

Notes

The present location of the tent that Roald Amundsen left behind at the South Pole in December 1911 Olav Orheim

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ABSTRACT. Determining the present precise location of Amundsen's tent is a function of 1) the precision of Amundsen's navigation in 1911, 2) the flow of ice since then, and 3) the amount of burial by intervening snow fall. These factors are discussed and it is concluded that the best location that can be given for the tent in December 2011 is 89° 58' 51" S, 46° 14' E, and lying 17 m below the present snow surface. The uncertainty in the position is 0.3 km, and is mainly related to uncertainties in the original positioning. It can be concluded with high certainty that the tent lies between 1.8 and 2.5 km from the South Pole.

The arrival of the five Norwegians at the South Pole and their navigation

Roald Amundsen and his four companions arrived in the vicinity of the geographic South Pole (SP) on 14 December 1911. Their main navigation was based on observing the sun elevation in the middle of the day. The direction in which the sun was at its highest gave them the heading they should follow to go straight south. Of course there were cloudy days, but on the whole this procedure functioned well. Magnetic compasses could not be used as the basis for navigation because of the large, unknown, magnetic declination that changed as they travelled southwards. However, they used the magnetic compasses daily to keep a southwards heading, and when they did not see the sun. During the preceding winter they had observed the magnetic declination, so this was known when they started. New values were determined along the route based on the positions found by solar observations. During the last few days before arriving at the South Pole area they had a fair amount of sunny weather, so they were very comfortable with their navigation at this stage.

When they halted on 14 December they proceeded to observe the sun for 18 hours. At the South Pole the sun elevation rises or falls steadily, with no diurnal dip or peak. So it was necessary to observe throughout the day to decide whether they had precisely reached the pole. Based on these observations they moved their camp 10 km further south on the next day, leaving behind an upright standing spare sledge. They then proceeded to take sun observations through 24 hours at their new position. When they departed on 17 December Amundsen left behind a thin walled tent with a thick base. Inside were items they did not need for the return, and two letters, one to Robert Falcon Scott, and one which he asked Scott to take with him and forward to King Haakon VII of Norway. These two letters were Amundsen's insurance that the news of their achievement should be known, should it happen that his group

did not make it back to Framheim at the coast. He expected that Scott would also reach the pole and return to his quarters, and if neither made it back perhaps the letters could be found by another expedition in a subsequent season. Amundsen also left behind a spare sextant, and some spare clothes.

Scott picked up the letters when his party arrived on 17 January 1912, but left the tent and contents behind. It is the location of this tent that is discussed here. Determining the present location depends 1) on Amundsen's group's ability to locate the position in 1911, 2) the motion since then of the *circa* 2800m thick ice mass that the tent is riding on, and 3) the depth of burial by snow fall. These are discussed below.

When Amundsen returned to Norway the sun observations were of course closely examined. An expert on maritime navigation, Anton Alexander of the Norwegian Hydrographic Service, analysed both the observation on 14–15 December, and the ones on 16–17 December, and compared these with the known theoretical sun elevations at 90°S. Alexander presented his analysis in September 1912. It is published in English as Appendix IV in Amundsen (1913). Alexander concluded that their position on 14 December was 89° 53' 50" S, 103° E, and on 16 December 89° 58' 30" S, 60° E. This was the location of their last camp, including the tent that was left behind. He further concluded that the maximum error in this position was 3 km.

The observations were reexamined by Hinks (1944). He reconstructed the observations more closely, and used the 24 hour observation to deduce the sextant's index errors and on the atmospheric refraction. Despite lack of information on pressure and temperature to calculate the latter he concluded that the navigation was considerably better than determined by Alexander, and that the position of the last camp was 89° 58' 45" S, 71° 36' E with a maximum error of only 0.32 km. The difference in distance between these two positions is 0.7 km; that is the revised position is well within the uncertainty circle given by Alexander.

The motion of the tent during the past century

The movement of the ice at the SP has been measured since the Amundsen-Scott South Pole Station was established in 1957. First by astronomical observations, from 1975 by Doppler satellite, and from 1991 by the Global Positioning System (GPS); this is the most precise of these. From the latter, Shupe and Hothem (2000) determined that the glacier under the station is moving in the direction of the Weddell Sea at an annual rate of 9.98 ± 0.01 m, along the 40° 46' 56" west longitude meridian. The uncertainties in the GPS observations are insignificant compared to the uncertainties in Amundsen's positioning. However, there is a need to consider whether the motion can have changed during the period from 1911 until the present.

The GPS positions show that the ice motion at the SP has not changed for the past decades. In the more marginal areas of Antarctica there is evidence of abrupt changes in glacier motion, also at time scales of less than 100 years. However there is no evidence of this from the central areas of Antarctica in locations where the bed rock is fairly flat, as is the case in the South Pole

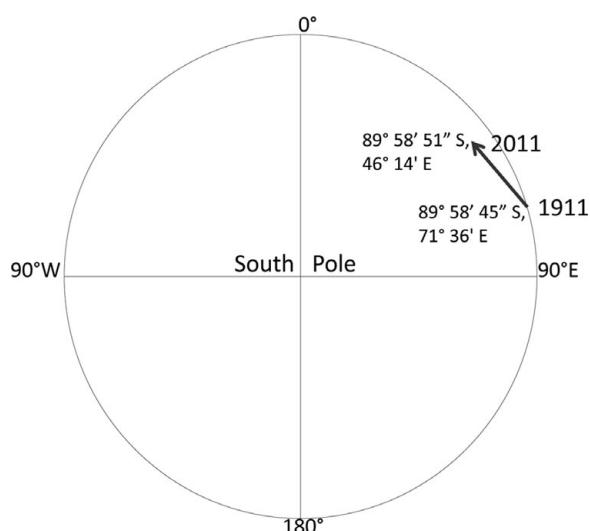


Fig. 1. Position of Amundsen's tent in 1911 and 2011. The arrow shows the ice motion during 100 years.

area. So I conclude that the present geographic location of the tent is most likely to be found by assuming that the ice motion during the whole 100 years has been the same as that recently determined by the GPS.

Adding this motion to the position given by Hinks (1944) as $89^{\circ} 58' 45''$ S, $71^{\circ} 36'$ E places the tent 100 years later in the position $89^{\circ} 58' 51''$ S, $46^{\circ} 14'$ E (see Fig. 1). The ice motion has brought the tent 170 m closer to the SP, to a distance of 2150 m. Perhaps appropriately it is now most likely about to enter into the southern extension of the Norwegian claimed area of Dronning Maud Land which extends from 20° W to 45° E (although the southern limit of this claim has not been set). An uncertainty of 0.3 km in the position means that it can be concluded with high confidence that the tent is located between 1.8 and 2.5 km from the South Pole.

The burial of the tent during the past century

While we can reasonably assume that the measured motion at the South Pole can be extended in time and space to cover the period and location in question, this cannot perhaps be assumed for the speed of burial. The first accumulation measurements at the pole were made by Giovinetto (1960). He concluded that the mean annual accumulation from 1911 to 1958 was 77 mm water equivalent (corresponding to about 0.2 m snow fall). Data from the snow pit that he dug to 27 m show that 100 year old snow was at a depth of 16 m.

However, the erection of the Amundsen-Scott Station at in 1957 increased the accumulation, because the buildings above the snow surface affect the wind patterns and increase the snow deposition. Gow (1965) concluded that because of this the accumulation in the station area had increased to 100 mm water equivalent, that is an increase of 30%. This effect is readily apparent; viewing the present station from a distance shows it to be located on a snow mound. However, as the tent position was about 2 km away from the Amundsen-Scott Station when it was established this effect must have been very small, and may well be considered insignificant in relation to other uncertainties related to variations in the accumulation. At the same time it should be recognised that subsequent establishments of large

buildings above the snow will have led to further local increases in the accumulation rate. For present purposes I have taken the average accumulation rate to be 77 mm from 1911 to 1956, and 85 mm from then until 2011. Using the compaction determined by Giovinetto (1960) this places the tent 17 m below the present snow surface. There is no evidence of other variations in accumulation rate (that is from climate change at the pole during the past century) that would make significant changes to this estimate.

When the five Norwegians left it, the tent itself was more than 1.5 m high, and they had extended the tent pole to be 4 m high, and placed a Norwegian flag and the pennant of *Fram* at the top of the flag pole. Possibly the pole would have remained vertical, and its top would then be about 13 m below present snow surface. The flag and pennant would be gone, doubtlessly worn to shreds by winter storms blowing low temperature snow which at -70 to -80° C has a hardness approaching that of quartz. The tent walls would possibly have collapsed during the autumn by snow falls and storms. If not, these too would probably have been torn to shreds during the first winter. However, the floor of the tent, and the contents of the tent, would have been snowed over and remain in place.

Some comments on why the tent can no longer be searched for

The 2011–2012 Antarctic field season is likely to consist of a number of adventurous activities linked to the centenary of Amundsen's and Scott's expeditions, and perhaps also to the less well known 1911–1912 Japanese expedition in the Ross Sea area. Conceivably some are also toying with an idea to search for the tent. Even if it had been legal this would be near impossible in practical terms. Nearly twenty years ago there were unrealistic plans to locate the metal sextant by radio echo sounding. In theory this could work, but around the station there are various metal items buried at depth, including some at depths similar to the tent. These latter are from failed cargo airdrops when the first station was established in 1957. When parachutes did not open the cargo was buried at depth in the snow and not always recovered. So there would be many signals to sort out, and then would follow the excavation! In any case, it would now be in contravention of regulations under the Antarctic Treaty. At the 2005 Antarctic Treaty Consultative Meeting the tent was designated as Historic Site and Monument No. 80, and from then on is protected from removal or damage. And incidentally, the ATCM two years later designated the South Pole area as Antarctic Specially Managed Area No. 5 to protect its scientific qualities, thus placing the tent in an area where all new activities need approval.

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Captain Scott's last camp, Ross Ice Shelf

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On 19 March 1912, Captain R.F. Scott, Dr E.A. Wilson, and Lt H.R. Bowers reached a latitude of 79° 40'S during their return journey from the South Pole. There they camped and were fatally delayed by a blizzard. The date of Scott's last diary entry is 29 March 1912 and he died on, or shortly after, that date, with his two companions, of starvation and cold. They had left their base at Cape Evans in stages from 24 October 1911 with a party of 16. Relay parties returned on 11 and 21 December 1911, and on 4 January 1912. Five men attained the South Pole on 17 January 1912 where they found that an expedition, led by R.E.G. Amundsen from Norway, has preceded them on 14 December 1911. 33 days had elapsed between the departure of the Norwegian party from the pole and Scott's arrival there. During the return journey over the Ross Ice Shelf, roughly along the 169°E meridian, two of the party of five died: E. Evans on 17 February 1912 and L.E.G. Oates on, or shortly after, 16 March 1912.

The last camp was found by a search party on 12 November 1912. Inside the tent were the three frozen explorers, their diaries and last letters, other records, exposed photographic film, geological specimens, and equipment. The site was carefully examined. Scientific and geographical items (including navigation calculations, film, and sketch books), personal papers and letters, a letter to King Haakon of Norway from Amundsen, and a few artefacts (including some left by Amundsen), were gathered. The bodies in their sleeping bags, with the tent, which was collapsed over them, their sledge, and other equipment were left. A large cairn of snow blocks, surmounted by a cross made from ski, was erected over the site. The last camp was only 11 nautical miles (20 km) from One Ton Depôt, which had been placed at 79° 28' 53''S, 169° 22' 04''E for the returning polar party. It was approximately 220 km from the safety of the shelter at Hut Point on Ross Island and a further 26 km across sea ice to the base at Cape Evans.

A century later there is much interest in the whereabouts of the last camp. Near its position in 1912 the Ross Ice Shelf is approximately 110 m thick and afloat on the southernmost part of the Ross Sea where it experiences tidal movement. The last camp is moving slowly towards the ice front while being buried deeper in the ice shelf as snow accumulates and consolidates. Flow lines indicate that the trajectory of the camp will be around Ross Island and will reach the Ross Sea to the east of Cape Crozier (77° 31'S, 169° 24'E) in a journey of about 240 km finishing at or near the 175°E meridian (Thomas and

others 1984). Measurements made during two years from 1960 indicate that the ice 170 km north of the camp is moving at 556 m annually in a direction of 003° (Swithinbank 1970). In the vicinity of 78° 50'S Scott's expedition reported the ice moving at 'one mile in three years' [approximately 620 m annually] (Debenham 1923). The ice movement increases towards the ice front to about 690 m annually (Swithinbank 1970). The snow fall and subsequent consolidation are difficult to measure due to drift and blizzards, but an ice accumulation of 15 cm annually near the last camp and increasing to 20 cm near the ice front has been determined (Thomas and others 1984). Thus, in a century, the last camp may be estimated to have moved approximately 60 km horizontally and have become buried by 16 m of ice.

These data suggest that the last camp may reach the position of the current ice front in around the year 2,250; some 340 years after the journey began. It will then be about 100 m deep in the ice shelf, and well below sea level. Owing to a balance of surface accumulation and bottom melting the ice front is about 140 m thick near the end of the trajectory. These calculations are subject to several uncertainties. The largest of these, when the last camp might reach the Ross Sea, involves the calving of the ice front. The normal course of events at the ice front is for a long period (on the order of half a century) of advance followed by a calving of an iceberg that displaces the ice front southward (by as much as 50 km, such as happened in 2001 when the massive iceberg 'B-15' calved from the shelf). That means that it is extremely unlikely that the bodies will emerge from a submerged part of the ice shelf, but instead, will be carried off within an iceberg when they get close enough to the ice front. Their final resting place will then be dependent on the ocean currents, the size of the iceberg, how it melts and breaks, whether the piece that holds the bodies ever capsizes, and other imponderables. In forthcoming centuries there may be major perturbations in the dynamics of the Ross Ice Shelf responding to climatic variations. In any event it seems certain that the bodies of Scott, Wilson, and Bowers, followed in due course by those of Oates and Evans, will ultimately be committed to the deep.

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