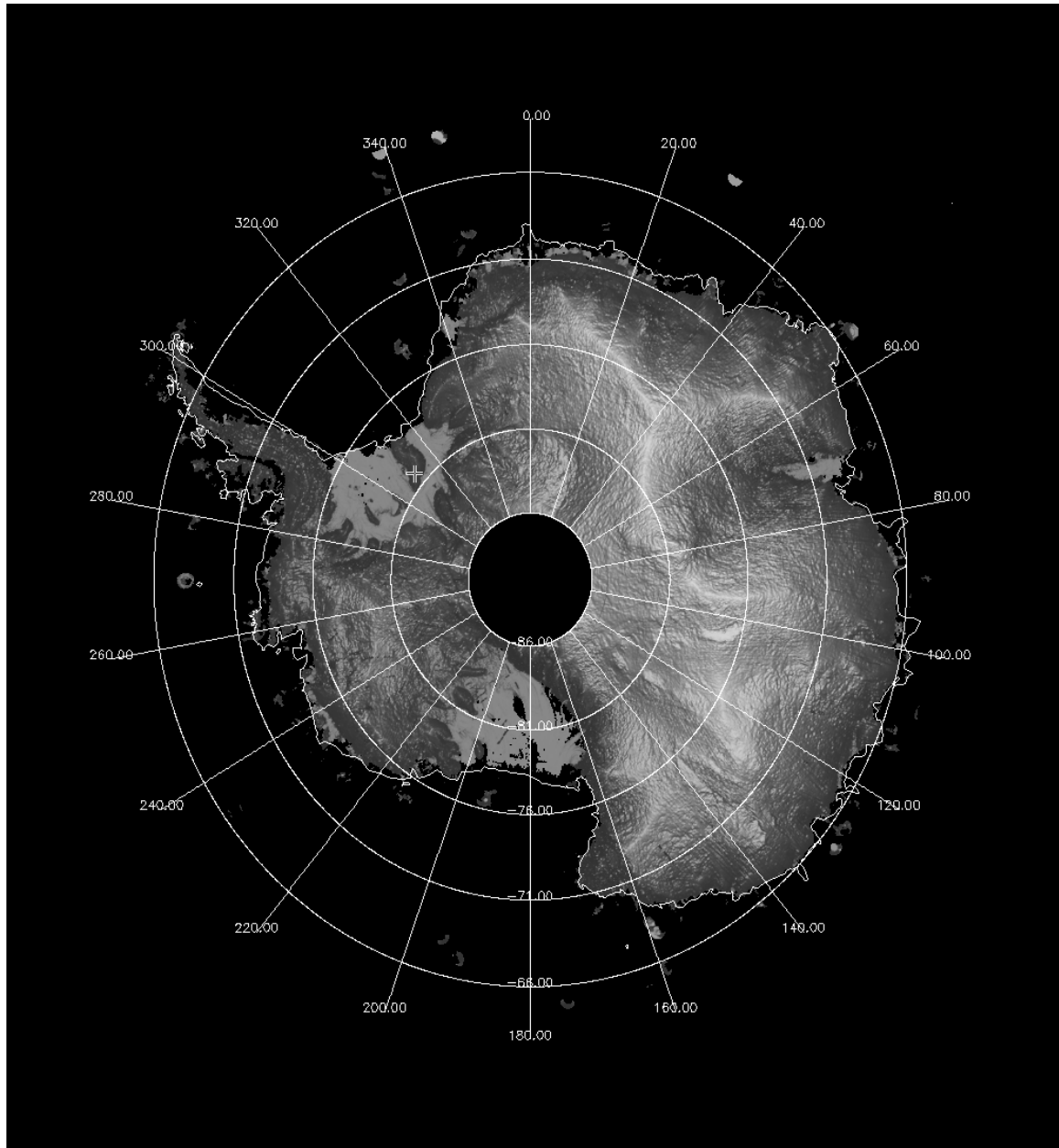


*Antarctic Cartography:
The Mapping of Terra Australis Incognita,
1531 - 2007*



<http://it.gsfc.nasa.gov/list.php>

'It hath euer offended mee to looke vpon the Geographicall mapps and find this Terra Australis, nondum incognita. The vnknown Southerne Continent. What good spirit but would greeue at this? If they know it for a Continent, and for a Southerne Continent, why then do they call it vnknowne? But if it bee vnknowne; why doe all the Geographers describe it after one forme and site?'

-Joseph Hall, 1605.

(Quoted by Richardson 1993: 67 – 68).

'A team of researchers have unveiled a newly completed map of Antarctica that is expected to revolutionise research of the continent's frozen landscape. The map is a realistic, nearly cloudless satellite view of the continent at a resolution 10 times greater than ever before with images captured by the NASA-built Landsat 7 satellite. The mosaic offers the most geographically accurate, true-colour, high-resolution views of Antarctica possible.'

-NASA *ScienceDaily* excerpt, 2007.

The above quotes give an insight into the exciting and complicated history of Antarctic cartography. They represent a paradigm shift from an unexplored 'Terra Australis Incognita' whose existence was portrayed in detailed but inaccurate topographic maps, to the representation of the Antarctic continent in the modern era using high-resolution, highly accurate satellite technology.

The following article comprehensively reviews the evolution of Antarctic cartography and gives an insight into the processes and problems associated with mapping of the polar regions.

Antarctica: The ‘Unknown Southern Continent’

Initially, the existence of Antarctica was postulated by the Greeks due to the belief that a Southern Continent must exist as a sister continent to the Arctic, necessary to create a ‘balance in nature’. The word ‘Antarctica’ means ‘opposite the bear’ – the ‘bear’ being the Arctic (Simpson-Housley 1992).

In 1531, a French geographer named Oronce Fine created the earliest map which specifically prescribed the existence of a southern land he named ‘Terra Australis’. His map was based on evidence from Magellan’s circumnavigation of the world in the 1520’s (Figure 1). At this stage in history, maps of Antarctica were based on the inventions of the mind and the perceptions of the cartographer and were used only to suggest the continent’s existence. They could not be used as reliable topographic documents because the continent had either not been discovered or had simply just been sighted from afar (McGonigal and Woodworth 2001).

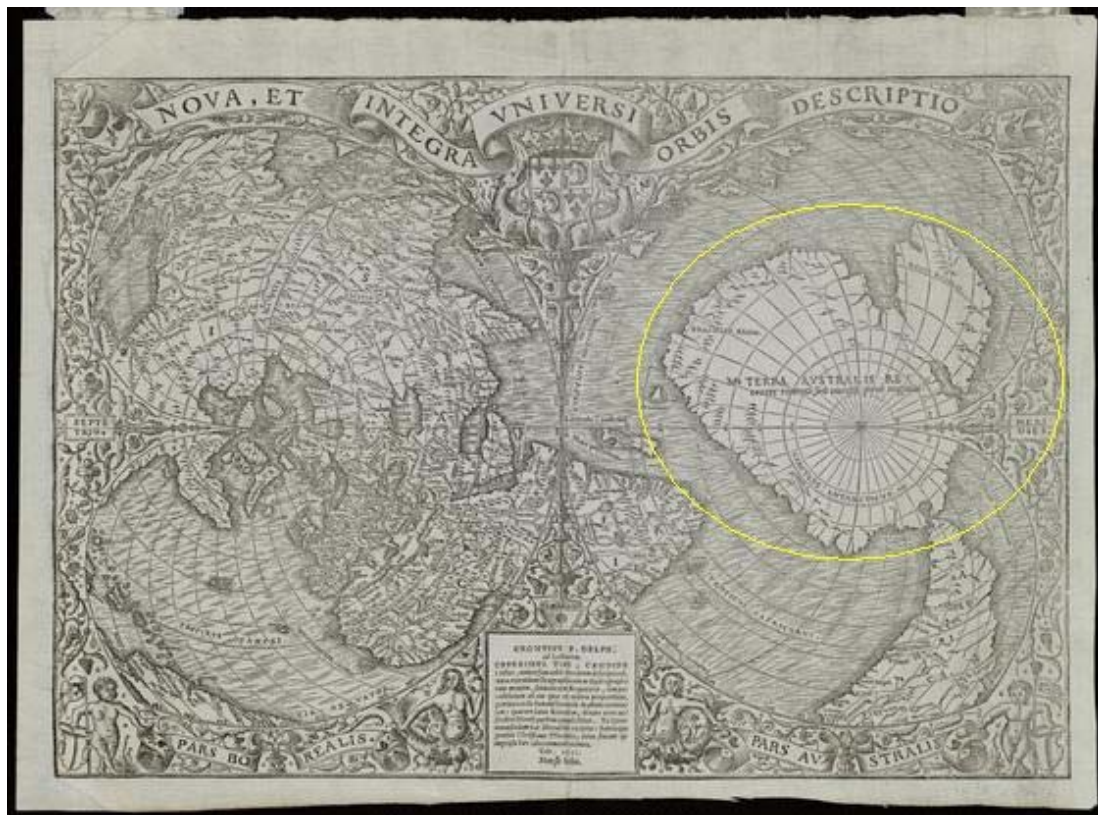


Figure 1. Oronce Finé’s 1539 map, ‘Nova, et integra Universi Orbis Descriptio’ with Terra Australis highlighted.

As early as 1578, ‘phantom islands’ were often added to charts when in reality they did not exist. McGonigal and Woodworth (2001) report the charting of 18 such islands up to 1929 and noted that these ‘islands’ were often icebergs which had been mistaken for land. Nevertheless, they had to be charted for safety reasons and were only removed after circumnavigation in the area had declared them non-existent.

In 1639, Henricus Hondius produced a map of a landmass named ‘Polus Antarcticus’ which delineates a simple outline of the continent and gives it a position on the globe situated below South America (McGonigal and Woodworth 2001) (Figure 2).

Although this map does give some idea of the continent’s shape, large areas of the coastline are still missing. Murray (2004) notes that there was an ‘urge’ during this time for the blank space at the bottom of the earth to be filled by some kind of landmass, and that ‘this both reflected a desire for the security of complete knowledge and also provided an important space for non-geographical discourse in maps that is no longer available.’

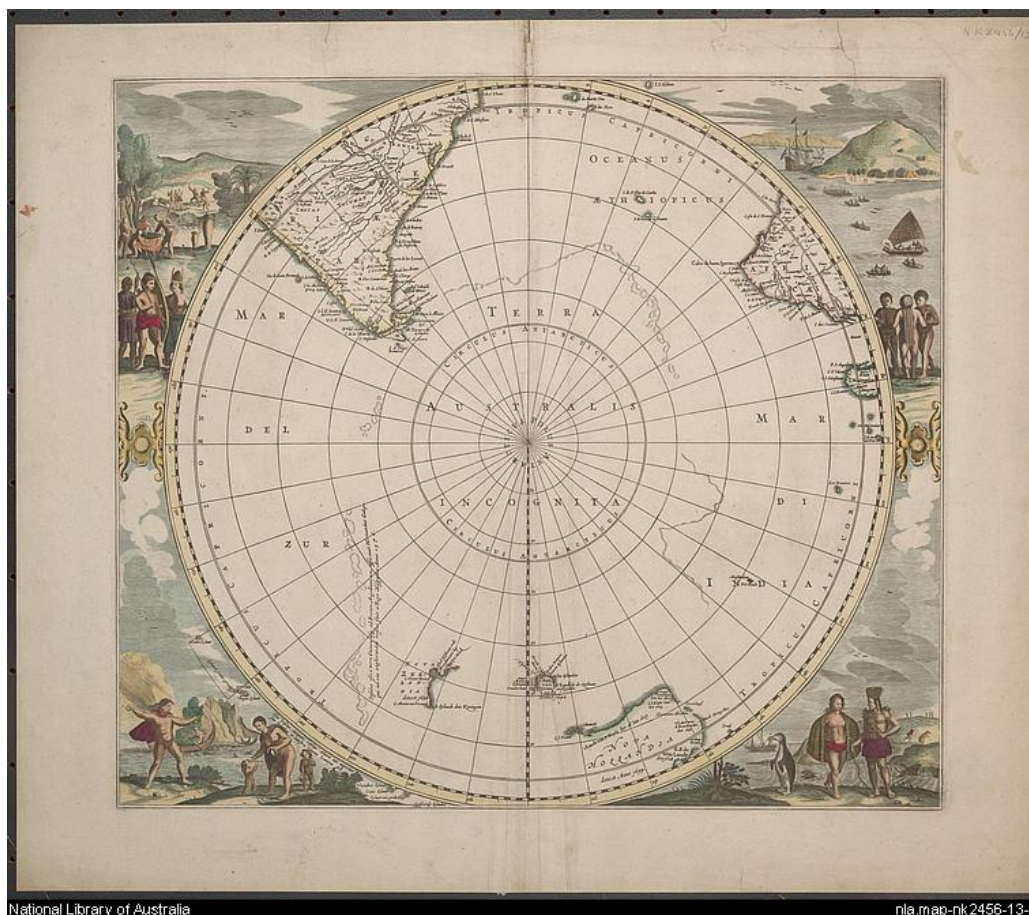


Figure 2. ‘Polus Antarcticus’ – Henricus Hondius (1639)

Exploration: Solving the Cartographic Puzzle

It was not until over a century later that Antarctic maps evolved from basic conceptual charts into more sophisticated maps based on exploration. The first significant exploration of the continent occurred between 1772 and 1775 when Captain James Cook completed his circumnavigation of Antarctica. His voyage has been described as being of 'prime importance in destroying the myth of *Terra australis*' (Simpson-Housley 1992) as evidence from the voyage was used to dismiss ideas that the continent was lush and green. In 1782, a map of Antarctica was created by cartographer Philippe Buache, using information gathered from Cook's voyage. It was in this map that the Antarctic continent was placed inside the Antarctic Circle along with the Sub-Antarctic islands of South Georgia and the South Sandwich Islands (McGonigal and Woodworth 2001).

Between 1819 and 1832, the navigators Thaddeus von Bellingshausen and John Biscoe made two separate voyages further south than Cook, and contributed even more cartographic information on the continent when West Antarctica was first sighted by Biscoe. Scientific literature published at this time on various Antarctic expeditions was invaluable in the evolution of Antarctic cartography. This is because the literature often had maps which accompanied it such as charts of Terra Adelie by Jules Dumont d'Urville, and of Victoria Land and the Ross Ice Shelf by James Ross (McGonigal and Woodworth 2001).

The British Admiralty made an attempt to bring the charts of the above expeditions together into two maps; the 1845 Chart of the South Polar Sea (Figure 3) and the Ice Chart of the Southern Hemisphere (1874). These charts were still largely void of information as there was still some uncertainty as to whether the continent was one landmass or a series of scattered islands.

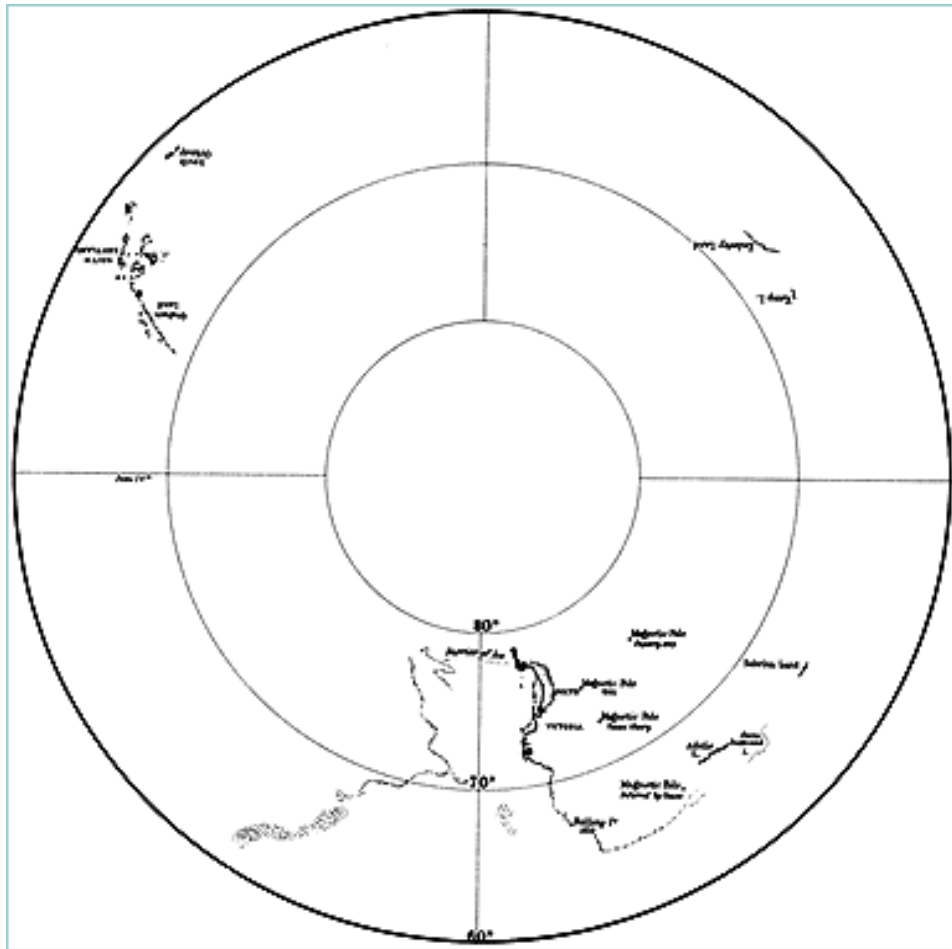


Figure 3. Chart of the South Polar Sea (1845) produced by the British Hydrographic Office after the expeditions of James Clark Ross

It was in the 20th Century that the Antarctic map really began to take shape. The Heroic Era of exploration made famous by names such as Scott and Shackleton played a huge role in putting the Antarctic jigsaw together. McGonigal and Woodworth (2001) note that charts obtained from the British National Antarctic Expedition (1901-1904) produce detailed and accurate information on Victoria Land and ‘represent the beginning of detailed coastal and land mapping of the Antarctic Continent’. Pieces of coastline around the peninsula in West Antarctica such as Graham Land were represented in these early maps as well as parts of the Ross Sea region.

The switch from sea-based navigation to land-based activities was a move that triggered the rapid evolution of Antarctic cartography. Holmes-Miller (1965) recalls

that there were many advantages to mapping on land, including the replacement of the sextant with the theodolite (Figure 4). 24hr daylight over the summer season presented problems for field parties due to the refraction which occurs due to the position of the sun lower in the sky.



Figure 4. Geologist L. Gould pictured on the Byrd Expedition 1928-1930 with a frost-covered theodolite

Tides and currents also hindered surveyors in making accurate judgments on position and location at sea, whereas a land-based party could use compasses and sledgemeters to increase accuracy. Scott's National Antarctic Expedition from 1901 – 1904 resulted in the charting of numerous glaciers, namely the Nimrod Glacier, the Koettlitz Glacier and the Ferrar and Taylor glaciers. The British Antarctic Expedition of 1907-1909 included mapping of the Polar Plateau, Victoria Land, the Drygalski Ice Tongue and beyond. Granite Harbour and areas of McMurdo Sound were added to maps on Scott's second expedition beginning in 1910 (Figure 5). At the close of the heroic era, Holmes-Miller (1965) notes "at this time we see mapping beginning to assume its true place in Antarctic exploration, that of providing the means for the illustration of other sciences, notably geology."

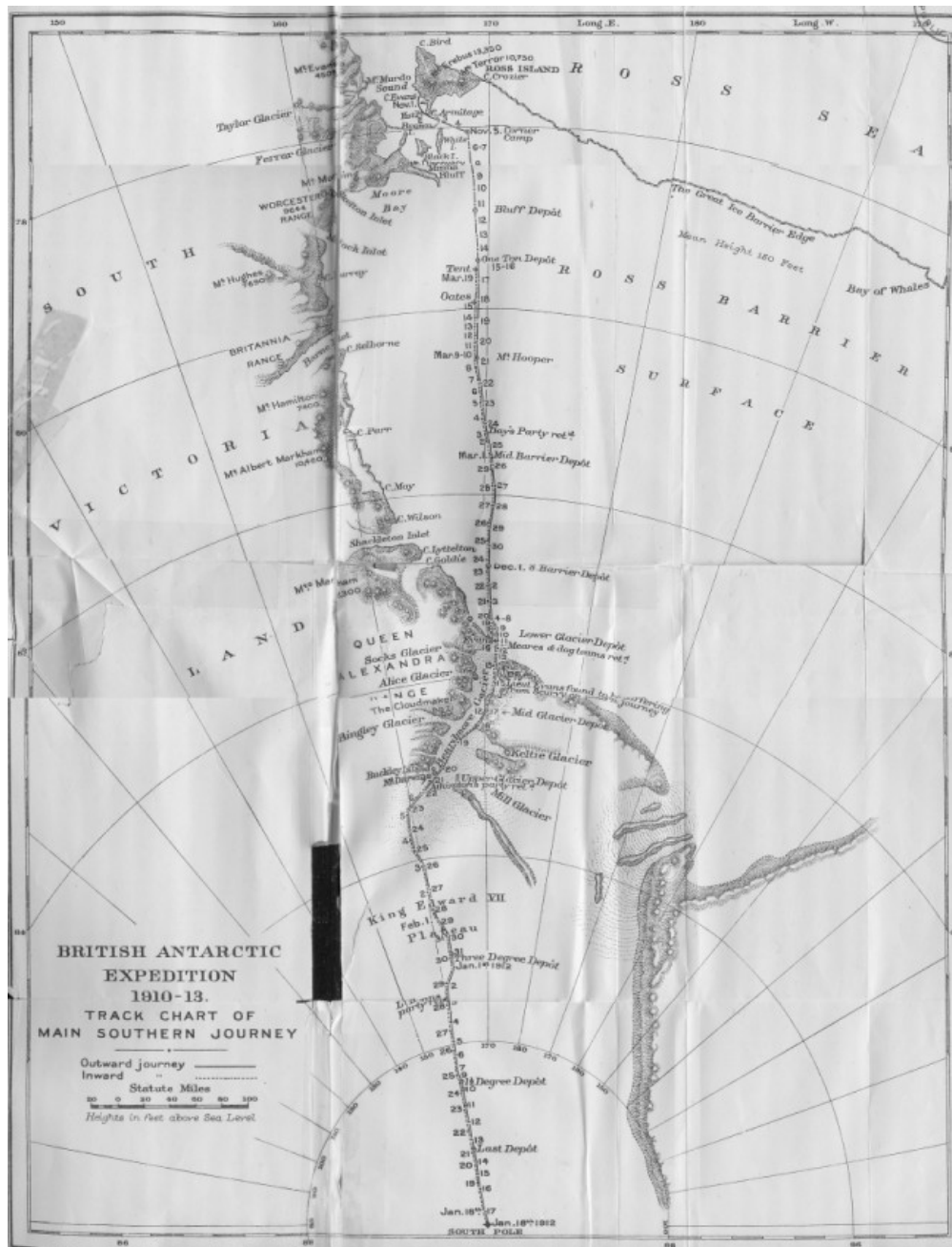


Figure 5. Chart illustrating the route taken on the British Antarctic Expedition (1910 – 1913)

The Role of the Aeroplane and Modern Land Surveying

Perhaps the biggest advance in Antarctic cartography occurred with the introduction of the aeroplane as a tool for mapping in 1928. By undertaking regular flights over the continent, surveyors were now able to use aerial photography to compliment surveys carried out on the ground. Holmes-Miller (1965) notes the importance of coupling both techniques as errors arose when only one method was used. At this stage hand-held cameras were the only means to obtain photographic information, until two

landmark studies in the late 1940's called Operation High Jump and Operation Windmill (Figure 6). These operations involved trimetrogon photography which allows photos to be taken at accurate levels at horizontal and vertical positions. Over 200 hours were dedicated to aerial photography during which the existence of the TransAntarctic Mountains was confirmed and the Ross Ice Shelf and Dry Valleys were mapped (McGonigal and Woodworth 2001).

In 1929, the BANZARE expedition led by Mawson included a number of over flights over the continent where photos were taken from a small aircraft and sketches were made which identified key features of the coastline (Grenfell Price 1962). An aeroplane was also used to survey the coastline and the Kemp, MacRobertson and Banzare coasts were subsequently added to the map.

Following on from this, Australia produced a map of the continent in 1939 - one of the first general maps of the continent (Figure 7).

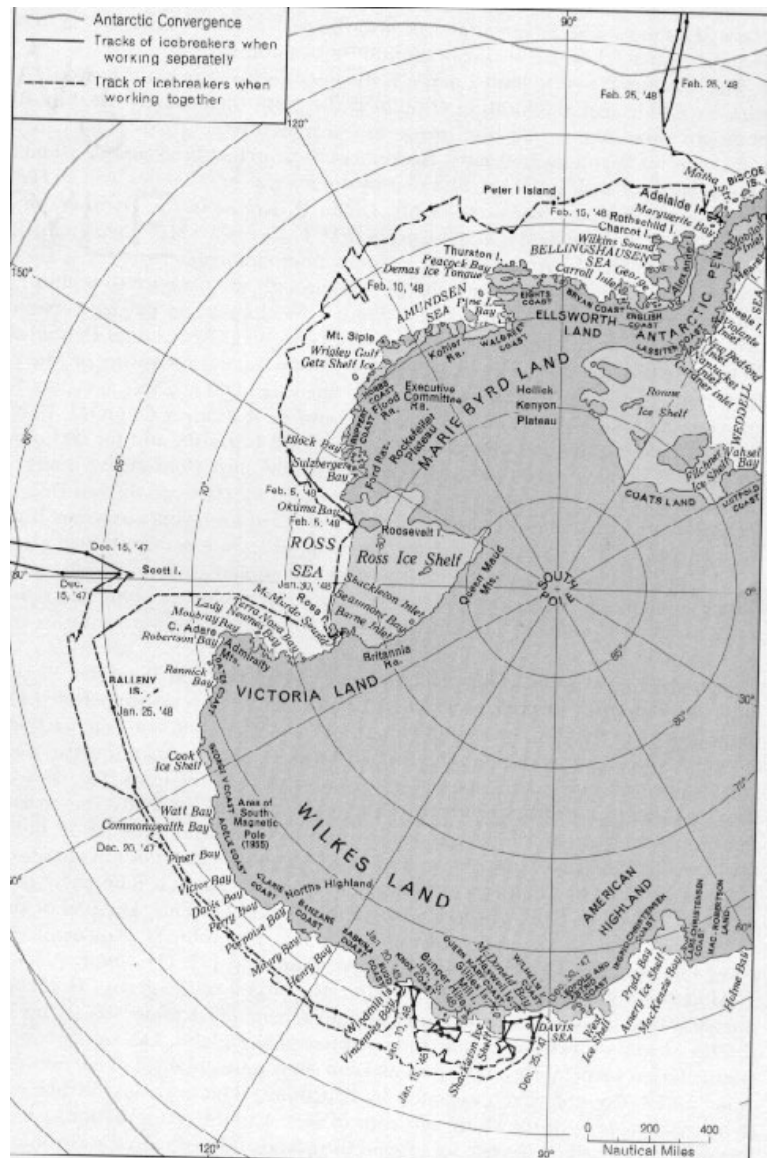


Figure 6. Map of Antarctica produced as a result of Operation Windmill

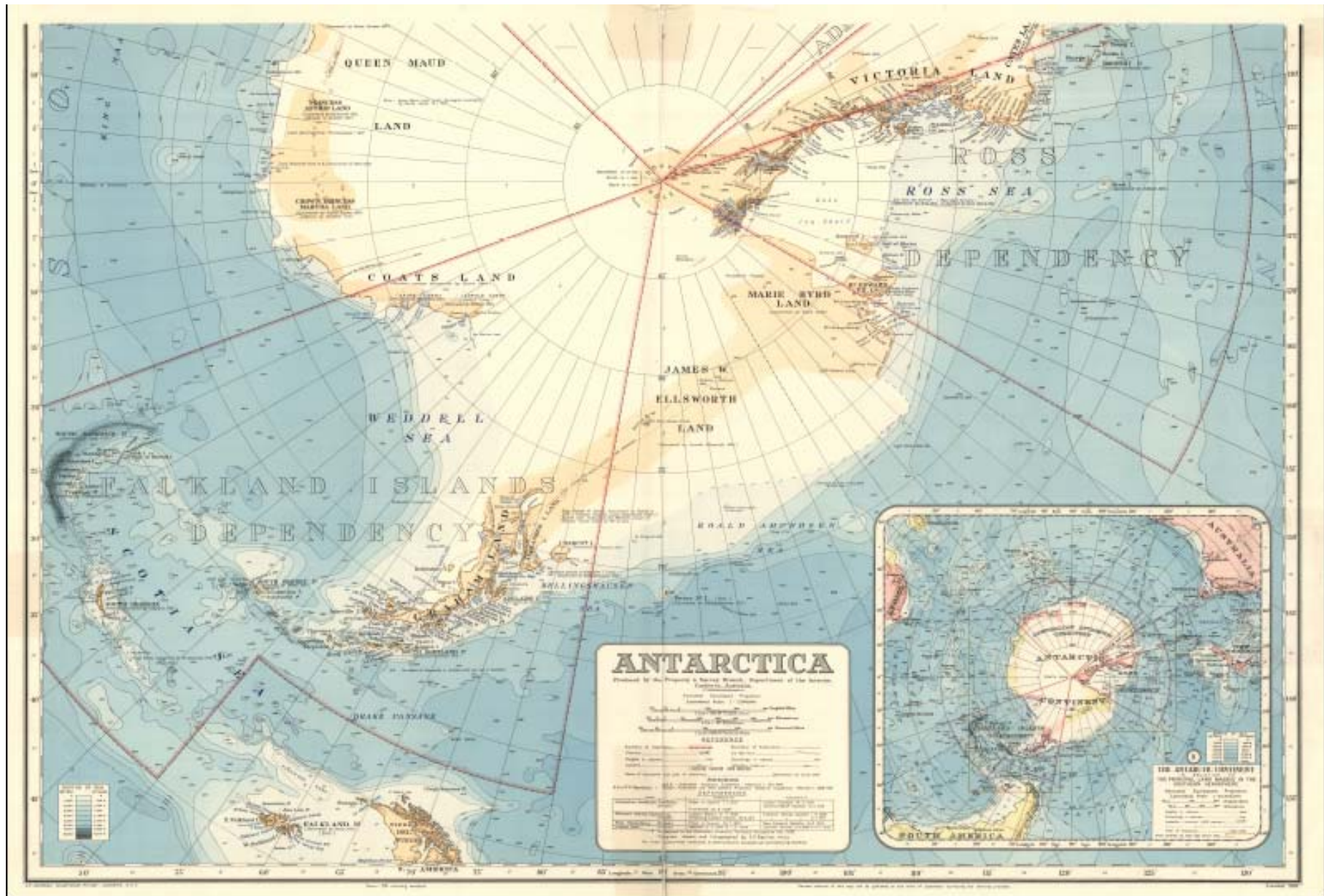


Figure 7. Map of Antarctica produced by Australia in 1939, following Mawson's BANZARE expedition

It was found during this time that numerous errors could be easily made when surveying on a continent with no obvious reference points such as trees or other landmarks. In 1959 the cartography division of SCAR made recommendations specific to the mapping of Antarctica. These recommendations included:

1. That the metric system should be used in all Antarctic mapping
2. That a 500 metre contour interval, with supplementary contours at closer intervals when required, is suitable for maps at scales smaller than 1:1,000,000.
3. That the International Spheroid should be used for all Antarctic mapping.
4. That maps at a scale smaller than 1:1,000,000 should be on the polar stereographic projection, with standard parallel at 71°.
5. That, in maps and charts at scales larger than 1:1,000,000 sheet lines should normally subdivide 1:1,000,000 sheet lines and a conformal projection should be used.
6. That the 1:1,000,000 scale should be adopted for hydrographic charting for scientific purposes and general coastal navigation.

(Holmes-Miller 1965)

A total of 98 expeditions to the Antarctic between 1900 – 1953 made a contribution to cartography in some shape or form, whether it was the naming of landmarks or the physical mapping of an area (Whitmore 1964). From 1956 onwards, New Zealand made many contributions to Antarctic cartography including charting of Cape Adare and beyond the Beardmore Glacier. Land surveying techniques were still fairly dominant where theodolites were still used to fix geographical positions with the aid of astronomical observations.

At this stage, the mapping of the Antarctic continent was occurring at a slower rate than desired, and efficiency needed to be increased in order to keep up with scientific demand (Swithinbank and Lane 1976, Whitmore 1964). It was noted that maps of the Antarctic were still fairly primitive and that errors were frequently found, including a position noted by Swithinbank and Lane (1976) which was out by 100km.

Technological Advancements: The Advent of the Satellite

Although some significant cartographic achievements had been made prior to the IGY in 1957 – 58, it wasn't until the 1970's that increasingly complex technology allowed mapping of the continent to move ahead in leaps and bounds.

It was the advent of remote sensing technology that for the first time, made it possible for the entire continent to be mapped in a matter of days and ice dynamics to be monitored. Remote sensing uses electromagnetic signals to measure backscatter which can then be used to define the surface features of a landmass such as Antarctica. Various properties of the ice sheet can be monitored such as ice sheet surface elevation, topography, ice surface motion, iceberg drift and thickness, and strain rates (Lubin and Masson 2006 Vol. 1). It was found that the polar regions were an ideal place to use such technology for many reasons, one being that the air is less humid at higher latitudes, making atmospheric windows more transparent and easier to penetrate (Lubin and Massom 2006 Vol. 2).

In 1963, the U.S. were the first to map Antarctica's ice edge using 'Declassified Intelligence Photography' which was compared with aerial photographs taken in the 1950's. The coupling of the two techniques was useful for detecting changes to the coastline over time. It covered large areas of the Antarctic ice sheet but results were affected by cloud cover (Lubin and Massom 2006 Vol.1).

The first satellite to incorporate remote sensing technology with the aim of mapping the entire continent was the U.S. Earth Resources Technology Satellite (more commonly known as Landsat-1), which made its first measurements in 1972. This satellite surveyed the Antarctic continent from a satellite 940km above sea level and used multispectral television cameras and multispectral scanning radiometers to cover areas of 185 square kilometres in one image frame. The satellite produced high quality images of ice and bedrock over large areas (Figure 8). The technology wasn't without problems however - the satellite could not penetrate through clouds, and field measurements were still needed in order to guarantee accuracy. This was realised during an assessment of the ERTS maps which yielded that numerous nunataks were

missing from the maps that had been previously recorded by surveyors and geologists (Swithinbank and Lane 1976).

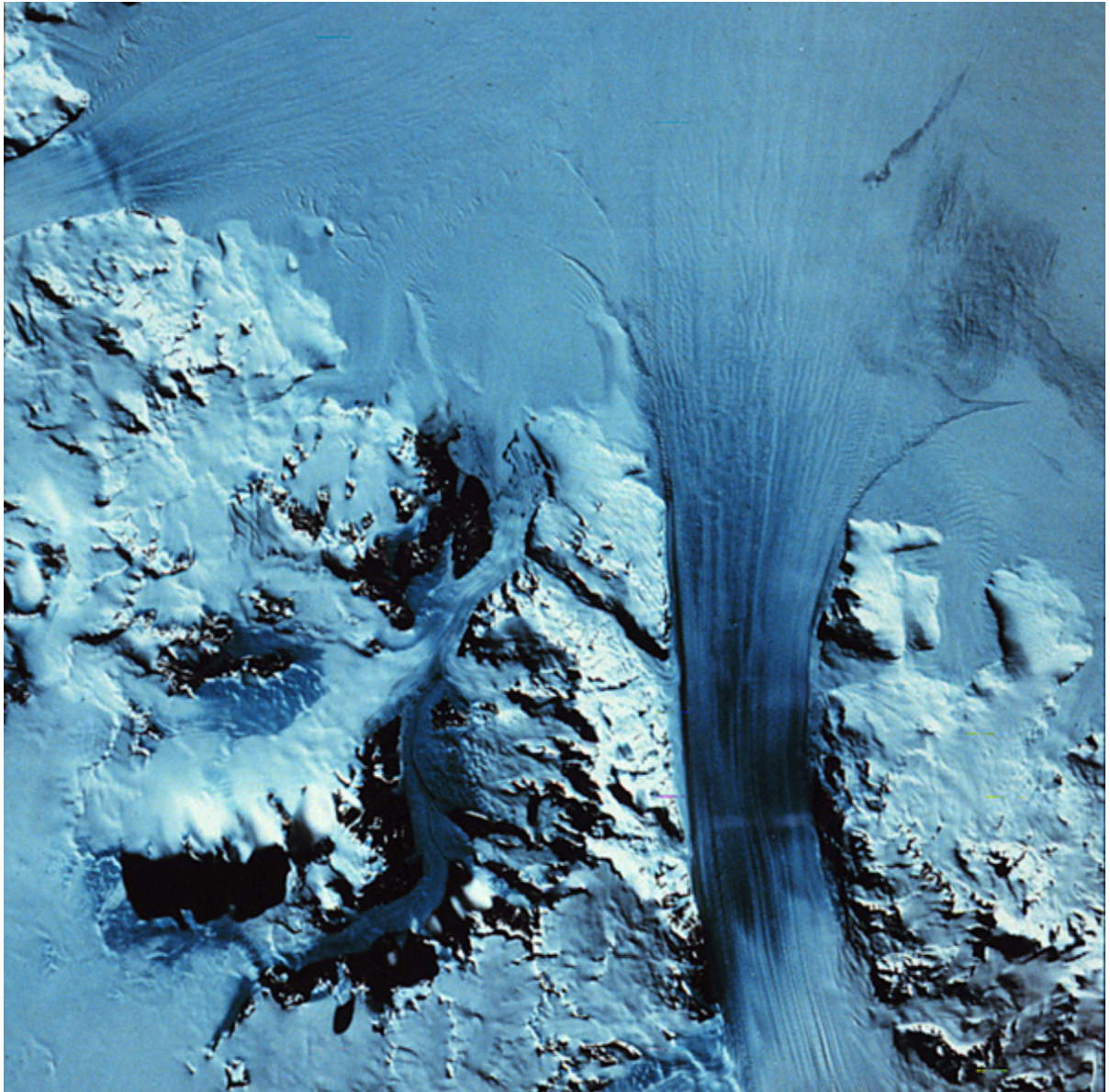


Figure 8. Landsat-1 image of the Byrd Glacier taken in 1974. Ice and bedrock are prominent features.

The overall success of the satellite in producing valuable imagery was however noted by scientists and cartographers who stated that ‘in the course of studying faraway regions that are notoriously inhospitable, dangerous and logistically challenging...glaciologists soon realised the immense benefits that satellite remote

sensing had to offer compared to in situ measurements...satellite remote sensing is an absolutely essential polar research tool.” (Lubin and Massom 2006 Vol. 2).

During the 1970's, the topography of Antarctica was also being mapped using a combination of balloons and remote sensing software (Levanon et al. 1977). In the summer of 1975, scientists took advantage of the 24hr daylight to release the balloons 12.5km into the air, fitted with radio altimeters, pressure sensors, and ambient temperature sensors. Data could only be transmitted if the balloon's solar panel was activated by a constant supply of light and the balloon was in sight of the NIMBUS-6 satellite. On average, balloons had a life of only 2 months and errors meant that measurements could be out by up to 60m (Levanon et al. 1977).

RADARSAT-1 Antarctic Mapping Mission 1997

The Radarsat Mapping Mission was carried out for the first time in 1997. The main aims of the operation were to use synthetic aperture radar (SAR), a remote sensing technique, to map the continent. SAR is a desirable method of mapping because it doesn't rely on clear skies and daytime to produce quality images as opposed to optical satellite imagery used previously. As a result of the Radarsat Mission, the first complete real time high resolution photograph of the continent was produced in just 18 days (Murray 2005) (Figure 9). The images are high resolution and are designed so that the response of the ice sheet to climate changes and surface velocity measurements can be monitored (Jezek and Farness 2003) (Figure 10). A problem associated with radar altimetry is that height measurements can be erroneous due to the fact that the radar can penetrate the snow pack. In addition to this, some remote sensing technology such as this 'have angles of view that leave large areas around the South Pole blank' (Murray 2005).

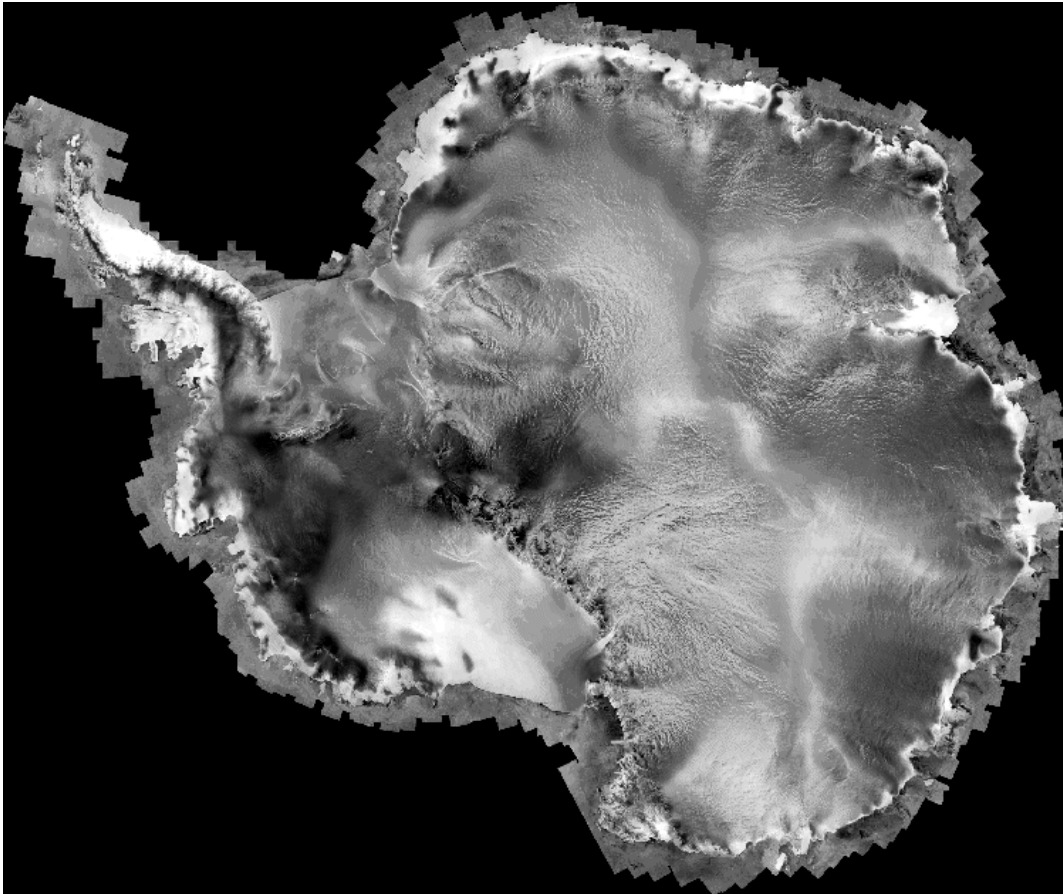


Figure 9. RADARSAT-1's complete SAR mosaic of Antarctica.

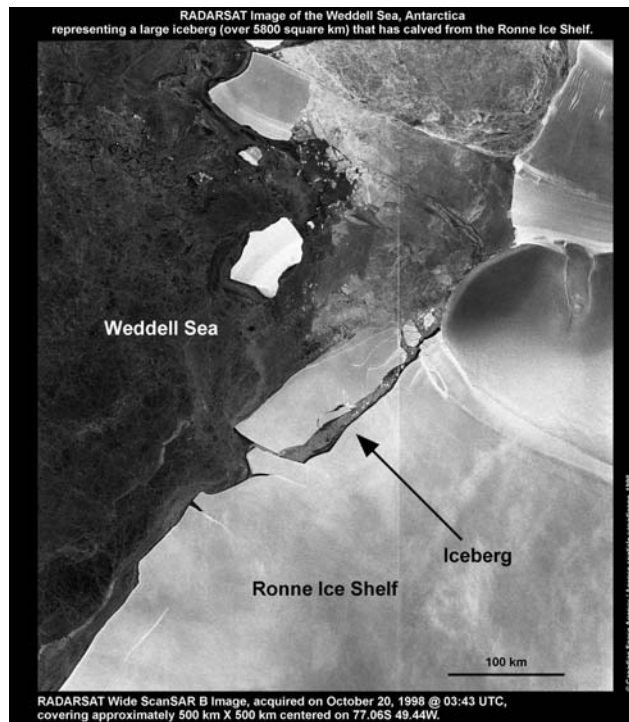


Figure 10. RADARSAT image of the Weddell Sea illustrating the calving of a large iceberg

ICESAT 1999

In 1999, remote sensing technology advanced once again with the invention of laser altimetry. The Ice, Cloud and Land Elevation Satellite or 'ICESAT' is an example of this technology which was designed to survey the polar regions (Figure 11). The satellite fired a laser shot every 170m and offered accurate but incomplete coverage of the continent (Figure 12), operating for a month at a time. The main objective of ICESAT was to measure the mass balance of the continent, however it can be used for numerous other purposes such as cartography (Figure 13). The laser produces an image of a point using two vectors, where the resulting vector 'can be readily transformed into geodetic latitude, longitude and height (or elevation) with respect to a reference ellipsoid' (Schutz 2005). Although the laser altimeter is seen as being a more advanced system due to its high level of precision, it cannot penetrate thick cloud cover as forward scattering of the laser signal causes errors to be made (Schutz 2005).

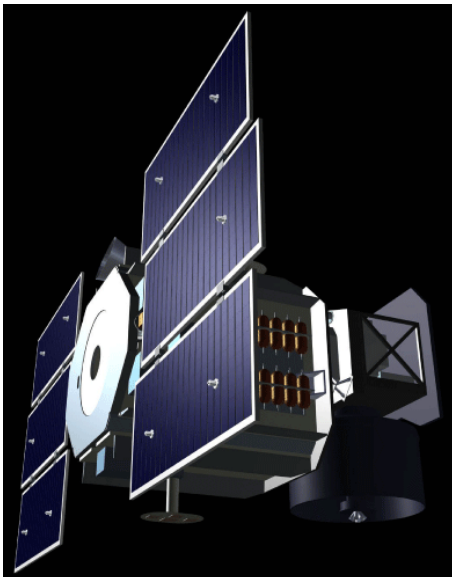


Figure 11. The ICESAT Satellite

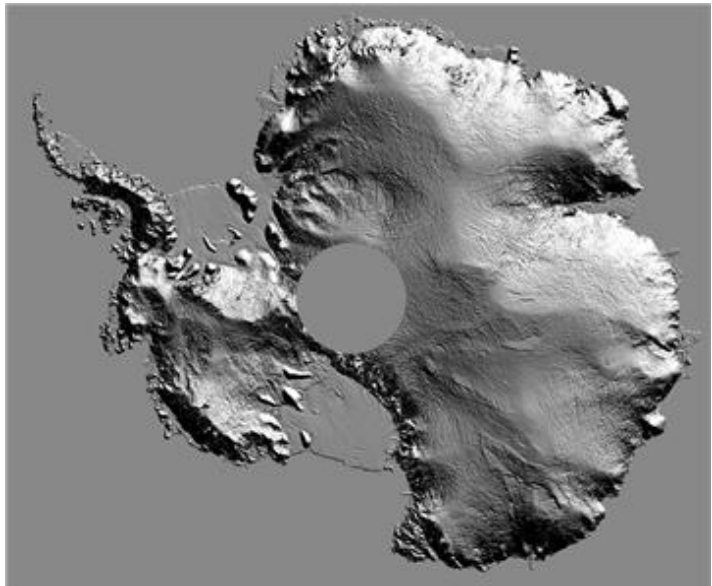


Figure 12. ICESAT image: Surface elevation of Antarctica.

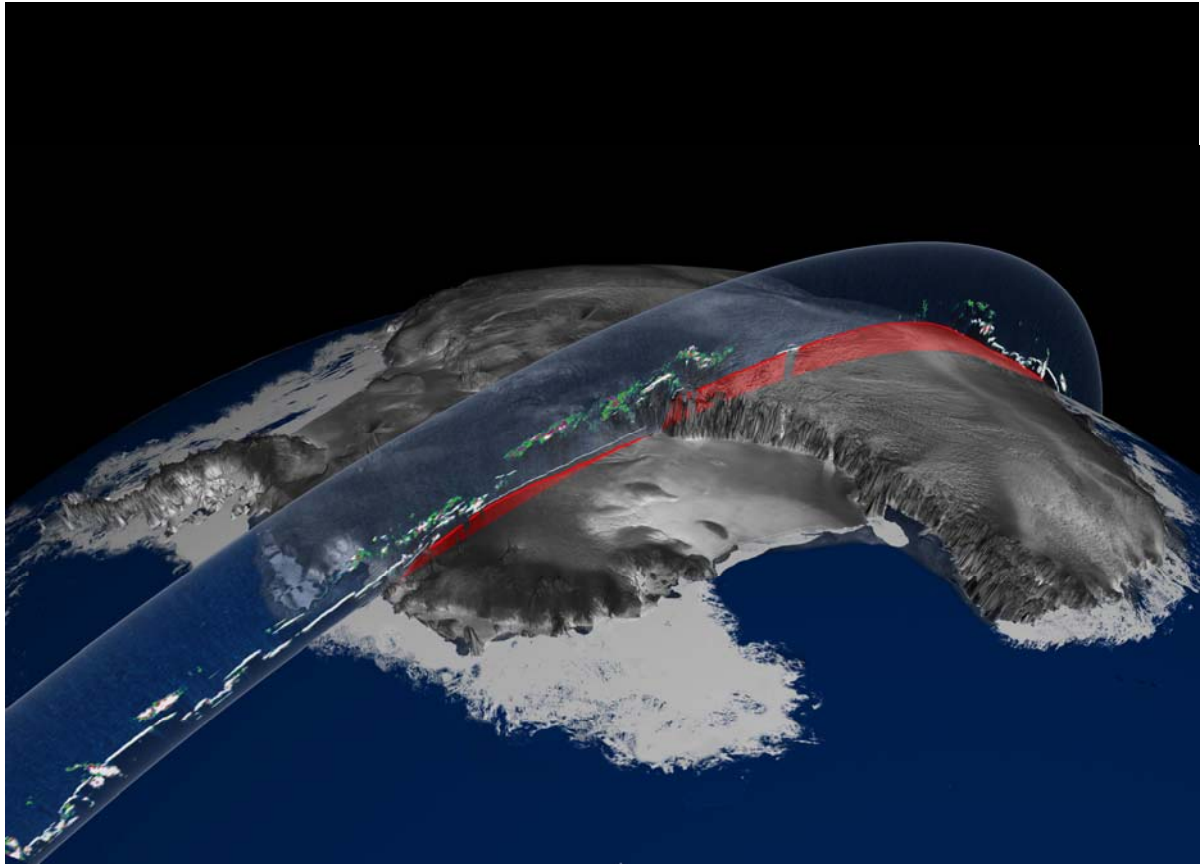


Figure 13. Artist's image of Antarctica illustrating the array of information which can be obtained from the ICESAT Satellite. The red area represents elevation measurements . Elevation is highest where the band is thickest over East Antarctica.

Present Day Mapping and the Future of Antarctic Cartography

Murray (2005) notes that 'today, the visible is being mapped as well as the visible, the moving as well as the static... views of the Earth and Antarctica are mediated by physics rather than geography.'

Unique features under the ice have been discovered, including the Gamburtsev mountain range and Lake Vostok (Figures 14 and 15). The ICESat Satellite was able to measure the surface elevation of this lake 4km under the ice with a minute 3cm margin of error (Schutz 2005).

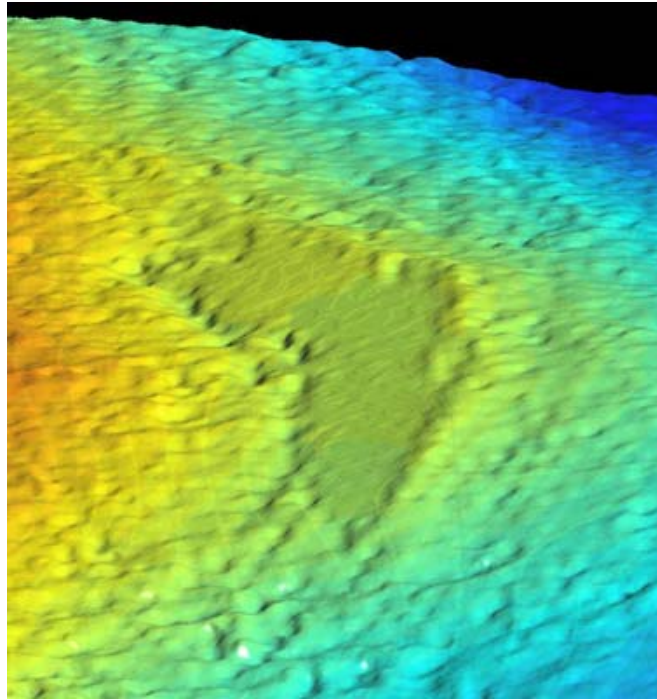


Figure 14. Map of Lake Vostok compiled from RADARSAT images

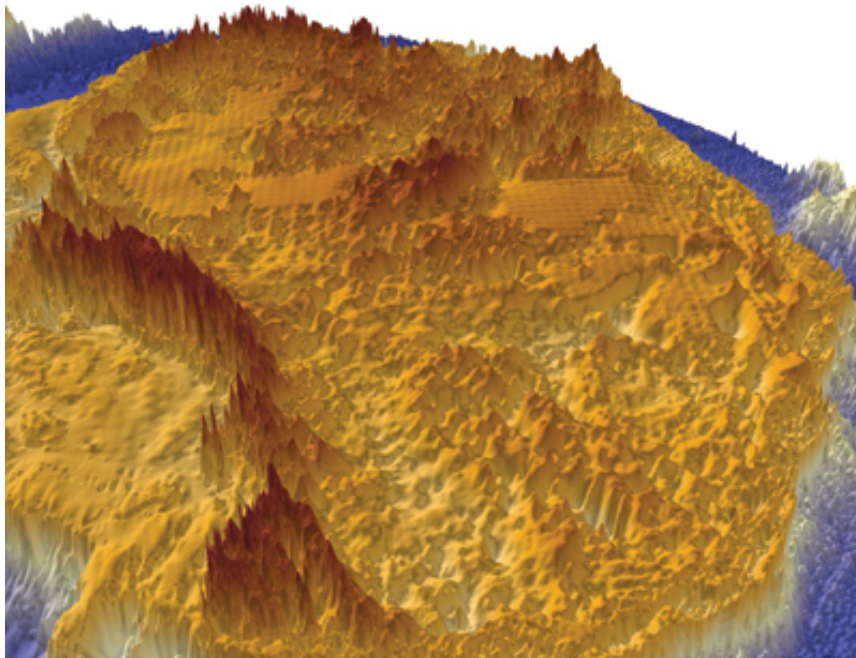


Figure 15. Model of the Gamburtsev Mountain Range, created with data obtained from the gravity sensing satellite, GRACE.

In 2007 the latest map of Antarctica was released as the result of a collaboration between NASA, BAS, the U.S. Geological Survey and the National Science Foundation. The map was compiled using 1,100 images taken between 1999-2001 by the Landsat Satellite which were compiled into a mosaic, creating the most advanced map of Antarctica to date (although the ‘doughnut shaped hole’ at the pole still exists due to the inability of currents satellites to capture images directly at the poles). The map is called the ‘Landsat Image Mosaic of Antarctica’, and it gives us an idea about how the continent has changed over time due to the time-lapse nature of the technology used (ScienceDaily 2007). Features can be viewed with amazing clarity, where islands, glaciers and even research stations can be easily identified in the images (Figure 16).

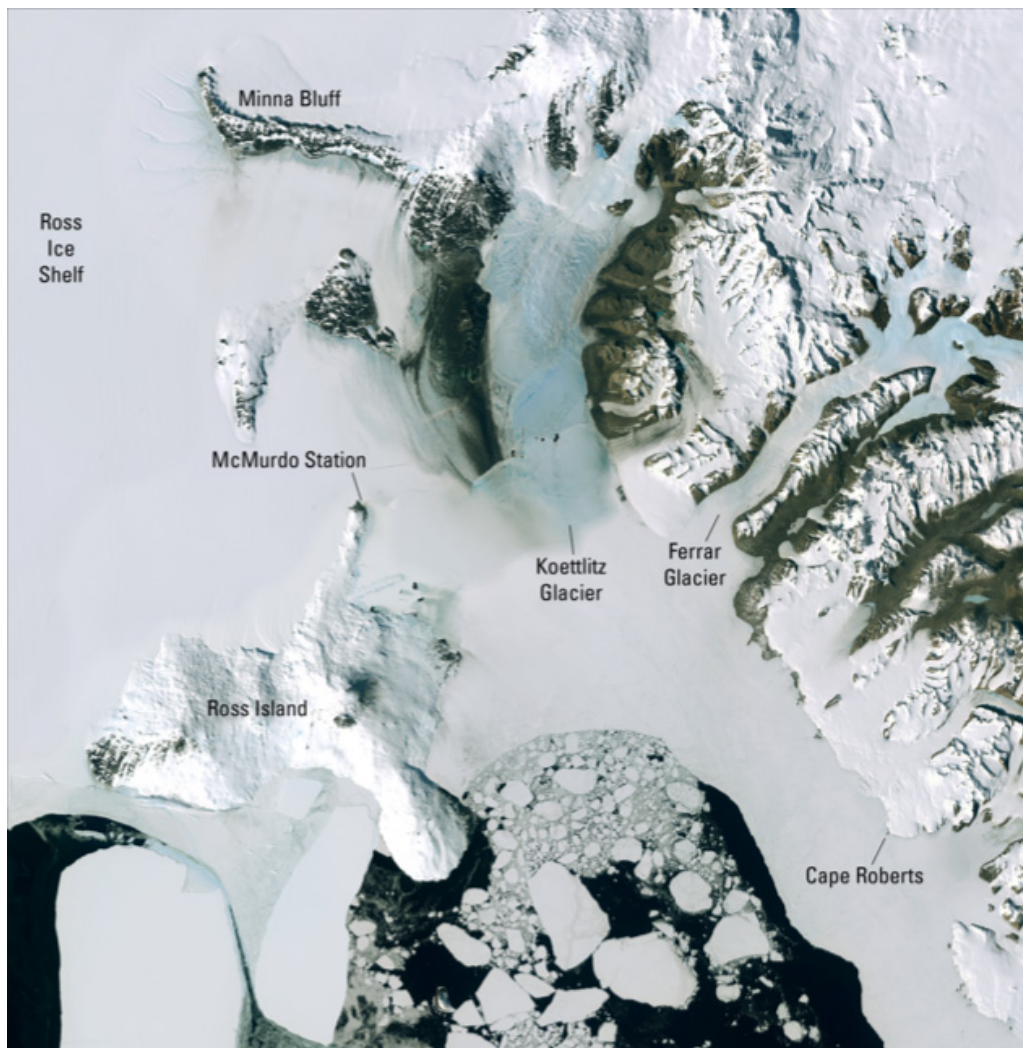


Figure 16. LIMA Satellite image of the Ross Ice Shelf, Ross Island and Cape Roberts

The satellite imagery has been used to create the most up to date topographic maps of the continent which supplement the satellite images (Figure 17).

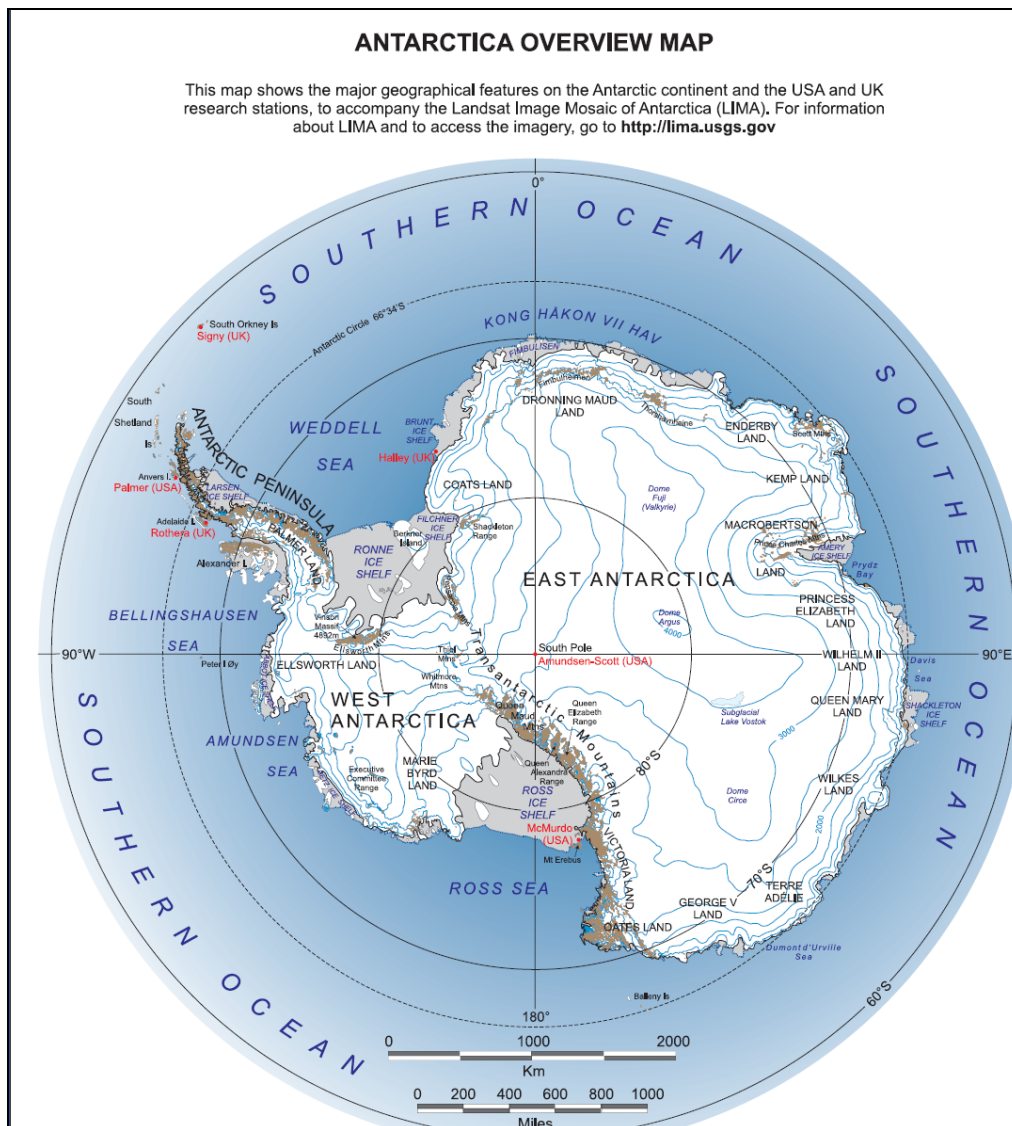


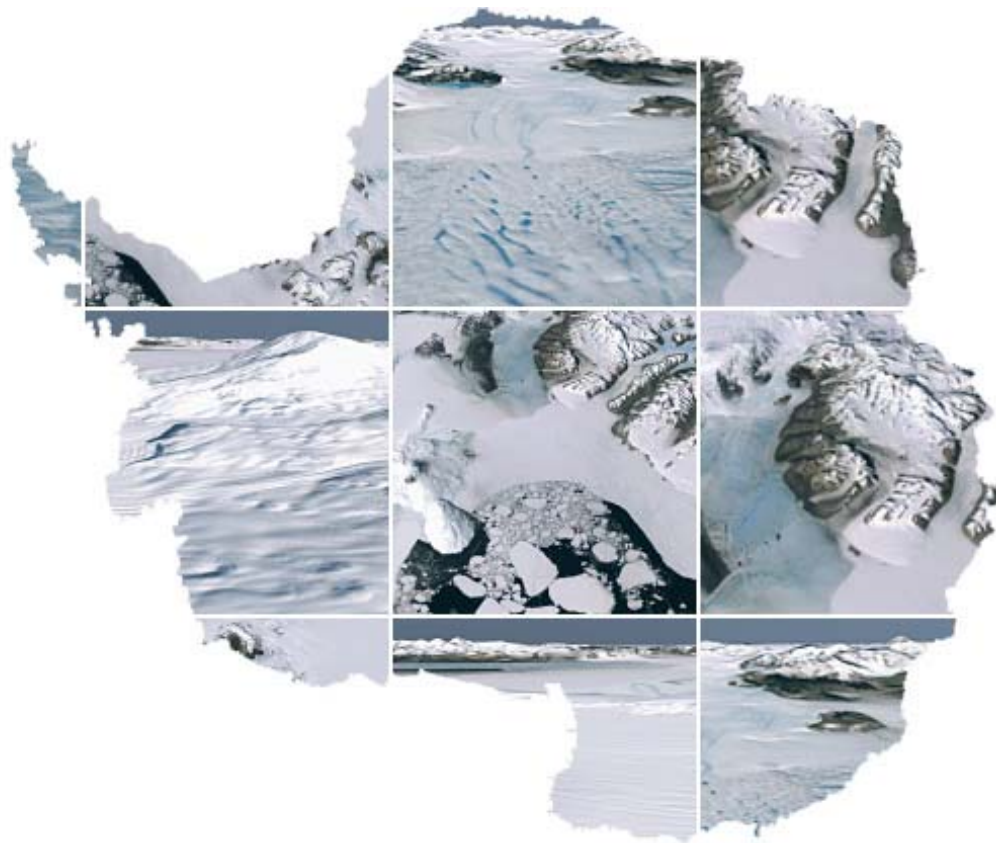
Figure 17. Map featuring the geographical features of Antarctica, based on LIMA images

The images obtained from the satellite are available to the public online, making Antarctic cartography an interactive experience available to anyone in the world.

Cartography in Antarctica has grown from the representation of the landmass in a series of relatively incoherent pieces, to the representation of the entire continent as part of the globe. The continent has essentially ‘appeared’ before our eyes as technology has allowed us to map an increasing number of features.

There are many challenges ahead for cartographers and scientists alike, if future technologies are to improve mapping and knowledge of the continent. It is important to reiterate that at the present time, satellite imagery must be coupled with ground-based measurements in order to obtain the most accurate measurements possible and eliminate errors which may otherwise be published on modern Antarctic maps. Lubin and Massom (2006 Vol. 2) note that ‘satellite remote sensing will never entirely replace in situ measurements’.

The name ‘Terra australis nuper inventa sed non plene examinata’, or ‘the lately discovered, but not completely explored southern land’ as Antarctica was once referred to by Oronce Fine, seems appropriate today as it once was in 1531. Although Antarctic cartography has evolved greatly over the last 400 years, Antarctica has by no means been ‘completely explored’ as there are still components of the internal ice sheet and basal topography which remain to be mapped. Lubin and Massom (2006 Vol.2) state that ‘no ideal, all-purpose remote sensor currently exists’. Perhaps such a sensor will be working to complete the Antarctic puzzle in the not so distant future.



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