New magnetic anomaly map of East Antarctica and surrounding regions

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Abstract More than 500,000 line-km of new airborne and shipborne data, recently acquired by the international community over East Antarctica and surrounding regions, significantly upgrade the Antarctic Digital Magnetic Anomaly Project (ADMAP) compilation and lead to substantial improvements in magnetic anomaly pattern recognition. New data have been matched in one inverse operation by minimizing the data differences for the areas of overlap. The aeromagnetic data show many previously unknown magnetic patterns, lineaments and trends, defining the spatial extent of Ferrar volcanics and plutonic Granite Harbour Intrusives in the Transantarctic Mountains and previously unknown tectonic trends of the East Antarctic craton. Regional aeromagnetic investigations have successfully delineated Early Paleozoic inherited crustal features along the flanks of the West Antarctic Rift System and the southern boundary of the Archean Ruker Terrane in the Prince Charles Mountains. Magnetic records along the East Antarctic continental margin provide new constraints on the breakup of Gondwana.

Citation: Golynsky, A., D. Blankenship, M. Chiappini, D. Damaske, F. Ferraccioli, C. Finn, D. Golynsky, A. Goncharov, T. Ishihara, S. Ivanov, W. Jokat, H. R. Kim, M. König, V. Masolov, Y. Nogi, M. Sand, M. Studinger, R. von Frese and the ADMAP Working Group, New magnetic anomaly map of East Antarctica and surrounding regions in Proceedings of the 10th ISAES, edited by A. K. Cooper and C. R. Raymond et al., USGS Open-File Report 2007-1047, Short Research Paper 050, 4 p.; doi:10.3133/of2007.srp050

Introduction

Given the extensive ice cover, magnetic surveying is the most effective method to characterize broad areas of sub-ice basement and expand our knowledge of Antarctica. Anomalies arising from the magnetic character of rocks in the earth's crust have revealed many aspects of earth processes and geodynamics, and mapping them comprehensively has been an integral part of many Antarctic expeditions for more than fifty years.

The first generation of the magnetic anomaly map of Antarctica reveals terranes of varying ages, including Proterozoic-Archaean cratons, Proterozoic-Palaeozoic mobile belts, Palaeozoic-Cenozoic magmatic arc systems and other important crustal features (Golynsky et al., 2006a). The map delineates intra-continental rifts and major rifts along the Antarctic continental margin, the regional extent of plutons and volcanics, such as the Ferrar dolerites and Kirkpatrick basalts.

The ADMAP database was produced from air, shipborne and satellite magnetic observations by the international working group of the Antarctic Digital Magnetic Anomaly Project (ADMAP). More than 1.5 million line-kilometres of near surface magnetic recordings were used in the construction of the map (Golynsky et al., 2001). The compilation merged available magnetic survey data collected by the international community from the IGY 1957-58 to 1999. Merging the accumulated anomaly data from marine, aeromagnetic and satellite observations provides a unique continental-scale magnetic anomaly view on the tectonic evolution of the Antarctic crust.

At present, the ADMAP Working Group is working to i) develop a DVD with its point data compilation up to 1999 for release to the World Data Centers, ii) implement ADMAP's protocols and to maintain and update the database as new magnetic survey data become available, iii) improve models of the Antarctic core field, iv) compile rock magnetic and other physical properties to support geological applications of the ADMAP database, and v) support the World Magnetic Anomaly Map initiative of the International Association of Geomagnetism and Aeronomy.

New data sets

Several international programs have focused on the first-order geophysical mapping of tectonic and geologic structures in the interior of East Antarctica and along its continental margins. As shown in Figure 1, they have resulted in a large amount of aero- and shipborne magnetic surveying since the end of the last century.

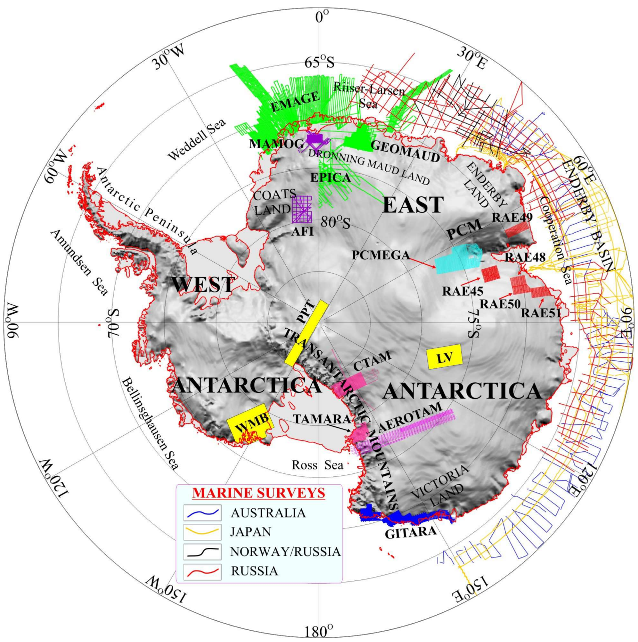

Figure 1. Line coverage of recently acquired near surface magnetic surveys used in this study. Map projections throughout this paper are polar stereographic. The coastline is from the Antarctic Digital Database. See Table 1 for survey specifications. PCM – Prince Charles Mountains.

One of the largest aeromagnetic datasets was collected by the Alfred Wegener Institute (AWI) over western Dronning Maud Land (DML) and its continental margin since the austral summer of 1996/97 (Jokat et al., 2003). Within the East Antarctic Margin Aeromagnetic and Gravity Experiment (EMAGE) project, a total of 90,000 km of aeromagnetic data were acquired along a 1200 km long segment of the East Antarctic coast. The aircraft flight pattern between 18°W and 8°E was extended by two helicopter surveys (~20,000 km) during the 1999/2000 season.

Traditionally the Indo-Antarctic continental margin is the sphere of scientific interest of Australian, Japanese, and Russian researchers who conducted several recent cruises into this region. The programs of the Polar Marine Geological Research Expedition (PMGRE, Russia) and Geoscience Australia (GA) acquired an integrated geophysical survey dataset including seismic, gravity and magnetic information of more than 50,000 and 20,000 line-km, respectively, along the continental margin of East Antarctica, west of the Astrid Ridge to George V Coast of Victoria Land (Gandyukhin et al., 2006, Stagg et al., 2005). Similar sets of geophysical data were collected by the Norwegian/Russian and Japanese expeditions in the Cosmonaut and Cooperation Seas (e.g. Joshima et al., 2001).

Aeromagnetic flights over East Antarctica have concentrated in the major regions of the Transantarctic Mountains (TAM), the Prince Charles Mountains-Lambert Glacier area, and western Dronning Maud Land – Coats Land. Additionally two surveys were acquired over Lake Vostok and in the western part of Mary Byrd Land. The majority of these projects ultimately succeeded in simultaneously operating and integrating laser altimetry, ice-penetrating radar, gravity, and magnetics aboard survey aircraft/helicopters (Figure 1; Table 1).

Map compilation

Evaluation of the creditability of any magnetic anomaly compilation depends on characterizing the input data and procedures used for their processing. The processing of recently acquired data was achived in several consistent steps. First, the processing of all recently acquired shipborne surveys by the PMGRE were re-examined. The magnetic data were edited for high-frequency errors, levelled and adjusted, and the data quality assessed by statistical analysis of the crossover errors. The mean square error (MSE) for these datasets varied from 2.5 to 12.0 nT, and suggested that these shipborne surveys were some of the highest quality of any carried out in the Antarctic.

Pre-processing of the GA and Norwegian track-lines allowed us to create a new dataset of only the recently gathered GA, NPD and PMGRE information. The subsequent cross-over analysis showed that they are levelled accurately. An internal adjustment of unified data set was performed iteratively by applying to the GA and NPD lines constant magnetic offsets derived from a cross-over analysis. The MSE of the combined dataset does not exceed 11.9 nT. This result would not be possible in the absence of the tie-lines conducted by the PMGRE within individual surveys and between neighboring surveys. This result ensured us that the new unified dataset can be used as a base net for the subsequent levelling of other information collected by international institutions along the East Antarctic continental margin.

Thus, a new compilation for the marine study area was produced which contained the above mentioned datasets, the Japanese (JARE40-42, TH98-99) lines, and all previous ADMAP marine magnetic profiles. An internal adjustment of the data set was done in similar way to the earlier line-network adjustment. Successive data gridding and imaging was used to examine the spatial correlation of magnetic lines and to identify the erroneous lines that may produce extreme distortions of magnetic anomalies. Levelling the united dataset for the entire study area reduced the initial MSE from 60.8 to 20.6 nT.

The patchwork merging of recently acquired aeromagnetic data with the ADMAP surveys requires levelling adjustments. These procedures were treated individually according to whether the survey data were available in grid form or as profiles. Large overlapping areas between the PMGRE and PCMEGA profile data in the Prince Charles Mountains (PCM) region allowed us to determine a datum shift between individual surveys rather accurately (138 nT). The irregular networks of older regional profiles over the Transantarctic Mountains were re-levelled using the CTAM project data. Other sets were knitted together by their overlapping areas. The final compilation merged the aeromagnetic and marine grids to create the master grid over East Antarctica and surrounding areas with minimal mismatch between the data sets along their boundaries as shown in Figure 2. The adjusted magnetic data were interpolated onto a 5 km grid using a minimum curvature algorithm.

Lithospheric magnetic anomalies were extracted from CHAMP satellite data and merged with ship and airborne magnetic surveys compiled within this study. Employing spectral correlation theory to filter the static lithospheric field components from the dynamic external field effects, we processed the CHAMP satellite magnetic observations for an improved magnetic anomaly map of the Antarctic crust. These results greatly facilitate predicting magnetic anomalies in the regional data coverage gaps (Kim et al., in press).

Table 1. Specifications of new airborne (1) and shipborne (2) surveys used in this study.

Organisation	Project	Country	Year	Line-km	Line spacing, km	Reference
[1]AWI	EMAGE	Germany	1996-2002	110,000	10/20	Jokat et al., 2003
[1]AWI	EPICA	Germany	1996-1999	13,600	variable	not published
[1]BAS	MAMOG	Great Britain	2001/02	15,500	1	Ferraccioli et al., 2005
[1]BAS	AFI	Great Britain	2001/02	5,000	30	Shepherd et al., 2006
[1]BGR	GEOMAUD	Germany	1995/96	14,800	4.4	Damaske, 1999
[1]BGR/U.Genova	GITARA	Germany/Italy	1999-2000	19,000	4.4	Damaske et al., 2003
[1]BGR/U.Melb	PCMEGA	Germany/Australia	2002/03	29,800	5	Damaske & McLean, 2005
[1]PMGRE	RAE45-50	Russia	2000-05	27,900	5	Golynsky et al., 2006b
[1]SOAR	PPT	USA	1998/99	13,000	10	Studinger et al., 2006
[1]SOAR	WMB	USA	1998/99	37,000?	5.3/10.6	Luyendyk et al., 2003
[1]SOAR	AEROTAM	USA/Italy	1999-2000	21,000	5.3/10.6	Studinger et al., 2004
[1]SOAR	Lake Vostok	USA	2000/01	20,000	7.5	Studinger et al., 2003
[1]USGS/BGR	CTAM	USA/Germany	2003/04	32,000	1.25/2.5	Anderson et al., 2006
[1]USGS/BGR	TAMARA	USA/Germany	1997/98	14,100	2.5	Damaske et al., 2002
[2]GA	AASOPP	Australia	2001/02	20,000	80-100	Stagg et al., 2005
[2]JNOC/GSJ	TH98-99	Japan	1998/2000	15,000	variable	Joshima et al., 2001
[2]NIPR	JARE40-42	Japan	1999-2001	39,700	variable	not published
[2]NPD/PMGRE	NPD/PMGRE	Norway/Russia	2002-04	8,000	variable	not published
[2]PMGRE	RAE41-50	Russia	1996-2005	50,000	70-80	Gandyukhin et al., 2006

Tectonic implications

The more than 240,000 line-km of new terrestrial magnetic observations for the East Antarctic continental margin lead to essential improvements in definition of magnetic anomaly patterns compared to the first ADMAP compilation. Aeromagnetic data collected by the AWI along the eastern Weddell Sea and Riiser-Larsen Sea continental margins provide new constraints on the timing and geometry of the early Gondwana breakup (Jokat et al., 2003).

Results of the compilation do not radically alter recent models describing first-order motion between the Antarctic, Australian and Indian plates, but they help resolve uncertainties about the early break-up histories of opening between these plates. It is highly likely that spreading in the Enderby Basin occurred around the same time as anomalies M10 to M0 were formed off the Perth Basin, Western Australia (Gandyukhin et al., 2006; Gaina et al., 2003). The history of the early spreading is complicated by the likelihood of one or several ridge jumps in which most of early seafloor crust was transferred to the Antarctic plate. Additionally, a large amount of the oceanic crust is now probably overprinted by igneous activity associated with the Kerguelen Plume, which began forming the Kerguelen Large Igneous Province from about 120-110 Ma.

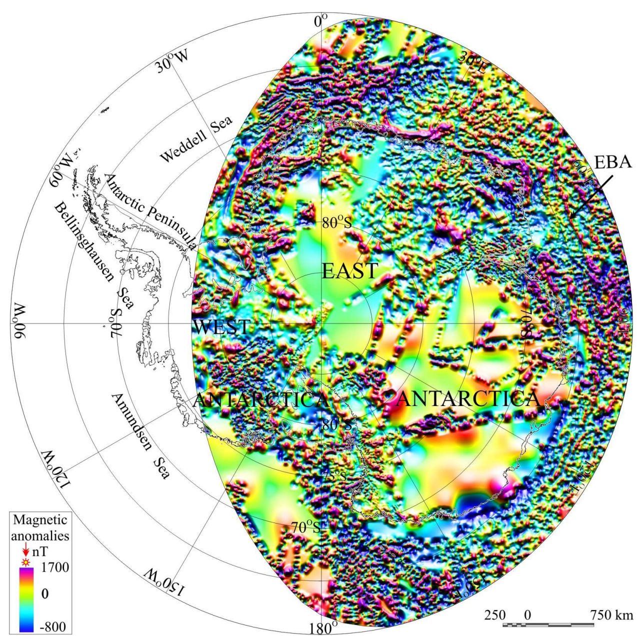

Figure 2. New colour shaded-relief magnetic anomaly map of East Antarctica and surrounding regions. Illumination is from the North at an inclination of 45°. EBA - the Enderby Basin Anomaly. See Plate 1 for large map.

Among other noteworthy peculiarities of the magnetic field is the curvilinear belt of positive magnetic anomalies running parallel with the coast of Enderby Land and MacRobertson Land, which we have named the Enderby Basin Anomaly (Figure 2). It extends from the western margin of Kerguelen Plateau up to the Gunnerus Ridge and appears to be associated with the continent-ocean boundary identified on the basis of seismic data.

Over the continent, the new data allow us to recognize previously unknown magnetic features and patterns including pronounced magnetic lineaments and trends that reveal, for example, the spatial extent of Ferrar volcanics and plutonic Granite Harbour Intrusives in the TAM and other unknown tectonic trends of the East Antarctic craton (Ferraccioli et al., 2005; Golynsky et al., 2006b; Studinger et al., 2003, 2006). Regional aeromagnetic investigations have been successful in delineating Early Paleozoic inherited crustal features along the flanks of the West Antarctic Rift System (Finn et al., 1999; Ferraccioli et al., 2002). The new magnetic data help characterize the sub-ice geology south of the PCM and define more accurately the southern boundary of the Archean Ruker Terrane.

Conclusions

Recent magnetic anomaly data acquired by the international community over the East Antarctica and surrounding regions upgrade the ADMAP compilation substantially. More than 500,000 line-km of new airborne and shipborne data have been matched by inversion to minimize the data differences within overlapping areas. These results provide a new and uniform window through which tectonic structures and lithologies of the East Antarctic Shield can be studied. The new map also shows where gaps in the data coverage still remain, thereby focusing the attention on areas where new data acquisitions would significantly enhance our knowledge of the Antarctic craton.

Acknowledgments. We are grateful to all members of the ADMAP Working Group for their contributions. Peter Milligan and W. Rack are thanked for helpful reviews. Review of the manuscript by Fred Davey is gratefully acknowledged.

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