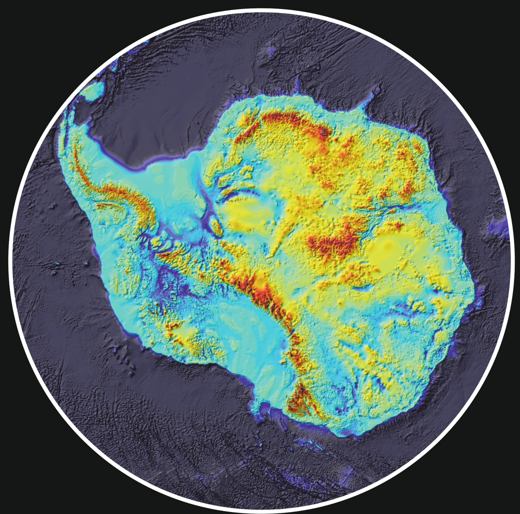
British Antarctic Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL
BAS Thematic map series
MAP1 2013

Bedmap2
Bedrock topography of Antarctica



The project:

Bedmap2 is a large collaborative international project to map the surface elevation, ice thickness and bed topography of the Antarctic Ice Sheet. We have used a multitude of different types of data to construct these products, including radio-echo sounding data from aircraft and ground based sledge expeditions, seismic surveys, swath bathymetry, satellite altimetry, contours on rock outcrops, satellite radar interferometry and image analysis of the grounding line. The ice thickness map alone uses 25 million individual survey points from 207 Antarctic airborne survey campaigns conducted over the last 50 years. Around sixty scientists from thirty five institutions based in fourteen countries have contributed to Bedmap2.

Merging such a quantity and variety of data posed a number of unique challenges. We tested gridding algorithms for subglacial environments by using a well-mapped area of the Scottish Highlands, and we experimented with the seamless merging of datasets of variable quality and density. We chose a gridding resolution that best represents the landscape with the data available and that is appropriate to the users of our products. As the final output will be used by a range of scientific communities (such as ice sheet modellers, structural geologists, geophysicists and oceanographers) it is important that the resulting datasets are suitable for all. The end procedure, modelled within a GIS framework, was necessarily complex.

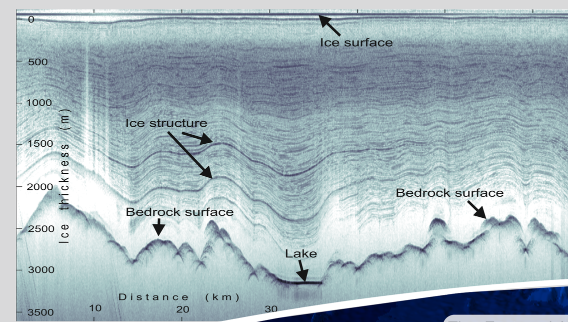
Here we present the final outputs of that project; the new Bedmap2 datasets of Antarctic ice thickness, surface height and bed elevation, mapped in planimetric, oblique and cross sectional perspectives.

BAS de Havilland Twin Otter

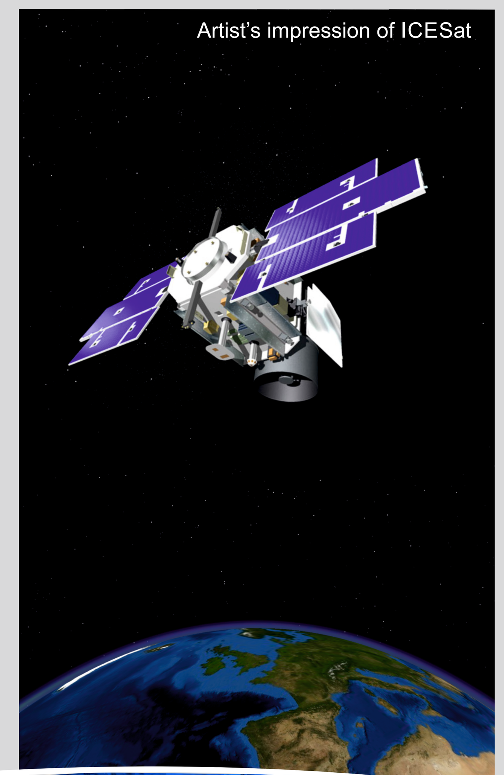
Data collection: the bed

Ice thickness measurements collected by radio-echo sounding (radar) make up the primary data source used to construct Bedmap2. By subtracting these from a surface elevation grid over grounded ice, we calculated the height of the bed. Most of the radio-echo sounding data used in Bedmap2 has been collected by aerial survey, using platforms like the de Havilland Twin Otter pictured left. Airborne survey allows for large quantities of data to be gathered over the wide open spaces of the Antarctic Ice Sheet. Thousands of kilometres of flight-lines can be flown in a single day and many gigabytes of profile data gathered. Radio-echo sounding from sledge borne surveys is still collected where very detailed bed topography is required, and seismic surveys are used to collect sub-ice-shelf data and to test the depths of subglacial lakes.

Below is a typical profile from a raw radio-echo sounding plot. The radio waves pass through the ice relatively undisturbed but are reflected by solid rock at the base of the ice. The distance between the sharp rock-ice interface and the ice surface can then be measured to reveal ice thickness.



Artist's impression of ICESat



In some areas, no radar data have been collected. Here, we used spaceborne measurements of the Earth's gravity field to estimate the altitude of the bed. This technique cannot pick out detailed features and can only give a coarse indication of the underlying topography giving an artificially smooth appearance to the bed in the areas it has been used.

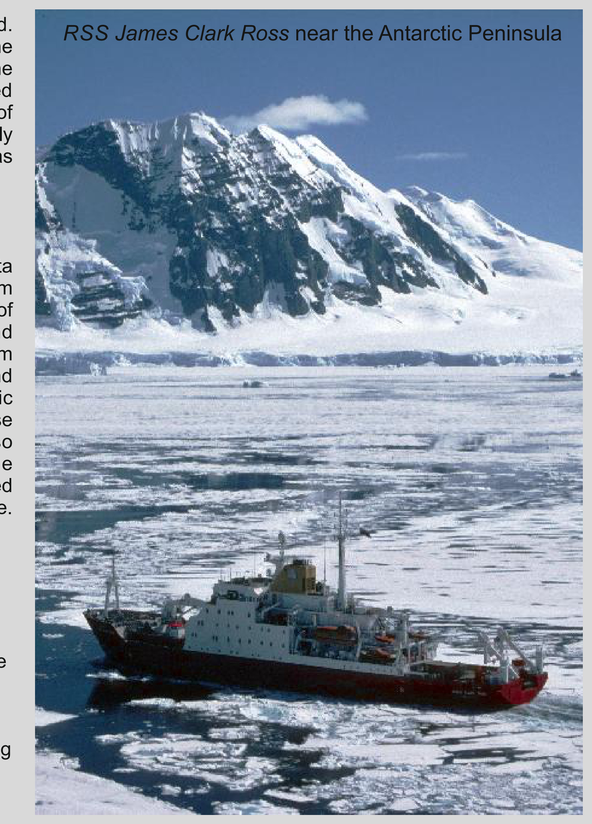
Data collection: surface and ice shelves

We constructed the surface from a number of data types. Over the ice most heights came from satellite measurements. We used a number of satellites such as ICESat (left), SPOT and ASTER platforms, either as raw data or from previously constructed grids. Over rocky and mountainous areas, pre-existing topographic contour data from the Antarctic Digital Database was the main input. Ice shelves were also measured by satellite altimeters and the thickness of these floating shelves was calculated from their density and hydrostatic equilibrium; i.e. the higher the ice surface the thicker the ice.

Data collection: the grounding line

We paid particular attention to locating accurately the grounding line - the area where glaciers flow off the land into the sea to become floating ice shelves. We compiled the latest published data from satellite radar interferometry and image analysis around Antarctica to make the new Bedmap2 grounding line.

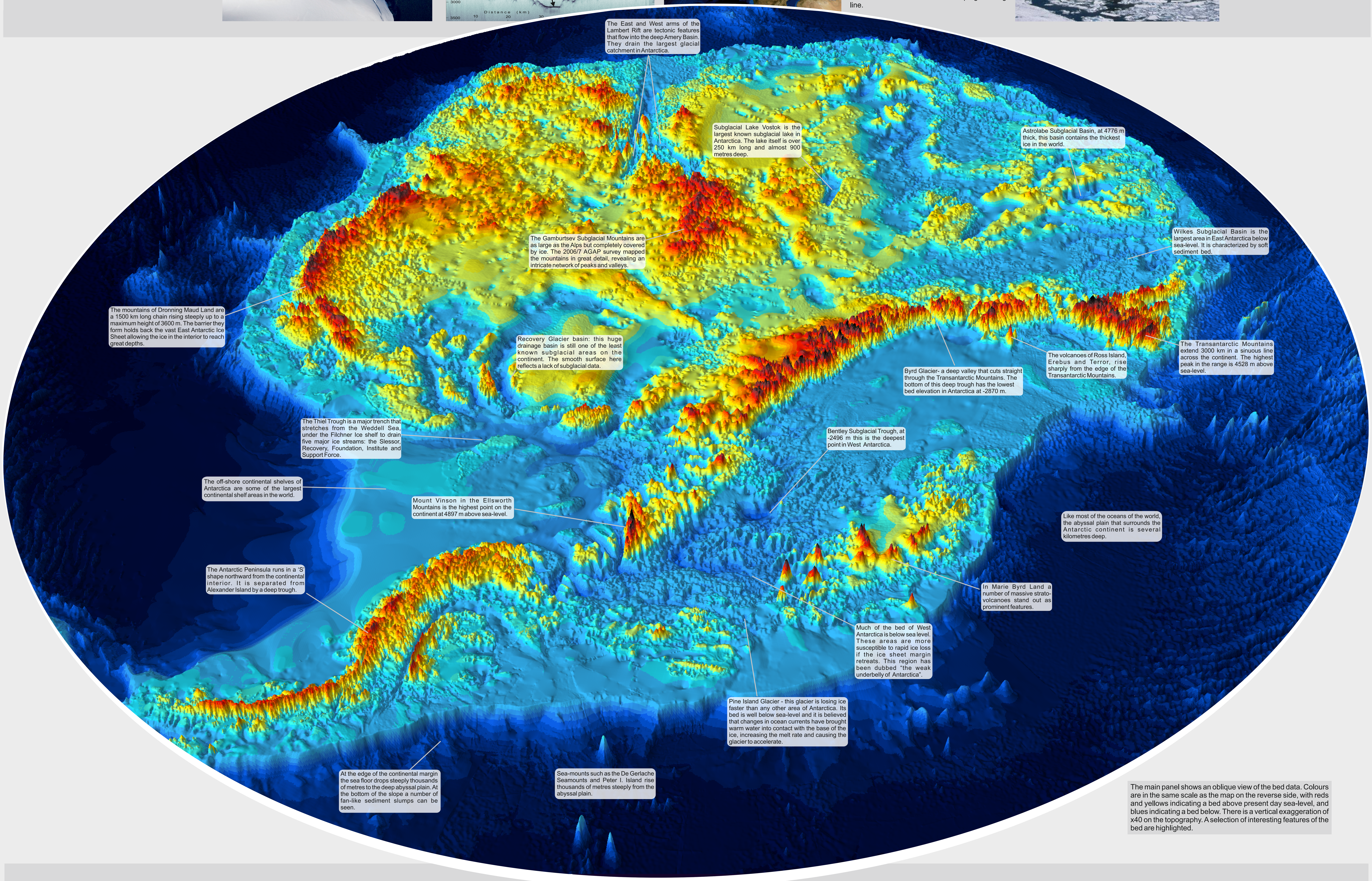
RSS James Clark Ross near the Antarctic Peninsula



Data collection: offshore

We complied a number of pre-gridded offshore bathymetry datasets. These included the General Bathymetric Chart of the Oceans and a number of other smaller grids published since 2008.

The main input for the majority of these grids was swath bathymetry from ships equipped with hydrographic survey systems such as the *RRS James Clark Ross* (left). Some measurements came from single-beam bathymetry collected from simpler ships' instruments, satellite altimetry and, in some cases, seismic and gravity measurements. These grids have been merged with under ice-shelf and coastal data to provide a smooth, seamless final model out to 60° South.



The main panel shows an oblique view of the bed data. Colours are in the same scale as the map on the reverse side, with reds and yellows indicating a bed above present day sea-level, and blues indicating a bed below. There is a vertical exaggeration of x40 on the topography. A selection of interesting features of the bed are highlighted.

Bedmap2 statistics

Area, volume and depth

Number of ice thickness measurements	24.8 million
Number of survey campaigns	207
Number of cells in the final grids	3,490,207
Area including ice shelves (10^6 km^2)	13.924
Area excluding ice shelves (10^6 km^2)	12.295
Ice Volume including ice shelves (10^6 km^3)	26.92
Mean thickness including ice shelves (m)	1937
Mean thickness excluding ice shelves (m)	2126
Thickest ice (Astrolabe Subglacial Basin) (m)	4776
Deepest bed point (Byrd Glacier) (m)	-2870
Area below sea level (10^6 km^2)	5.50
Area below sea level as a % of the total grounded area	44.7
Potential sea-level equivalent (m)	58.3

Potential contribution to sea-level (m)

	Total potential contribution	Potential from ice grounded with a bed below sea-level
Antarctica	58.3 m	22.7 m
East Antarctic Ice Sheet	53.3 m	19.2 m
West Antarctic Ice Sheet	4.3 m	3.4 m
Antarctic Peninsula Ice Sheet	0.2 m	0.1 m

Data for this map has been taken from:

Bedmap2: improved ice bed, surface and thickness datasets for Antarctica

The Cryosphere, 7, 375-393, 2013, doi:10.5194/tc-7-375-2013

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Reference:
Fretwell and Pritchard *et al.* Bedmap2: improved ice bed, surface and thickness datasets for Antarctica. 2013. The Cryosphere, 7, 375-393, 2013, doi:10.5194/tc-7-375-2013

Publication web address:
http://www.the-cryosphere.net/7/375/2013/

website:
www.antarctica.ac.uk/bedmap2

Map compiled by P.T. Fretwell, Mapping and Geographic Information Centre, British Antarctic Survey. March 2013.

ISBN 978-0-85665-205-9

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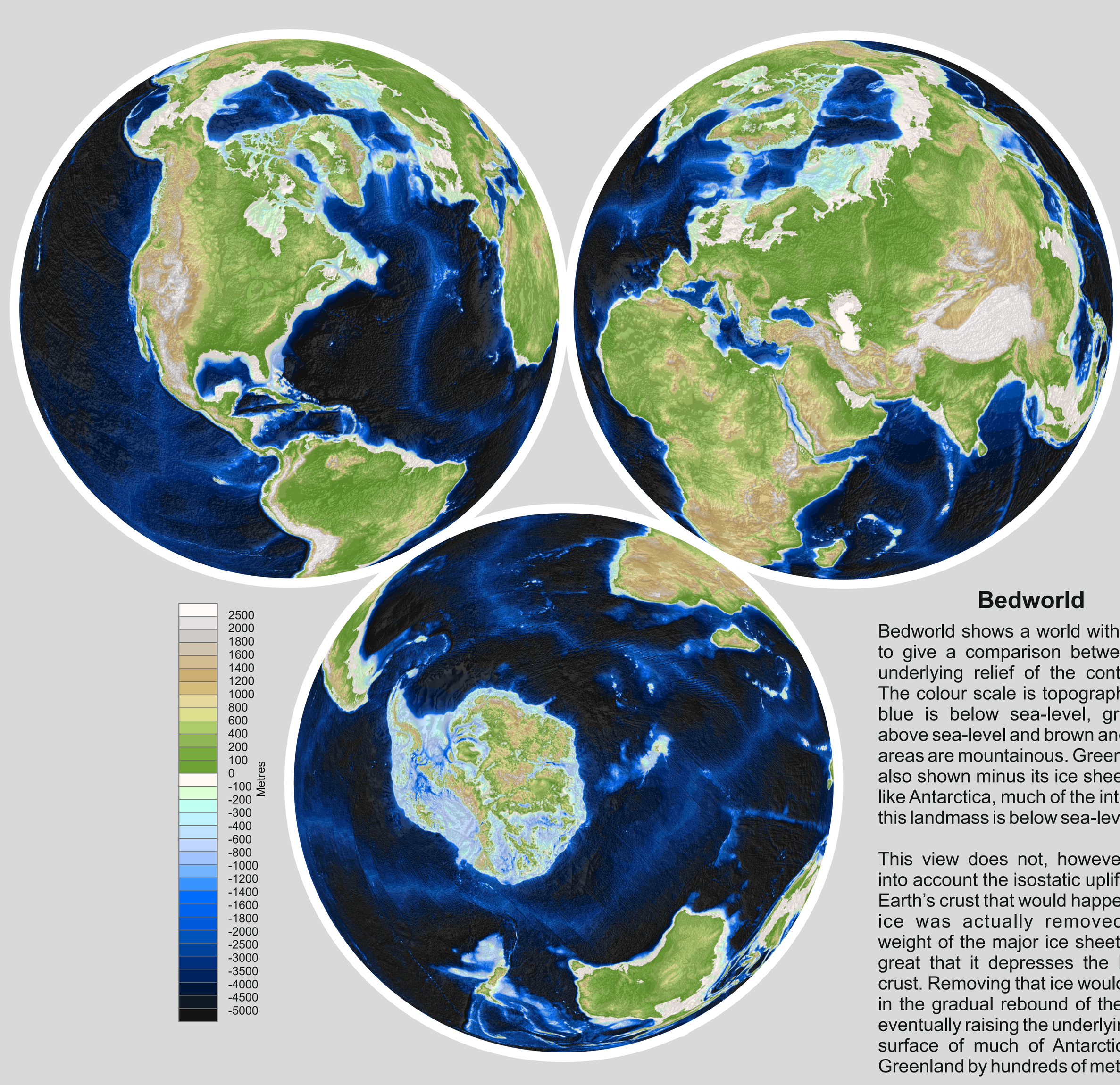


Bedworld

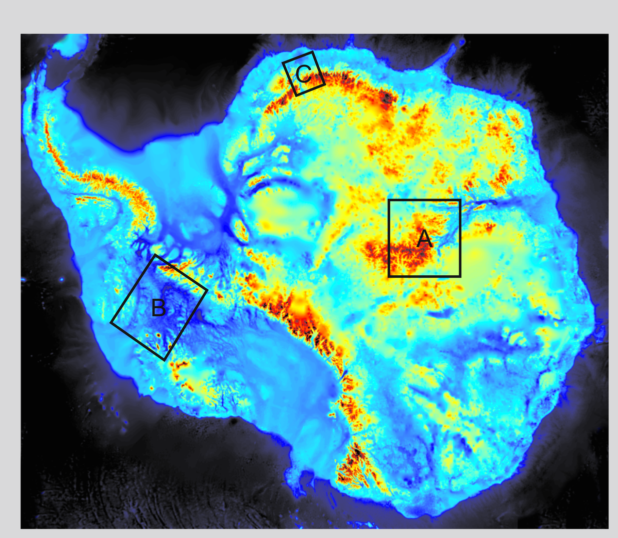
Bedworld shows a world without ice to give a comparison between the underlying relief of the continents. The colour scale is topographic, i.e. blue is below sea-level, green is above sea-level and brown and white areas are mountainous. Greenland is also shown minus its ice sheet, and, like Antarctica, much of the interior of this landmass is below sea-level.

This view does not, however, take into account the isostatic uplift of the Earth's crust that would happen if the ice was actually removed. The weight of the major ice sheets is so great that it depresses the Earth's crust. Removing that ice would result in the gradual rebound of the crust, eventually raising the underlying rock surface of much of Antarctica and Greenland by hundreds of metres.

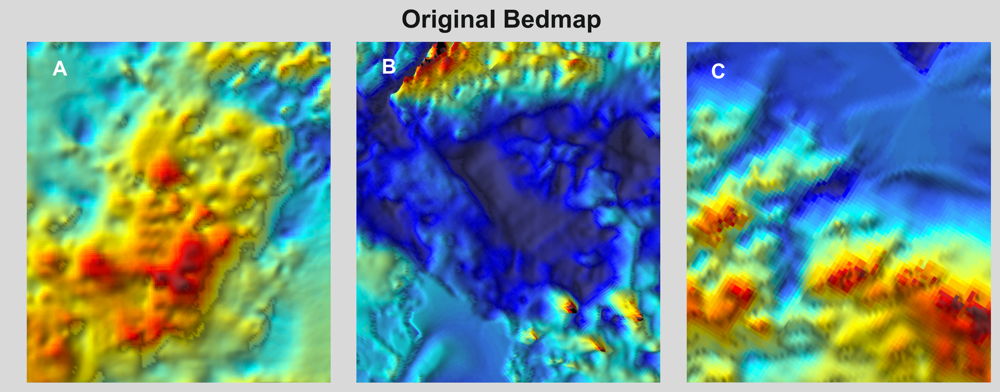
Comparison of Bedmap2 with the original Bedmap

The Bedmap2 project is a follow up to the original Bedmap project published in 2000. Although not the first attempt to map the subglacial environment (the SPRI Folio contained a map of the bed and predated Bedmap by more than fifteen years) the original Bedmap was groundbreaking in its coverage and detail. It used 140,000 survey points from 118 survey campaigns, had a resolution of 5 km and showed many new features previously undescribed.

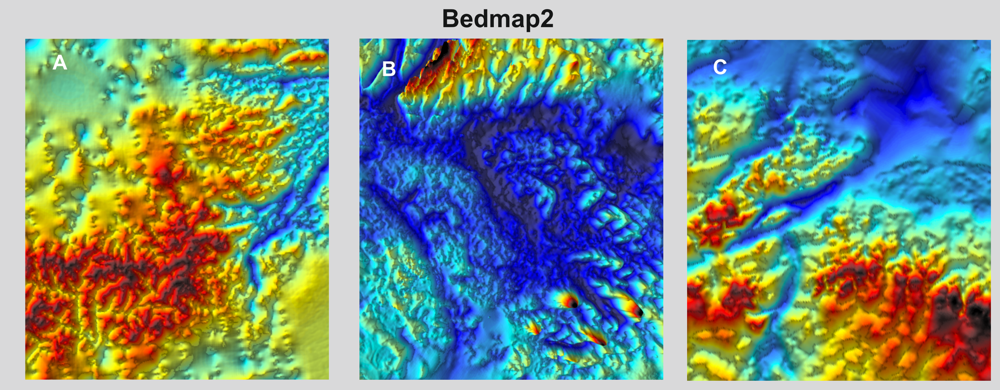
Since the original Bedmap project, there have been many new survey campaigns that have revealed new features and detail in the subglacial topography. Bedmap2 added to the original data set and includes 25 million survey points, nearly 20 times the original number, from 207 survey campaigns. We have now mapped the continent at 1 km resolution and have data in 34% of the 1km grid cells, a doubling of the previous coverage, although in many areas of the continent the sparse data density means that the effective data resolution still remains around 5 km.



Original Bedmap



Bedmap2



The increase in resolution has allowed some features, such as the Gamburtsev Subglacial Mountains, to be mapped in much greater detail but increasing detail is not the only new feature of Bedmap2; many new subglacial environments, like the Lambert Subglacial Highlands, have been map and described in full for the first time.

The maps above show three comparisons between the original Bedmap and Bedmap2. The areas shown are:
A. the Gamburtsev Subglacial Mountains
B. West Antarctica
C. Fimbulisen.

These three comparisons show clearly the improvement in resolution and detail between the two maps.

Uses of Bedmap2

Bedmap2 is more than just a map, the data are essential inputs for modelling the future evolution of the Antarctic Ice Sheet. Some parts of West Antarctica in particular have recently been losing ice, which is contributing to sea-level rise. Statistics calculated from the grids provide new estimates of the amount of ice in Antarctica and the potential sea-level contribution that the loss of this ice could have. Removal of all the ice on the Antarctic continent would raise global sea-level by 58 m .

Bedmap2 shows that the bed of Antarctica is, on average, lower than previously thought and that there is more ice stored in the ice sheet than we had realised. The lower bed also means that much more of the ice sheet is grounded below sea level (an increase in volume of around 23%) . This makes these areas more vulnerable to rapid deglaciation if the ice sheet margins are forced to retreat farther inland.

The cross-section below, taken from the three primary data-sets of Bedmap2, shows the ice surface, ice bottom (the lake surface) and bed of the area around Subglacial Lake Vostok in East Antarctica. Cross sections such as these are easily visualised using the Bedmap2 data-set.