west and northwest of the Helge Massif. This area, which Amundsen christened "Devil's glacier", connects with the larger Amundsen glacier that descends through the mountains to the Ross Ice Shelf.

Amundsen took the bearings of five peaks in the Helge Massif on 29 November, the four major ones mentioned above and yet another one among them. The bearings were 125.32°, 133.75°, 142.18°, 156.25° and 161.88° (Drewry & Huntford, 1979). However, these bearings need to be adjusted anti-clockwise 7.6° due to Amundsen's overestimated magnetic declination, hence, the five bearings should in fact be 117.72°, 126.15°, 134.58°, 148.65° and 154.28°. The bearings were taken at the depot on latitude 86°21'S according to a solar observation by Hassel (2011, p.137). According to the analyses in this paper, the approximate longitude for that depot should have been 166°20' W. However, if 86°21'S, 166°20' W, was the true position for the depot, it is easy to see that the bearings of the peaks in the Helge Massif would all have been much more southerly. Furthermore, the distance to the Helge Massif would have been more than twice the distance Amundsen (2010, p.308) and Wisting (2011, p.143) estimated. Hence, 86°21'S, 166°20' W, was not the true location of the Devil's glacier depot.

However, we can use available information to derive the actual location of the depot. When the Helge Massif is viewed from an approximate northwesterly direction, the outermost peaks are Mount Hassel to the left and Mount Prestrud to the right (see Fig. 2). Hence, the two extreme bearings recorded by Amundsen must have been of these two peaks. We know now that the exact coordinates of Mount Hassel are 86°28' S, 164°28' W, and that those of Mount Prestrud are 86°34 S, 165°7' W (Alberts, 1995). Based on spherical geometry (see Appendix A), the approximate location from which a bearing 117.72° would point at the peak of Mount Hassel, and a bearing of 154.28° would point at the peak of Mount Prestrud, can be calculated as 86°24'28" S, 166°24' W. Hence, the most likely explanation is that the depot in fact was located in that location, that is, about three miles more to the south than what Hassel's latitude observation at the depot showed, but almost exactly along the route in Table 2. The assumed slightly more southerly location is also supported by the fact that the previous camp was located on 86°17'S, according to dead reckoning, and both Amundsen (2010, p.308) and Wisting (2011, p.143) estimated that they had travelled about 6 miles before reaching the place where they lay down the depot. This is also an illustration of the fact that most observations and estimations made by Amundsen and his men during the southern journey were naturally characterised by uncertainty, hence, all analyses based on those observations and estimations, such as the one in this paper, should in turn be regarded as approximations.

It is interesting to note that an assumed location for the Devil's glacier depot on 86°21' S, 168°30' W, that is, on the approximate location where conventional wisdom previously placed it, would mean that the distance from the depot to the Helge Massif would be about three times what Amundsen and Wisting estimated. Furthermore, the bearings of the peaks in the Helge Massif would not match those recorded by Amundsen. In particular, the angle between the bearings of the outermost peaks would be much too narrow. Hence, the depot cannot have been in that location.

During 30 November, they continued crossing Devil's glacier. The visibility was fine, and they could see both the Helge Massif and the "G chain" clearly. Wisting (2011, p.144) mentioned that they could see land to their south; hence, they actually saw it slightly east of south because of their overestimated magnetic declination. But because they thought it was south of them, they must have intended to pass close to the westernmost part of it. When they camped on 1 December, their estimated position (see Table 2) was about 86°34' S, 165°47' W, that is, just a mile or two west of Mount Prestrud in the Helge Massif. Both Bjaaland (2011, p.129) and Wisting (2011, p.144) noted that they had seen the land east of them during the day, despite fog and snowdrift (Amundsen, 2010, p.310); hence, it must have been very close by.

During the next few days, until 3 December, they travelled almost continuously with very low visibility due to fog and snowdrift. However, the weather cleared on 4 December, and Amundsen (2010, p.311) and Hassel (2011, p.145) both noted that they saw land for the last time, more specifically between bearings 281.25° and 253.125° without adjustment for magnetic declination. Amundsen thought it was the Helge Massif. Naturally, 4 December was therefore also the last day in the chapter "Through the Mountains" in Amundsen's published narrative of the journey *The South Pole* (Amundsen, 1912). Their current estimation of magnetic declination at that time was 143° E, so they apparently believed they saw the mountains between bearings 64.25° and 36.125°, but because the actual magnetic declination was 136.8°, they actually saw them between 58.05° and 29.925°. At the time, they were about at 87°07' S, 164°05' W; hence, it can only have been the "G chain" they saw (a fact also noted by Drewry and Huntford, 1979), because a bearing of Mount Kristensen would have been about 30° at that time, and the Helge Massif mountains were almost due north of them. Furthermore, Mount Bjaaland, the highest of the peaks in the Helge Massif, is only about 8,500 feet high; hence, it was entirely hidden below the horizon some 30 miles to the north. On the other hand, Mount Kristensen and other peaks in the "G chain" are over 11,000 feet high and would still have been visible.

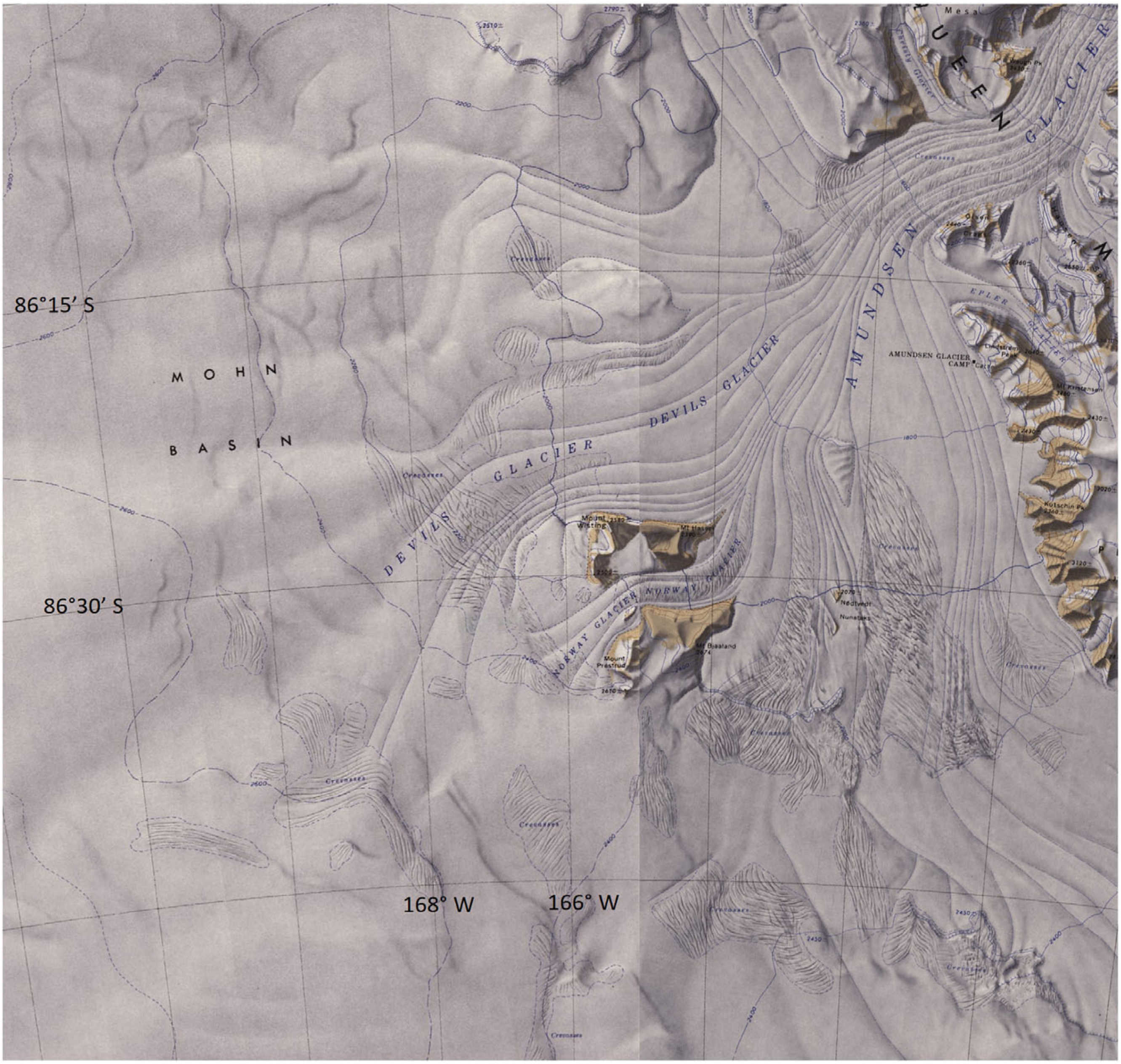

Figure 2. The Helge Massif. The figure was created by cropped sections from the maps USGS (1967a) and USGS (1967b).

In Figure 3 below, Amundsen's approximative route from the Butcher's Shop on 85°35' S to 87°07' S according to the analysis here is indicated by the green arrow, thereby illuminating the easterly drift created by the overestimated magnetic declination. The red arrow represents an assumed approximate route due south between the 168th and the 169th meridians. Figures 2 and 3 also display the "G chain" to the east of the Helge Massif.

On 5–7 December, Amundsen continued to travel almost blindly due to bad visibility, but from 8 December until he reached the South Pole on 14 December, both weather and surface were fine (Amundsen, 2010, pp.312–315). However, there were no landmarks to be seen. The easterly drift continued due to the overestimated magnetic declination, as shown in Tables 1 and 2, and Amundsen thus seems to have crossed the 89th parallel close to the 155th meridian. When he took their first observation of longitude on the entire southern journey, after having arrived at the South Pole according to dead reckoning (he was actually on 89°56' S), Amundsen discovered that he was not at all on the meridian he thought, and various measurements based on different assumptions gave very different results. Hassel (2011, p.143) notes in his diary that Amundsen had found that there was "something rotten" with the longitude. Of course, one kilometre in the east-west dimension at 89°56' S corresponds with about 8 degrees of longitude, so the margins were narrow. Hanssen (1941, p.94) mentions that they may well have travelled around the pole point instead of over it. However, the fact that the party continuously had drifted off to the east from their intended meridian during the entire journey over the polar plateau probably contributed substantially to the confusion at the South Pole. As mentioned before, Hinks (1944) provides detailed analyses of both Amundsen's and

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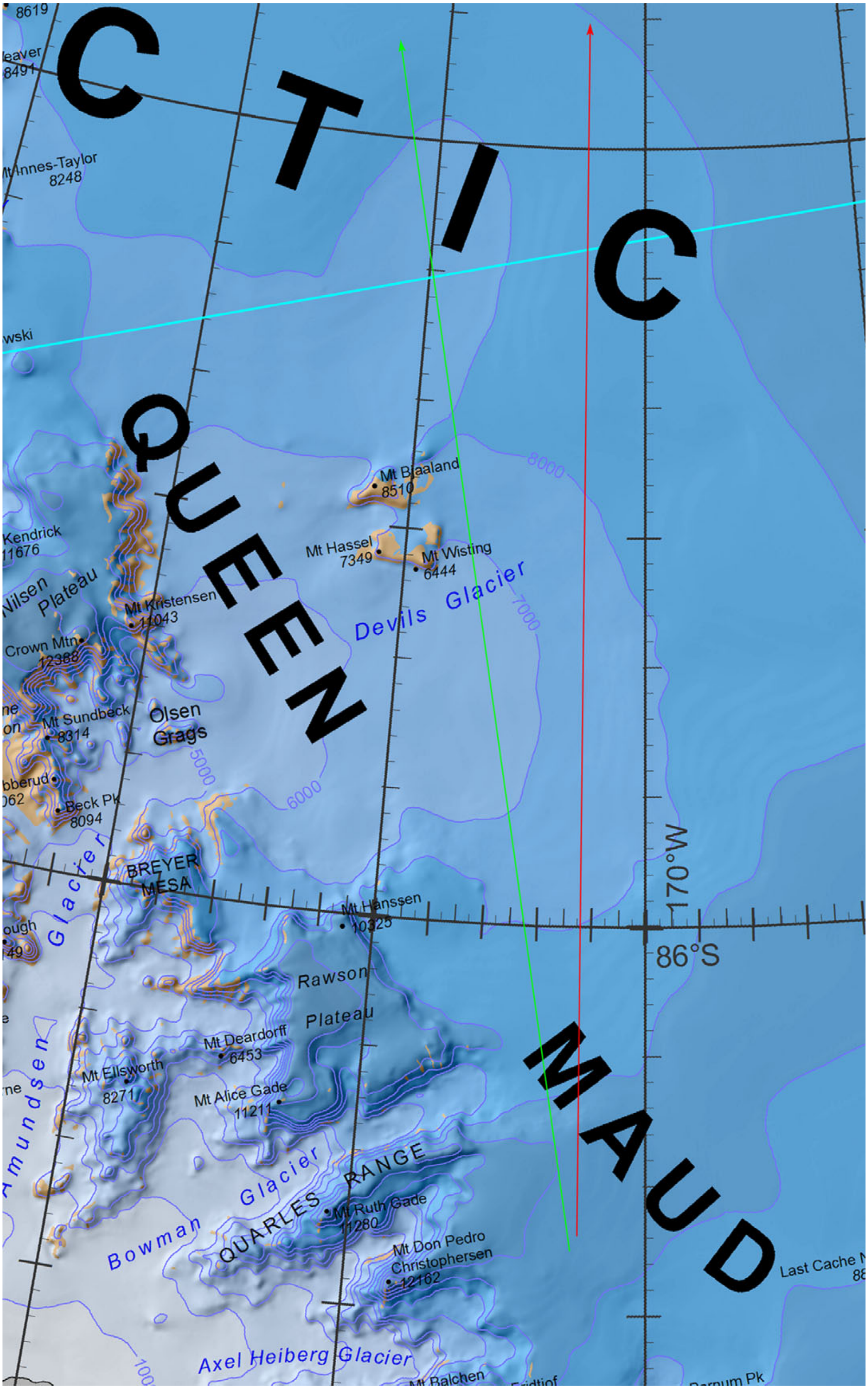

Figure 3. Amundsen's approximative route from the Butcher's Shop at 85°35' S to 87°07' S (green arrow).

Scott's movements in the vicinity of the actual South Pole point based on their thorough measurements of solar altitude.

The return journey

On 17 December, Amundsen and his men started their journey back from the South Pole. They did not see any landmarks until 27 December, on about 88° S, they could see land in a 230.625° bearing without adjustment for magnetic declination (Amundsen, 2010, p.319). At that point, their estimated magnetic declination was 143° E, but the actual declination according to IGRF was 136.7° E, hence the true bearing of the observed land was 7.325°. They had essentially followed their outward tracks until then, so the longitude must have been about 162°35' W. Amundsen described this sight of land in much more detail in *The South Pole* (Amundsen, 1912, pp.141–142), where he (correctly) assumed that it was the continuation of the mighty "G chain" although he could now see it stretch considerably farther south. He was able to observe these mountains during the journey the next few days too due to the fine weather.

On 2 January, still in fine weather, Amundsen and his men were camping only about 3 miles away from the Helge Massif (Amundsen, 2010, p.321), which Amundsen now (correctly) could see was much lower than he had estimated on the outward journey. Interestingly, both Wisting (2011, p.152) and Hassel (2011, p.149) thought that they were now travelling *closer* to these peaks – following a slightly more easterly route – than on the outward journey, an opinion shared by all except Bjaaland (2011, p.134). Thus, when they could not find their previously laid depot on 86°21' S, 166°20' W, on 3 January in thick fog, they turned west to search for it. When they could not find it, they decided to ignore the depot entirely and set course directly for the Butcher's Shop. After having travelled 5 miles, the fog cleared and they could see that they in fact had travelled too far to the west along the Helge Massif, even though it was close by (Hassel, 2011, p.150). After another couple of miles, Amundsen changed his mind and let Hanssen and Bjaaland return southwards for the supplies in the now clearly visible depot location (Amundsen, 2010, p.322; Bjaaland, 2011, p.134; Hanssen 1941, p.98).

Hence, "... despite seeming to be so near land..." (Amundsen, 2010, p.321) when they passed Mount Prestrud and Mount Wisting in the Helge Massif, they had in fact passed farther away from these mountains than on the outward journey, thereby ending up to the west of their depot. The visibility when they passed that area on the outward journey was very bad compared to the conditions on the return journey; hence, nobody but Bjaaland understood how very close to the Helge Massif they must have travelled during the first days in December 1911. Together with the prior analysis of the bearings of the peaks in the Helge Massif taken on the outward journey, this must be regarded as solid support for the reconstructed route in Table 2, which puts Amundsen and his men much closer to the Helge Massif than what previously has been assumed.

During the next two days, they were able to follow the cairns they built on the outward journey back to the Butcher's Shop. Interestingly, Amundsen (2010, p.323) noted that the land "... was totally unrecognisable, like I never have seen it before". This shows how difficult orientation based on landmarks was in foggy conditions in such surroundings, even for experts such as Amundsen and his men. Hence, it is not surprising that they could pass so much closer to the Helge Massif on the outward journey than they were aware of.

Three weeks later, the five men and eleven surviving dogs were back in Framheim, after having descended the Axel Heiberg glacier, and then crossed the Ross Ice Shelf effectively along their outward track.

Conclusion

Given the previously established presumption in the literature that Roald Amundsen travelled due southwards approximately between the 168th and 169th meridians over the polar plateau during late November and early December 1911, several anomalies have remained, for example, the observed proximity to and the observed bearings for the peaks in the Helge Massif. In this paper, we have noted that Amundsen consequently overestimated the magnetic declination during his South Pole journey. As a result, a detailed mathematical reconstruction of his route based on modern knowledge about the magnetic declination at the time shows that he subsequently but unknowingly trended somewhat towards the east while travelling southwards across the polar plateau. These results explain the previous anomalies mentioned above.

Of course, the reconstructed route here is only an approximation. Firstly, it is based on the distances and compass courses registered by Amundsen himself during his journey, and such data can never be perfect under such circumstances. Secondly, the actual route taken by Amundsen and his men can obviously not be described as perfectly straight lines connecting the camp sites – crevasses and other difficult areas forced them to make minor deviations on many occasions. Nevertheless, in contrast to previous attempts to recreate Amundsen's route, the approximate route here is based on reliable values for the magnetic declination at the time, and spherical geometry is applied throughout to derive each location based on the previous location. The route is also based on an updated and corrected location for the Butcher's Shop camp. Finally, the results are confirmed through Amundsen's own observations along the Helge Massif. Hence, the results here should be regarded as valid. Amundsen clearly did not travel approximately due south over the polar plateau roughly between the 168th and the 169th meridians in 1911.

This paper has contributed to the general understanding of Roald Amundsen's expedition to the South Pole, in particular regarding the inconsistencies between his previously assumed route and some of his observations of peaks in the Transantarctic Mountains. It has also illuminated how difficult it could be for explorers during the heroic age to make proper estimates of magnetic declination and positions. Finally, it is an illustration of how details regarding the actual execution of a historical expedition can be corrected much later. The methodology used here may well be applied to other historical expeditions too in order to provide a better understanding of them.

Conflict of interest. The author declares none.

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Appendix A

In order to reconstruct Amundsen's route over the polar plateau, spherical trigonometry (Todhunter, 1886) was used to estimate new positions based on previous positions, distances and compass courses adjusted for magnetic declination. The trigonometric formulas applied here are

$$\varphi_2 = \operatorname{asin}(\sin\varphi_1 \cdot \cos(d/R) + \cos\varphi_1 \cdot \sin(d/R) \cdot \cos\theta)$$

and

$$\lambda_2 = \lambda_1 + \operatorname{atan2}(\sin\theta \cdot \sin(d/R) \cdot \cos\varphi_1,\ \cos(d/R) - \sin\varphi_1 \cdot \sin\varphi_2)$$

where ϕ_1 and λ_1 are latitude and longitude for the previous position, ϕ_2 and λ_2 are latitude and longitude for the new position, θ is the true bearing (in degrees, clockwise from true north), d is the distance travelled (in km) and R is the earth's radius (assumed to be 6371 km). All angles are in radians.

As an illustrative detailed example of how these formulas are applied (the result is used in this paper to derive the actual location of Amundsen's camp Butcher's Shop), we can calculate the new position if we start at latitude 85°35' S and longitude 167°38' W, and travel in a direction 1.6° for 26 km. In decimal degrees, the origin is latitude –85.5833 and longitude –167.6333. These values are transformed to radians through multiplication with π/180, which gives –1.4937 and –2.9257. The bearing is also transformed to radians in the same way, which gives 0.0279.

The latitude in radians of the new positions is then calculated as

$$\varphi_2 = \operatorname{asin}(\sin - 1.4937 \cdot \cos(26/6371) + \cos - 1.4937 \cdot \sin(26/6371) \cdot \cos 0.0279) = -1.4896.$$

Then, the longitude in radians of the new positions can be calculated

$$\lambda_2 = -2.9257 + \operatorname{atan2}(\sin 0.0279 \cdot \sin(26/6371) \cdot \cos - 1.4937,\ \cos(26/6371) - \sin - 1.4937 \cdot \sin - 1.4896) = -2.9243.$$

These values are transformed back to decimal degrees through the division with π/180, which gives latitude 85.35 and longitude 167.55, which in the traditional DMS format corresponds with latitude 85°21' S and longitude 167°33' W.

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