The Quest for the Magnetic Pole: navigation and research into polar terrestrial magnetism.

ANTA 502 Review

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Introduction

At the conclusion of Scott's *Discovery* expedition, Albert Armitage wrote the following:

> *The observations for variation have proved very good, and the results of these alone are sufficient reward for all the monotonous labour connected with the magnetic observations, if, as I believe they will do, they enable those who go down to the sea in ships to navigate with a greater measure of confidence and safety those waters that wash the shores of our southern possessions and South America.* (Armitage 1905)

Armitage was one of many navigators, scientists and expeditioners to investigate the nature of terrestrial magnetism up to the famous sledge journey by Mawson, McKay and David to the vicinity of the south magnetic pole in January 1909. I believe that geomagnetic research flourished between 1830 and the Heroic era of Antarctic exploration. Although much research had been undertaken during that period, and many questions answered, Louis Bauer (Director of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington) indicated there were still gaps in fundamental knowledge when he wrote in 1914:

> *The accumulation of data must at present be the chief aim of the student of the earth's magnetism.(Bauer 1914)*

This review will briefly describe some aspects of development of the science of geomagnetic research, especially during the Victorian era. It will also discuss its place in the art of traditional navigation and the linkage to selected high latitude expeditions.

The Mysteries of Terrestrial Magnetism

Mariners have long known the usefulness of geomagnetism as an aid to navigation. In a general sense a compass will align along a line of force that approximates geographic north and south if you are observing in low latitudes. As the observer moves to higher latitudes the reliability of the alignment of the compass becomes reduced due to lines of force of terrestrial magnetism deflecting the compass. The compass needle also becomes “sluggish” and is slow to re-align as the ship changes course. This phenomenon was noted by Charles Royds during a sledging journey in 1902 (Royds 2001). Anyone helming a square-rigged ship on a compass bearing would appreciate that the added difficulty of a sluggish compass could have serious consequences. Calculating the indicated compass bearing for the helmsman to adhere to, in order to follow a true meridian is a challenge for the navigator. An acute observer may also notice that the needle of a compass designed for terrestrial use may not remain horizontal at higher latitudes, indicating an increase in the “dip”.

We now believe that terrestrial magnetism is the result of processes within a liquid, iron-rich layer of the earth’s outer core. The earth’s magnetic field is generated by a dynamo effect from movement of this material. (Phillips 2003)

The net result is that the simple metaphor of the earth as a magnet, with a fixed north and south polar orientation and unwavering field strength is unsuitable for practical use. We know that there are currently two magnetic poles, one each at high northern and southern latitudes, that they move, they are not necessarily related to the geographic poles, the intensity of the magnetic field changes over time and that magnetic orientation of compasses can be confused by materials in the earth or onboard a ship. Magnetic storms caused by solar eruptions can also influence compasses. Paleomagnetic studies show that there have been many reversals of the orientation of the magnetic fields of the earth in the past and there may have been more than two discrete poles at any time.

Navigation and Elements of Terrestrial Magnetism

The primary element of terrestrial magnetism for maritime navigators is compass error. This reflects whether the compass indicates a true bearing, and if not, by how much. This element is comprised of variation and deviation. Deviation is the compass error caused by the elements of the vessel like metals in the construction. Variation is the compass error created by the geomagnetic conditions.

Almost any ship's log up to the introduction of reliable gyroscopic repeating compasses (around the time of the Second World War) had entries for Latitude, Longitude, distance made good by dead reckoning and (compass) variation. In order to maintain effective progress on a desired course the navigator must calculate the variation and deviation (see below) and account for it when plotting the track and giving instruction to the helmsman.

Magnetic observers endeavour to record the elements of direction and intensity of the magnetic field that may then be represented by a system of imaginary lines on the earth's surface.

There are three types of chart traditionally of practical use to the mariner. It is important to note that the terrestrial magnetic field is constantly but slowly changing so these charts represent a snapshot in time.

Charts of lines of **equal magnetic variation** show the general arrangement of the isogonic lines and indicate the magnetic meridian of any place on the chart. The lines converge at the magnetic poles. This type of chart is the most useful in practical navigation.

Charts of lines of **equal magnetic dip** (isoclinal lines) are analogous to the geographical equator and lines of latitude. Where there is a line of no dip it is referred to as the magnetic equator. Where the dip is 90° it is the magnetic pole. This factor is important to navigation when considering the changes to deviation as a ship moves across the surface of the globe.

Charts of lines of **equal horizontal force** are of most relevance to the navigator who is considering the effects of permanent magnetism in the hard iron of the ship.

Taking measurements of the following elements related to the earth's magnetic field creates these charts.

Dip: The angle that the magnetised needle, when free to move vertically makes with the horizontal. At a magnetic pole the dip is 90° and the (dipping) needle points directly downward. This is also referred to as "inclination".

Variation: The angle that the position of the magnetic needle, undisturbed by local attraction of ships influence, makes with the geographical meridian. This is also referred to as the Declination of the compass needle by mariners.

Intensity: The strength of the magnetic field of the earth varies and the intensity can be measured by a technique that measures the number of vibrations of a freely swinging magnetic needle in a given time period.

Deviation: the deflection of the compass needle from the magnetic meridian caused by the iron on board a ship, including material employed in construction of the ship, its equipment and cargo. The value of the deviation varies according to the direction of the ship's head and the error from this source can be calculated by "Swinging the Ship" (see appendix).

The Expansion of magnetic research

In 1815 Paris was the centre of excellence in the magnetic sciences. National rivalry was a spur to General Sir Edward Sabine to lead a campaign through the British Association for the Advancement of Science and the Royal Society to regain the lead in the field. (Cawood 1979). This was a period of discovery and scientific collection and description (especially with respect to biological collecting). Amassing data on the physical sciences was also part of this tradition. Terrestrial magnetism studies and the interpretation of massed data might reveal patterns leading to revelations about cosmic laws or phenomena. It was clear that informative magnetic studies required collection of data across the globe and at high latitudes, as well as at fixed magnetic observatories.

Commercial considerations probably also supported this enterprise. Ships were sailing at high latitudes (whaling, sealing, voyages to the colonies etc) and any updated maps showing magnetic field irregularities could improve the accuracy of navigation, reduce passage times and prevent disaster. Improved position finding and knowledge of compass errors allowed more accurate hydrographic survey and mapmaking, both important to cementing sovereignty claims.

A further consideration is the development of better instrument making. Instruments used for the detection of the elements of the geomagnetic field are high precision and generally delicate as the forces under investigation are subtle.

Antarctic Expedition Milestones and Terrestrial Magnetism

Cook (*Endeavour*, then *Resolution* and *Adventure*)

Whilst coasting northward along the eastern shore of New Holland in 1770 Captain Cook and Joseph Banks engaged in a conversation about erratic behaviour of the compass brought on by proximity to the land. Further North Cook named a geographic feature “Magnetic Island” in reference to this phenomenon.(Brunton (ed) 1998) Daily logs of the *Endeavour* included Latitude, Longitude and compass variation. Cook, or the ship’s master (Molyneaux) would have therefore been occupied with determining true North from a noon sun sight with a sextant and finding the compass error at that moment. Cook, like all competent navigators was preoccupied with continually determining compass errors. James Clark Ross when describing Cook in his narrative of the voyage of discovery into the Ross Sea (Ross 1843) in brilliant understatement merely refers to Cook as ‘the navigator” knowing that his contemporaries will understand his meaning.

Gauss and Humboldt

Carl Freidrich Gauss was a polymath who was concerned with terrestrial magnetism and developed a method for making absolute measurements of the elements of geomagnetism. He then opened an observatory in 1834. Amundsen notes that Gauss developed his theory ‘as to the sequence and varied appearance of the phenomena of terrestrial magnetism at a certain moment of time according to geographic latitude and longitude.’ (Amundsen 1907) Although Gauss’ theory predicted the location of the south magnetic pole actual observations close to that elusive location were required for certainty (and to support the theory). Humboldt was a contemporary of Gauss and it was after discussions between these gentlemen that Gauss revisited the problem and developed his theory.

Ross, D’Urville and Wilkes

James Clark Ross was a giant in the arena of polar magnetic studies. He was first to the north magnetic pole, then located on the western side of the Boothia Peninsula where he made magnetic observations. On arriving in June 1831 he wrote:

> *“I believe I must leave it to others to imagine the elation of mind with which we now found ourselves now arrived at this object of our ambition: it almost seemed as if we had accomplished everything we had come so far to see and to do; as if our voyage and all its labours were at an end and that nothing now remained for us but to return home and be happy for the rest of our days …”(Savours 1962)*

Ross was subsequently selected through Sabine’s influence with the admiralty to take the *Erebus* and *Terror* expedition to attempt to sail to the South Magnetic Pole. This expedition was dispatched at a time when magnetic science cooperation was balanced against scientific and political rivalry. Dumont D’Urville (*Astrolabe* and *Zélée*) and Charles Wilkes (*Porpoise*, *Peacock, Vincennes, Sea Gull* and *Flying Fish*) were on a similar mission. In fact Wilkes received some training in the use of magnetic instruments from Ross. Wilkes and D’Urville actually sighted each other near the Antarctic coast in January 1840.

A number of colonial observatories were established as reference points during this period to support the British observations at sea. Franklin (then Governor of Van Diemen’s Land) built Rossbank Observatory using convict labour on arrival of Ross’ expedition in Hobart in 1839. It stood in the current grounds of the Tasmanian Governor’s residence in Hobart.

The oil painting of Rossbank (magnetic) Observatory by Bock (see Appendix) shows the eminent polar navigators and magnetic observers Ross, Crozier and Franklin standing amongst a collection of the tools of their trade. On tree stumps in the left foreground are a telescope, a level or theodolite and a dip needle. No doubt additional instruments (magnetometers) were housed in the original observatory hut behind.

After the return of the expeditions of Ross, Wilkes and D'Urville there were no further expeditions concentrating on the physical sciences until the international coordinated efforts of the early 1900's. The *Challenger* voyage of Nares (1872-1876) was scientific but concentrated on oceanography. The International Polar year of 1882-1883 did not initiate any expeditions south but did stimulate magnetic and meteorological observations in high northern latitudes.

Scott's *Discovery* Expedition

Scott's research ship *Discovery* was purpose built for the 1901-1904 expedition to Antarctica. One of the key elements (especially from the point of view of the Royal Society sponsors) to be investigated was terrestrial magnetism. A magnetic observatory was built on the deck for observations at sea and within 30 feet of that observatory all materials used in the ship's construction were of non-magnetic materials. The shrouds of the standing rig were not seized with wire, no steel cables were used and no nails or other metal fasteners were used in that locality. Mattress springs were taboo and the wardroom upholstery buttons were made of lead. Also included were phosphor bronze stoves that were found inadequate to handle the heat of coal burning. When the expedition landed at Hut Point peninsular two prefabricated magnetic huts were assembled. This is where the physicist operated the Eschenhagen and absolute magnetometers daily over two years in addition to some pendulum observations (to measure gravity), and auroral observations.

The magnetic research was part of a coordinated regime of observations between the Antarctic expeditions of Erich von Drygalski (the German *Gauss* expedition) and Dr Otto Nordenskjöld (the Swedish *Antarctic* expedition), on the 1st and 15th day of each month. Absolute observations were made every two hours over the 24-hour period on those days in synchrony with the other expeditions.

Armitage describes the instruments in detail. For the observatory there were two unifilar magnetometers, two Barrow's dip circles and the Eschenhagen self-recording apparatus. For other "shore work" (sledge journeys) and ship board observations there were a number of azimuth compasses, Fox circles, Lloyd-Creak dip circles and accessories. These were the zenith of quality instruments for the task of determining variation, declination and intensity.

Complete sets of observations on land were made at Simon's Town (near CapeTown), Christchurch (at the observatory still standing in the botanic gardens), at Winter Quarters and in the Falklands. Armitage spent time taking his magnetic observations at Capetown in a tent on the plateau using a monofilial magnetometer with assistance from local physicists. The magnetic observatory in Christchurch, like that in Melbourne had its usefulness undermined by the advent of electric tramways, causing significant local disturbance to magnetic fields. The Christchurch magnetic observatory, a diminutive timber hut in the grounds of the Botanic Gardens was used by members of the *Discovery* expedition for observations prior to their departure south but was later relocated to Amberley. The importance of fixed, land based magnetic observatories is emphasised by Eric Webb in correspondence to Quartermain (Webb 1967) where he notes:

> *I believe both Bernacchi and Mawson's instruments were thus also inter-compared at Christchurch…*

Shipboard work involved observations twice daily as well as determining variation when shooting the sun (by sextant) for position. The ship was swung prior to departure at Stokes Bay then off South Trinidad Island, off Simon's Town, at Port Lyttelton, then at Cape Adare, near Wood Bay, off Cape Crozier and then in McMurdo Sound. On the return leg she was swung in the Auckland Islands, again off Lyttelton, the Falkland Islands and upon the return to Stokes Bay (Armitage 1905)

Bernacchi writes about the practical (indeed commercial) value of charting magnetic variation in his personal *Discovery* journal (Bernacchi 1902)

> *Our knowledge of terrestrial magnetism generally will be greatly advanced & our acquaintance with the variations taking place in so high a latitude & in the vicinity of the magnetic pole must be of considerable practical value in correcting the navigation charts from year to year from our observations taken at sea and on land.*

To assist with accurate prediction of the location of the South Magnetic Pole a series of observations was made by Bernacchi on a sledge journey across sea ice the south-east (on a line away from the magnetic pole and away from the magnetically disturbing influences of the ship and the volcanic rocks) from Hut Point in November 1903.

Amundsen (*Gjoa* Expedition)

Roald Amundsen is remembered most for his attainment of the South geographic pole. He had a very significant prior achievement in being first through the North-West passage (1903-1906) in his small ex-sealing boat *Gjoa*. He could have achieved that feat more quickly but he chose to undertake a routine of magnetic observations in the vicinity of the north magnetic pole. He arranged training for his second engineer, Wiik at Potsdam magnetic observatory prior to departure to ensure the value of their observations. He made a great contribution to magnetic science by repeating the work undertaken by James Clark Ross in 1831 close to the magnetic pole. In his paper to the RGS (Amundsen 1907) he gives a lucid description of the instrumentation that confirms that he was also using a clockwork magnetometer, probably of the Eschenhagen design.

Upon his return he was fêted by the RGS and given a somewhat ironic accolade. Sir George Goldie, then president of the RGS applauded Amundsen’s priority to put science before geographical exploits. After the failure of Scott’s bid for the South Pole, Amundsen was criticised for focusing on notoriety and disregarding science. Also in that RGS president’s address Goldie used the line from Tennyson (“To strive, to seek, to find and not to yield”) in reference to Amundsen. This line of course later became synonymous with the heroically tragic Scott.

Mawson and Webb (*Nimrod* and *Aurora* Expeditions)

The Australian Douglas Mawson was part of a three-man party (lead by Edgeworth David and with McKay) who sledged from Cape Royds to the vicinity of the South Magnetic Pole during Shackleton’s 1907-1909 *Nimrod* expedition. This feat pinned the location of the magnetic pole that had moved a considerable distance since the predictions of the Ross, Borchgrevink and Scott expeditions.

Eric Webb who accompanied Mawson on his *Aurora* (1911-1914) expedition was a native of Lyttelton. Mawson had sought assistance from the Carnegie Institution to find a skilled magnetician and Webb had been working for the Institution on a magnetic survey of Australia at Melbourne Observatory and then in South Australia. Webb states that Charles Wilkes had made the only prior (shipboard) magnetic observations to the north or west of the South Magnetic Pole. In an interview recorded by Len Bickel (Webb 1975) he describes the process of taking magnetic observations requiring up to six hours and including latitude, longitude, azimuth for grid North, and using the magnetometer for the magnetic meridian then dip circle for vertical force. Combining these results will yield total force and declination. Mawson's plan was to make a sledging journey to approach the magnetic pole from the north (departing from Commonwealth Bay) to complement the earlier journey during Shackleton's *Nimrod* expedition. At every camp they determined the dip and variation of the compass and as they approached the (magnetic) pole the compass became sluggish and at one stage the variation altered by 90° in 11 miles. Webb returned to Lyttelton to find that the news that Captain Scott was missing had entirely eclipsed the achievements of the Mawson expedition.

Wilkins

The most stunning feat of navigation has recently been described by Simon Nasht in his biography of Sir Hubert Wilkins (Nasht 2005). Wilkins spent the whole of a trans-arctic flight constantly recalculating position by sun sights. In the far north the compass error is great and highly variable due to proximity to the north magnetic pole. Navigation by compass was therefore considered too unreliable so traditional methods were employed using a sextant, tables and longhand calculations.

Bauer and the Carnegie Institution

Louis Bauer describes the extensive work of the Carnegie Institution in relation to terrestrial magnetism in his treatise on the voyages of the vessels *Galilee* (1905-1908) and *Carnegie* (1909-1913). Collectively they travelled over 160,000 nautical miles making magnetic observations across the globe. The Carnegie was even more specialised than the Discovery for magnetic observing having no ferruginous materials in her construction except for a few unavoidable engine components. The observations at sea were complemented by land based observatory results. Bauer states the job is unfinished. (Bauer 1914)

Methods of navigation have changed since the heroic age of Antarctic exploration but research into terrestrial magnetism continues.

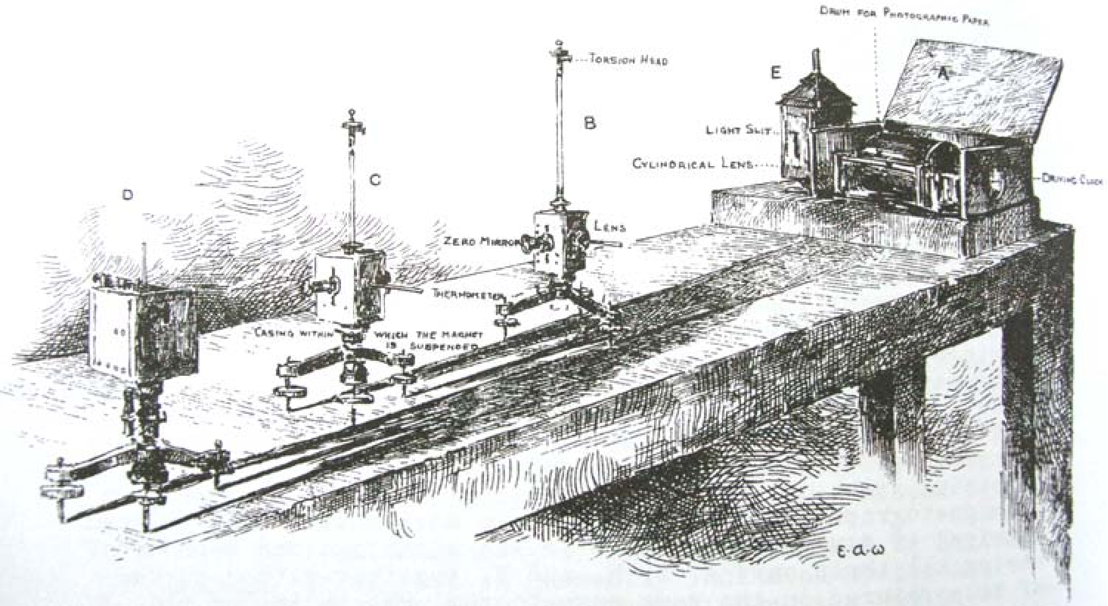
Appendix

Rossbank Observatory by Thomas Bock (1790-1855) Oil in the Tasmanian Museum in Hobart. Picture shows Captains Ross, Crozier and Franklin in foreground with observatory buildings in background.

Magnetometers

Scott's 1901 *Discovery* expedition was equipped the newest development in magnetometers. Louis Bernacchi was left behind when the *Discovery* sailed in order that he could travel to Potsdam observatory. There he trained in the operation of the newly invented clockwork-drive magnetometer by its creator Professor Eschenhagen. Bernacchi then travelled by fast steamer bringing the instrument (one of only three) and met the Discovery in New Zealand. He provides an articulate description of the operation of the magnetometer in the South Polar Times published during the *Discovery* expedition at Winter Quarters. (Mawer 2006) It's value is in the clockwork mechanism that makes it an automatic recording instrument with a photographic paper roll and timed shutter opening to record a beam of light reflected from the magnetised bars. No longer did every observation require a trip out to a magnetic hut and time consuming manual operations. The drawback of the instrument was that it provided a comparative measure of changes in the elements of the earth's magnetism, but not an absolute measure. Observation with another set of absolute instruments was still required periodically to calibrate the automated device. Eschenhagen died in 1902 and never saw the results of the continuous observations made during over two years at Hut Point.

Michael Barne setting up the Kew pattern unifilar magnetometer at Simonstown (South Africa) with colleagues from the local observatory.

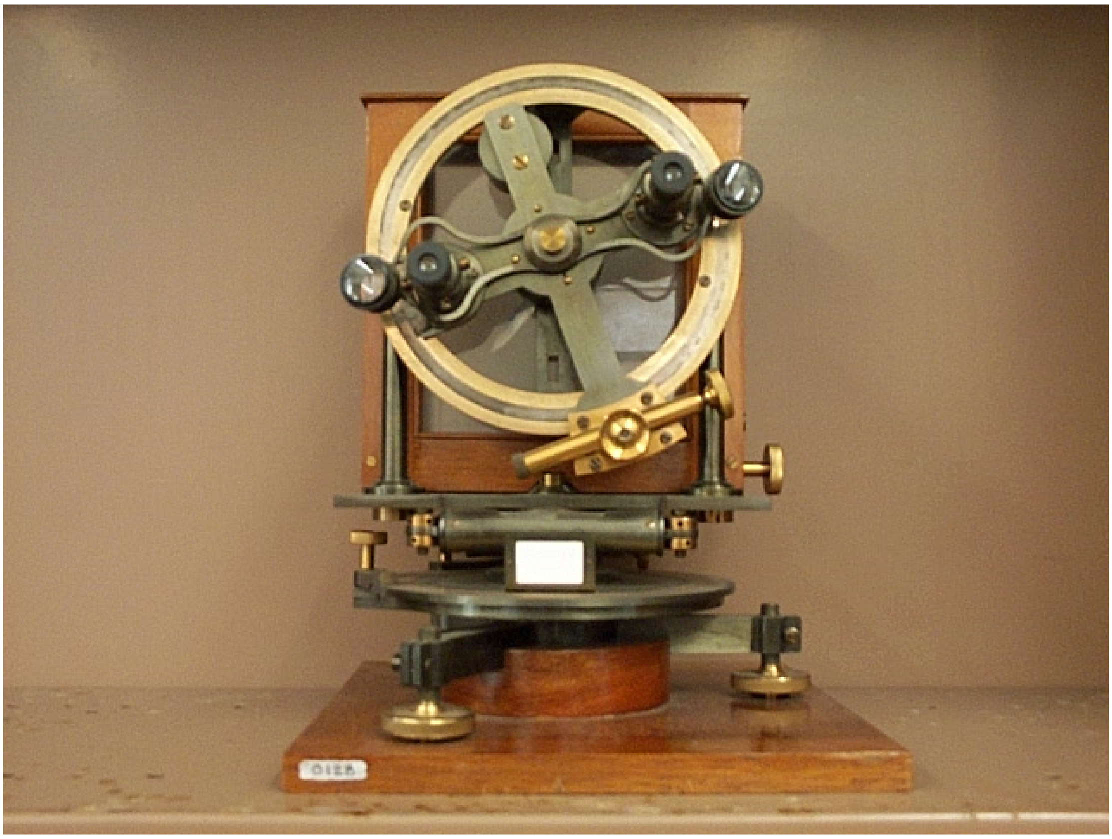


Eschenhagen Magnetometer.

Edward Wilson’s drawing of the Eschenhagen magnetometer apparatus that accompanied Bernacchi’s article in the South Polar Times (May 1902 edition) describing his magnetic work.

Dip Circles (Lloyd-Creak and Fox)

Dip circles are used to determine the angle of inclination of the magnetic field. At the magnetic poles the needle points down at 90° to the horizontal. The Lloyd-Creak is a development of the more simple Fox circle but is apparently less functional for polar work as the graduations are very fine and difficult to read in the field. The following illustration is a dip circle held in the University of Queensland physics museum.



Position Finding-Sextants and Theodolites

A critical task of the magnetic observer was to make accurate observations for location (latitude and longitude). This was possible using a sextant or theodolite (depending on whether at sea or taking terrestrial observations) for making observations of celestial bodies then making appropriate corrections and calculations after reference to nautical tables (altitude, azimuth and hour angle of observed bodies). Louis Bernacchi improved the accuracy of his location determination in the Antarctic winter of 1903 by making observations of occultation of stars. (Skelton 2004)

In high latitudes when observing on land or ice, the sextant becomes unreliable for determining zenith altitudes. The low altitude of the sun, even in midsummer in high latitudes intensifies errors (e.g. parallax) that must be corrected when determining the corrected observed angle.(Harbord 1938)

Sextants generally rely on a visible horizon but on ice an artificial horizon could be used. This consisted of a mercury bath that allowed a reflection of the sun's image to replace the horizon and the angle would then be halved. Two problems with this technique were encountered. One is that mercury does freeze at extreme low temperatures. The other is that that surface of the mercury bath tended to get drifted over with windblown snow. Amundsen used this technique at *Polheim* in mid December 1911 to fix his position at 90° South.

The accuracy of chronometers is of prime importance when calculating location from observation of celestial bodies. Improvements in construction and therefore accuracy of chronometers translated into improvements in all hydrographic charts, terrestrial maps and of course charts of magnetic variation.

Swinging the Ship

An element of accurate navigation is checking the compass deviation that varies according to the location and the direction of the ship's head. It is therefore necessary to carry out a manoeuvre known as ”swinging the ship”. This is no mean undertaking as crew would have had to launch the ship's boats and haul the ship around with a hawser to progressively face the cardinal compass points by rowing. Having determined true North by an azimuth sun sight, or repeating bearings on a fixed distant object the error of the compass is recorded for all directions of the ship's head allowing compensation to be made when setting course at sea. Armitage carried out this task at the beginning and end of the voyage, at Capetown, Lyttelton and a number of times in the Ross Sea.

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