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First stage of INTRAMAP: INtegrated Transantarctic Mountains and Ross Sea Area Magnetic Anomaly Project

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Abstract
INTRAMAP (INtegrated Transantarctic Mountains and Ross Sea Area Magnetic Anomaly Project) is an international effort to merge the magnetic data acquired throughout the «Ross Sea Antarctic Sector» (south of 60°S between 135°-255°E) including the Transantarctic Mountains (TAM), the Ross Sea, Marie Byrd Land, and the Pacific coast, and also to begin the compilation efforts for new data over the Wilkes Basin. This project is a component of the continental scale Antarctic Digital Magnetic Anomaly Project (ADMAP). The first stage of INTRAMAP addresses the analysis and merging of GITARA (1991-1994) and GANOVEX (1984) aeromagnetic surveys together with ground magnetic data (1984-1989). The combined data sets cover an area of approximately 300 000 km^2 over Victoria Land and adjacent Ross Sea. Map and profile gridding were implemented to integrate the data sets. These approaches are studied for improving existing strategies to adopt for the whole magnetic compilation effort. The final microlevelled grid that we produce is a new tool for regional interpretation of the main tectonic and geologic features of this sector of Antarctica.

Key words *magnetic anomalies – Antarctica – magnetic map compilation – potential field data*

1. Introduction

Within the framework of the evolving ADMAP project (Johnson *et al.*, 1997; Chiappini *et al.*, 1998), an international consortium called INTRAMAP (INtegrated Transantarctic Mountains Ross Sea Area Magnetic Anomaly Project) was initiated at the end of 1997 (Chiappini *et al.*, 1997). Preliminary magnetic anomaly maps considered here were presented at the ADMAP II Workshop held at Istituto Nazionale di Geofisica (ING) between September 29 and October 2, 1997. This project is aimed at compiling and integrating all existing near-surface and satellite magnetic anomaly data collected in Antarctica and surrounding oceans south of 60° S within the Antarctic sector 135-255E (fig. 1) into a digital database.

INTRAMAP is warranted in terms of the huge amount of modern data that are available for compiling the Ross Sea Antarctic sector. In addition, significant geologic and geophysical advantages summarized in the next section may be obtained by integrating near-surface (*i.e.* ship-

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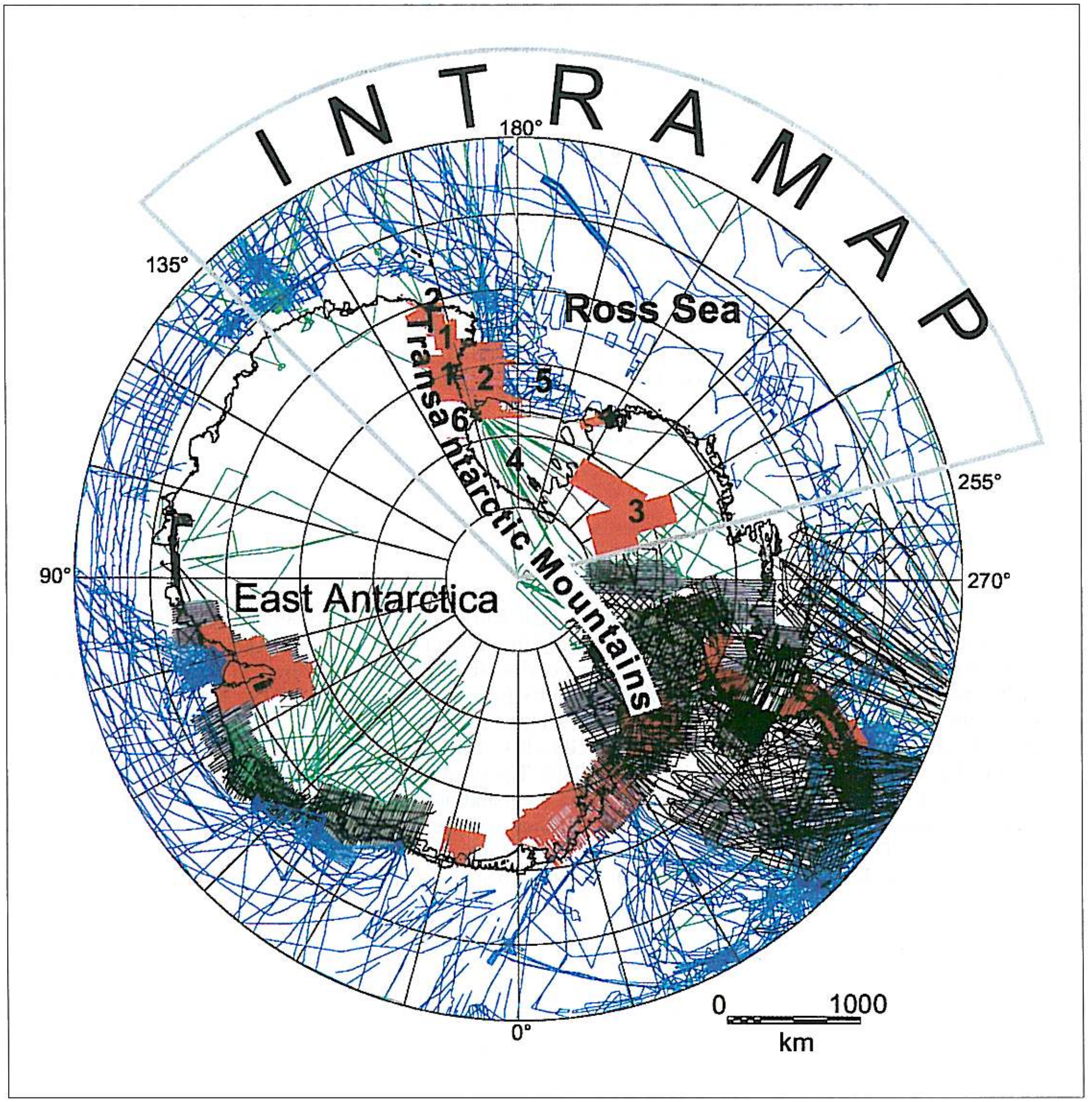

Fig. 1. Location of the INTRAMAP sector within the general framework of ADMAP. Red lines indicate aeromagnetic surveys with line spacing less than 5 km; black lines delineate surveys with line spacing around 20 km; green lines reflect surveys with line spacing of about 50 km; and blue lines show the marine track lines. Numbers 1, 2 and 3 refer to the location of GITARA, GANOVEX and CASERTZ surveys. Numbers 4, 5 and 6 refer to widely spaced profiles of the region, marine magnetic lines and an aeromagnetic survey flown in the Dry Valleys region respectively (Pederson *et al.*, 1981).

Table I. Catalogue of the main aeromagnetic surveys in the INTRAMAP sector (updated from Johnson *et al.*, 1996).

1) GITARA	
Location	Victoria Land, Marie Byrd Land
Type	Helicopterborne
Date	1991-1997
Line spacing	4.4 and 2.2 km (Tie lines 22 km apart)
Survey height	2745 m
Magnetometer	Caesium, towed bird configuration
Line km	35000
Navigation	Beacon, GPS, DGPS
Navigation accuracy	50-10 m
Countries	Italy, Germany
Funding	PNRA, BGR
2) GANOVEX	
Location	Ross Sea, Northern Victoria Land
Type	Airborne and Helicopterborne
Date	1984-1993
Line spacing	4.4 and 8.8 km (Tie lines 22 km apart)
Survey height	3660-2745-610 m
Magnetometer	Proton precession (wingtip), Caesium, towed bird
Line km	76400
Navigation	Doppler, Beacon, INS, GPS
Navigation accuracy	100-50 m
Countries	Germany, U.S.A.
Funding	BGR, NSF
3) CASERTZ	
Location	Central West Antarctica
Type	Airborne
Date	1990-1994
Line spacing	5 km square grid
Survey height	1000 m above terrain
Magnetometer	Proton precession, towed bird
Line km	50000
Navigation	Transponder, DGPS
Navigation accuracy	1 m
Countries	U.S.A.
Funding	NSF

borne, airborne and oversnow) surveys with satellite data. Finally the processing techniques that will be developed are of considerable interest also outside the Antarctic.

The research involves six phases:

1) Acquisition of all available digital magnetic data sets in the region and digitizing all analog, profile and contour data.

2) Integration of individual aeromagnetic surveys.

3) Integration of ground magnetic data with aeromagnetic data.

4) Levelling of marine magnetic profile data to obtain coherent marine magnetic grids.

5) Integration of the merged aeromagnetic-ground magnetic data set with the marine magnetic grids.

6) Evaluation of the use of satellite data for control on the regional scale crustal field.

As shown in fig. 1, the aeromagnetic surveys to be merged were acquired by the GANOVEX and the new GITARA surveys over the Ross Sea, the Transantarctic Mountains and over Marie Byrd Land (Damaske *et al.*, 1994; Bozzo *et al.*, 1997a,b), and also include data collected during the CASERTZ aerogeophysical programmes over West Antarctica (Blankenship *et al.*, 1993; Behrendt *et al.*, 1996) and older profile data distributed throughout the region. Extensive ground magnetic measurements carried out in the area of Terra Nova Bay in Victoria Land (Bozzo and Meloni, 1992) are also available for the compilation. Marine magnetics have been collected in the Ross Sea and in the Pacific Ocean adjacent to Northern Victoria Land and offshore Wilkes Land (*e.g.*, Behrendt *et al.*, 1987; Lodolo and Coren, 1997). Table I presents a catalogue of the main modern aeromagnetic data sources in the INTRAMAP area. A sub-set of Antarctic satellite data (von Frese, 1997) over the Ross Sea region is also available for inclusion in this effort.

In the following sections the geologic rationale for the compilation is outlined, the GITARA 1-2-3 and GANOVEX IV magnetic surveys are reviewed, the re-processing and integration procedures that were applied as a first stage of the INTRAMAP project are considered and the role of INTRAMAP and its procedures for developing the objectives of ADMAP are discussed.

2. Geologic rationale

While a detailed seismic grid allows quite confident geophysical interpretation of the tectonic patterns of the Mesozoic and Cenozoic Ross Sea rift (*e.g.*, Salvini *et al.*, 1997), only few seismic lines image the deep crustal structure of the Transantarctic Mountains (TAM) rift flank (O'Connell and Stepp, 1993; Della Vedova *et al.*, 1997). A recent compilation of gravity measurements over Victoria Land yields new information on crustal thickness and structure of the TAM (Reitmayer, 1997), but many more data are needed for detailed geologic interpretation.

Since rocks of the Ross Sea region have diverse magnetic properties, analysis of the anomalies caused by these rock assemblages can improve knowledge of the geologic, tectonic and geothermal characteristics of this sector of Antarctica. New regional GITARA aeromagnetic data collected over the TAM, for example, highlight several crustal features of the South-central Victoria Land and beneath the ice-covered Polar Plateau margin. These features include the extent and spatial distribution of Jurassic tholeiitic rocks and the existence of a suite of magmatic arc rocks linked to the Paleozoic Ross Orogen (Bozzo *et al.*, 1997a). Previous GANOVEX and marine magnetic surveys over the Ross Sea revealed extensive alkaline volcanism associated with Cenozoic rift fabric trends (Behrendt *et al.*, 1996). Ground magnetic data collected in the Terra Nova Bay region provide ground control for aeromagnetic anomalies and information on magnetic properties of the rocks that is essential for geologic interpretation (Bozzo and Meloni, 1992).

Within this framework, INTRAMAP will allow a view of regional scale magnetic trends that are difficult to observe in individual data sets mentioned above. In fact the merged magnetic anomaly maps will help to connect geologic, seismic and gravimetric studies of the various national and international field programs operating in the Ross Sea region.

Major structural and geologic problems of the Ross Sea Area (fig. 2) that can be investigated with an integrated magnetic data set include the geometric, kinematic, thermal and dynamic

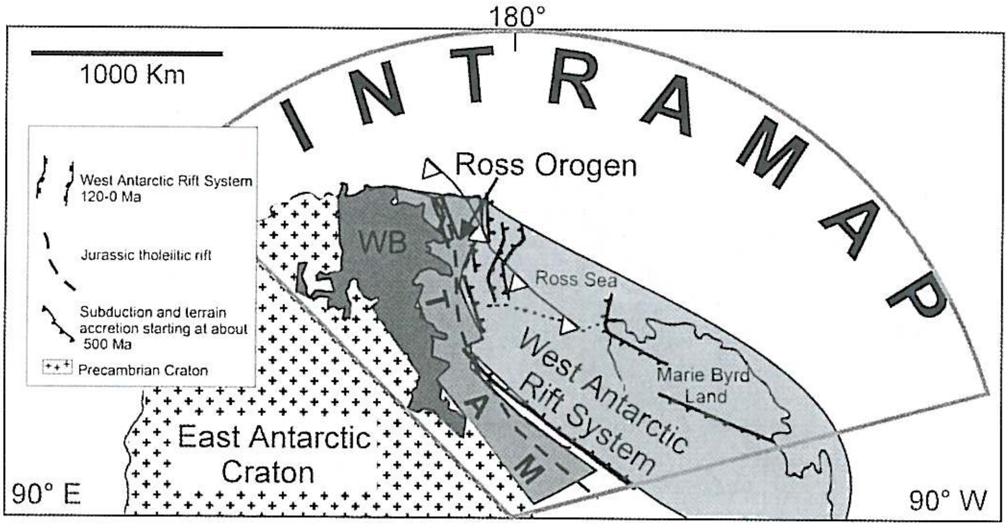

Fig. 2. Regional geology of the INTRAMAP sector of Antarctica.

properties of:

1) The Paleozoic Ross Orogen and Devonian-age magmatic arcs and the terranes that docked against the Precambrian East Antarctic craton.

2) The Jurassic tholeiitic rift rocks including mainly the Ferrar Dolerites and the Kirkpatrick Basalts.

3) The Cretaceous intrusive and volcanic province of Marie Byrd Land.

4) The Cenozoic alkaline magmatism and structures within the West Antarctic rift system and along the TAM.

5) The Wilkes subglacial Basin at the backside of the TAM.

From the geodynamical point of view, the merged magnetic data may reveal separate tectonothermal provinces belonging to the West Antarctic Rift System that in turn could define crustal blocks with differential uplift along the TAM rift shoulder and in Marie Byrd Land. The magnetics could also provide insight towards differentiating the role of active and/or passive rifting in the development of tectonic and magmatic patterns of the West Antarctic rift system (Behrendt *et al.*, 1996) and the role that pre-existing structural and crustal grain may have played in later rifting events.

3. Survey layouts and processing

GANOVEX IV was an airborne aeromagnetic survey flown in 1984/1985 and located between latitudes 72°40′ and 77°30′S and longitudes 154° and 179°E. The TAM sector was flown at 4000 m, while the Polar Plateau section was carried out at 3000 m and the Ross Sea was surveyed at about 610 m above mean sea level. Profiles were acquired at a spacing of 4.4 km for most of the survey areas, while the tie-line interval was 22 km (fig. 3). Proton precession magnetometers in a wing-stinger configuration were used to measure the total magnetic field. Compensation was achieved with active coil compensators. Navigation relied upon a Radar Doppler system, a ground based Trident system and a VLF/OMEGA. Magnetic base stations were installed to monitor magnetic time variations that in general are known to be particularly critical in these areas (Damaske, 1988).

Original processing performed by PRAKLA included: i) pre-processing of aircraft data (errors, double records, spikes and compensation), ii) removal of diurnal variation using low pass filtered base station data and least squares levelling procedures and iii) removal of IGRF 1985.0

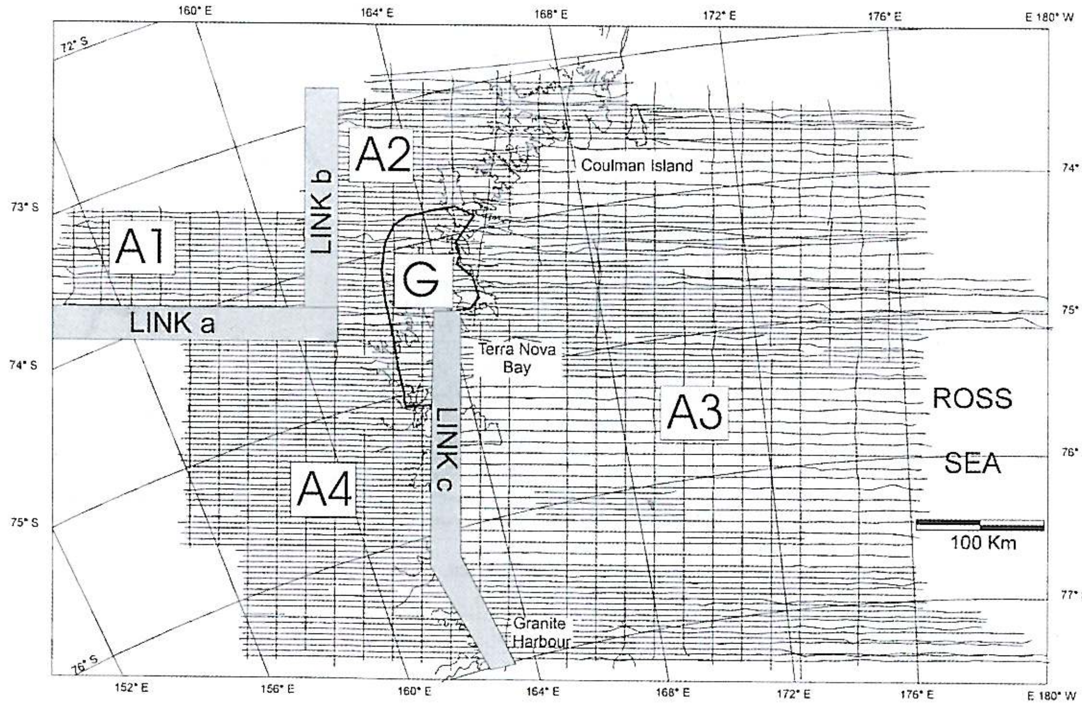

Fig. 3. Flight lines of the GITARA 1-2-3 and GANOVEX IV aeromagnetic surveys over Victoria Land and adjacent Ross Sea. Note also the area of ground magnetic measurements (G). The shaded rectangles highlight areas of overlap between sectors of adjacent surveys. LINK-a is an example of areas of mismatch between overlapping sectors of different surveys flown at the same altitude; LINK-b shows areas of mismatch for the same survey flown at different altitude; and LINK-c gives areas of mismatch between different surveys at different altitudes.

using IGRF 1980 (Peddie, 1983). Empirical DC level corrections were also applied to the regional field that were equal to + 70 nT for the Ross Sea sector, and – 30 nT for the TAM section. The processed data were then gridded with a weighted average procedure with a radius of influence of 5 km from each grid point and a cell size of 440 m. Magnetic anomaly maps at a 1:250000 scale were produced from the final grid (BGR and USGS, 1987). These maps furnished the first coverage of tectonic provinces both within and bordering the Ross Sea (Bosum *et al.*, 1989). Since the 1984/1985 survey several additional aeromagnetic GANOVEX campaigns have been performed that have extended the geophysical reconnaissance of Victoria Land (Damaske, 1994).

Over 400 ground magnetic measurements were also collected in the Terra Nova Bay region during four Italian expeditions (1985-1989). Data processing included removal of diurnal variation, the IGRF (Barraclough, 1987), and elevation corrections. These data were then mapped at a 1:250000 scale (Bozzo *et al.*, 1992).

During the 1991-1994 austral summers, three GITARA (German ITalian Aeromagnetic Research in Antarctica) helicopter-borne surveys were flown. The magnetic data cover an area of approximately 50000 km^2 between Terra Nova Bay and Granite Harbour. Line spacing was 4.4 km for profiles and 22 km for tie lines flown at an altitude of 2700 m. An optical cesium magnetometer in a towed-bird configuration was adopted, while proton precession magnetometers were used as base stations. Three different navigation systems were employed that included: a ground based system (Trident IV) in 1991-1992; a combined ground-based and GPS system in 1992-1993 and a differential GPS system with a positional accuracy of 10 m (Bozzo *et al.*, 1997b) in 1993-1994. Standard processing techniques were applied to the three surveys including: repositioning of flight paths (data gap interpolation, spike removal, comparison of navigation data acquired with different systems), removal of diurnal variation and subtraction of IGRF 1990.0 extrapolated to the appropriate epoch using the coefficents of Langel (1992) and statistical levelling. Microlevelling procedures in frequency domain were also applied to the individual gridded data sets (Ferraccioli *et al.*, 1998). The magnetic anomaly data was gridded by applying a weighted average procedure with a radius of 6 km from each grid point and a grid cell size of 440 m. A 1:250000 scale magnetic anomaly map was compiled over the central-southern part of Victoria Land by from these three GITARA datasets (Bozzo *et al.*, 1997a).

4. Data re-processing and merging

The aeromagnetic grids obtained from the original GITARA and GANOVEX surveys were at first simply placed side-by-side to qualitatively estimate discrepancies between the adjacent magnetic anomaly values at survey boundaries (fig. 4). An ideal compilation aims at improving upon the signal-to-noise ratio of individual data sets, to ensure a smooth undetectable transition from one data set to the other and maintain the correct amplitude and spectral integrity of the magnetic signal in the final map.

Prior to developing a re-processing and merging scheme to integrate the data sets, three different situations were considered: i) areas of mismatch between overlapping sectors of different surveys flown at the same altitude such as in the zone designed LINK-a in fig. 3; ii) areas of mismatch between overlapping regions belonging to the same survey, but flown at different altitudes (LINK-b); iii) areas of mismatch between overlapping regions belonging to different surveys and also flown at different altitudes (LINK-c).

Two different approaches were independently adopted to integrate the data sets: i) re-levelling the profiles; ii) integrating grids. To achieve this, differences at overlapping survey edges were analysed both along profiles (fig. 5a-c) and overlapping grids (fig. 6a-c). The overlapping grids and profiles between the TAM section and the Ross Sea section of the GANOVEX IV are not shown since the peculiarities along this link are similar to those encountered at LINK-b.

By analysing the statistics reported in table IIa-c, it is easy to notice that the largest DC level shift (40 nT) is at LINK-a where flight height is however uniform (figs. 5a and 6a). The regional magnetic field over the GANOVEX Polar Plateau section appears in fact to be 40 nT lower than the one calculated for the GITARA (table IIa), thus indicating that errors in the regional reference field adopted are very likely. It was also noted that shifting the Polar Plateau section

Table IIa-c. a) Statistics of the overlap grid between the GITARA and the Plateau section (PLA) of the GANOVEX IV surveys. b) Statistics of the overlap grid between the Plateau and TAM section surveys of the GANOVEX IV. c) Statistics of the overlap grid between the GITARA and the Ross Sea section surveys of the GANOVEX IV.

LINK-a	Mean	40
GITARA-PLA (nT)	Min.	– 36
	Max	100
ⓐ	SD	20
LINK-b	Mean	– 5
PLA- TAM (nT)	Min.	– 69
	Max	123
ⓑ	SD	16
LINK-c	Mean	14
GITARA- ROS (nT)	Min.	– 124
	Max	88
ⓒ	SD	31

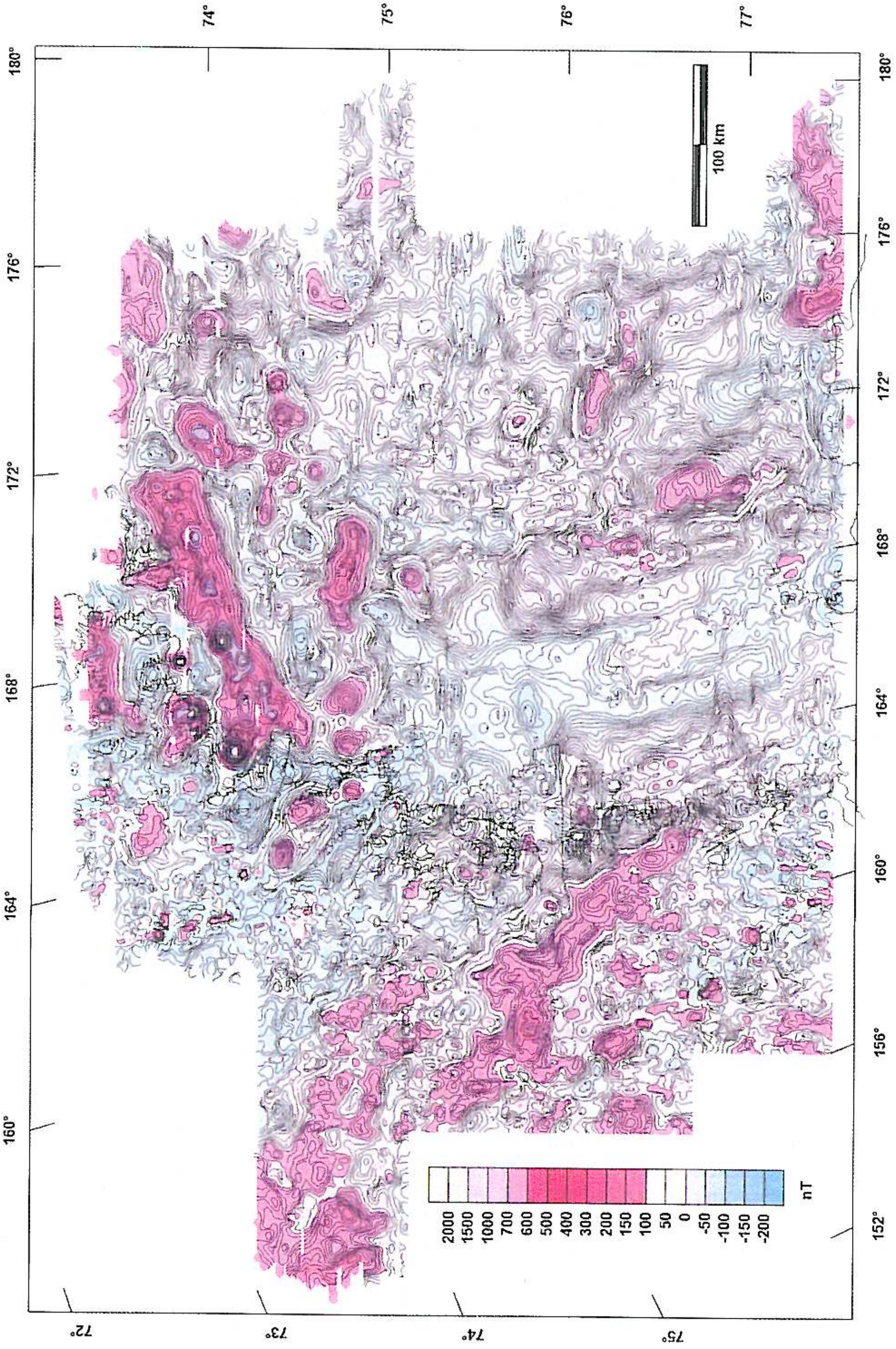

Fig. 4. Original non re-processed grid of the GITARA 1-2-3 and GANOVEX IV aeromagnetic surveys.

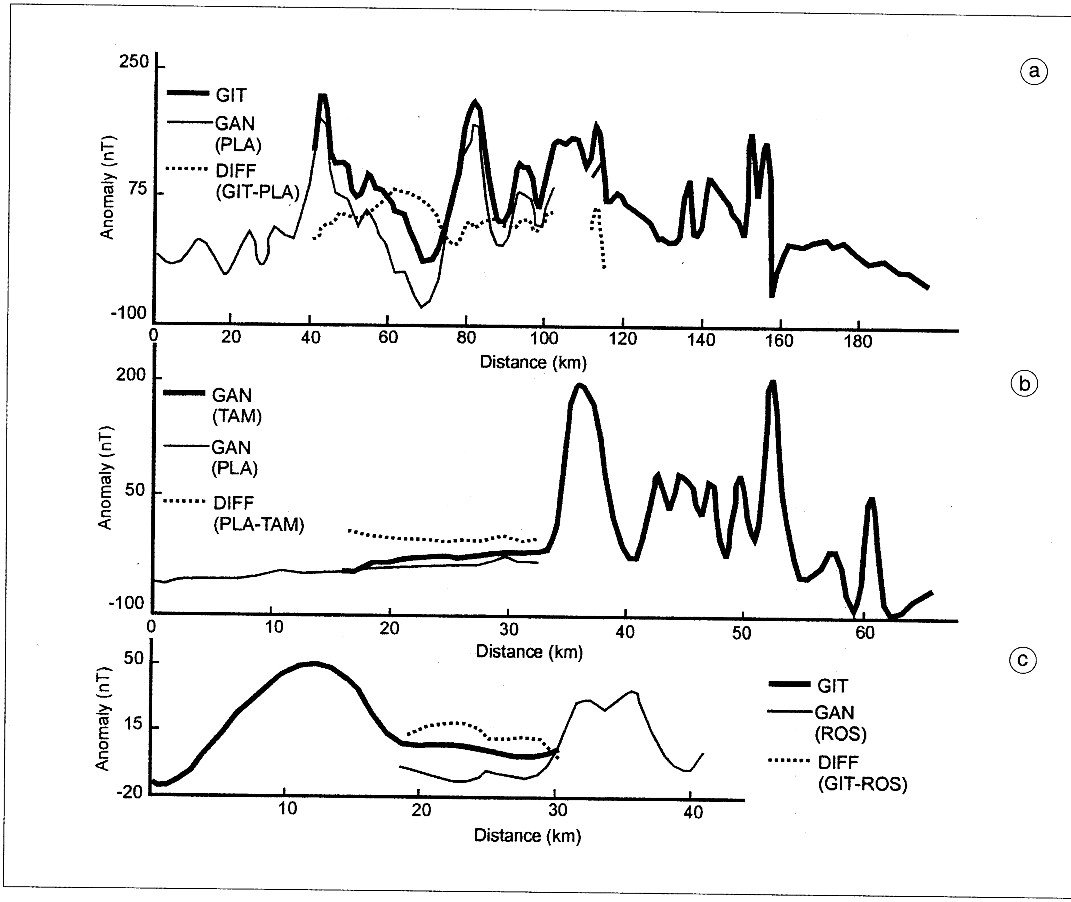

Fig. 5a-c. Profiles at LINK-a, -b and -c respectively. Abbreviations: GIT = GITARA; GAN (PLA), (TAM), (ROS) indicate the Plateau, Transantarctic Mountains and Ross Sea sectors of the GANOVEX IV.

upwards 5 nT would already be sufficient to reduce the mean differences at LINK-b to 0 nT (see table IIb). To reduce mismatches at LINK-b, downward continuation of the TAM section from 4000 m to 2700 m (that is equal to the survey altitude of the adjacent Polar Plateau section) was performed. However this step was found to be very problematic even though an optimum Weiner filter was used to reduce the additional noise due to the continuation itself. Also upward continuation of the Ross Sea sector to 2700 m does not appear to be profitable, since it would result in a great loss of detail over this key region of the rift system (fig. 7). It was thus decided to maintain the data sets at their original height and give greater weight to the more modern GITARA survey in both the profile and grid approach.

In the grid approach we first applied DC level shifts to the different sectors of the GANOVEX IV data to keep the level as close as possible to that of the GITARA data; then a smooth cosine filter was applied to the overlapping regions to reduce the high frequency discrepancies. The smooth correction grid was then sampled along the original lines. Re-levelling of

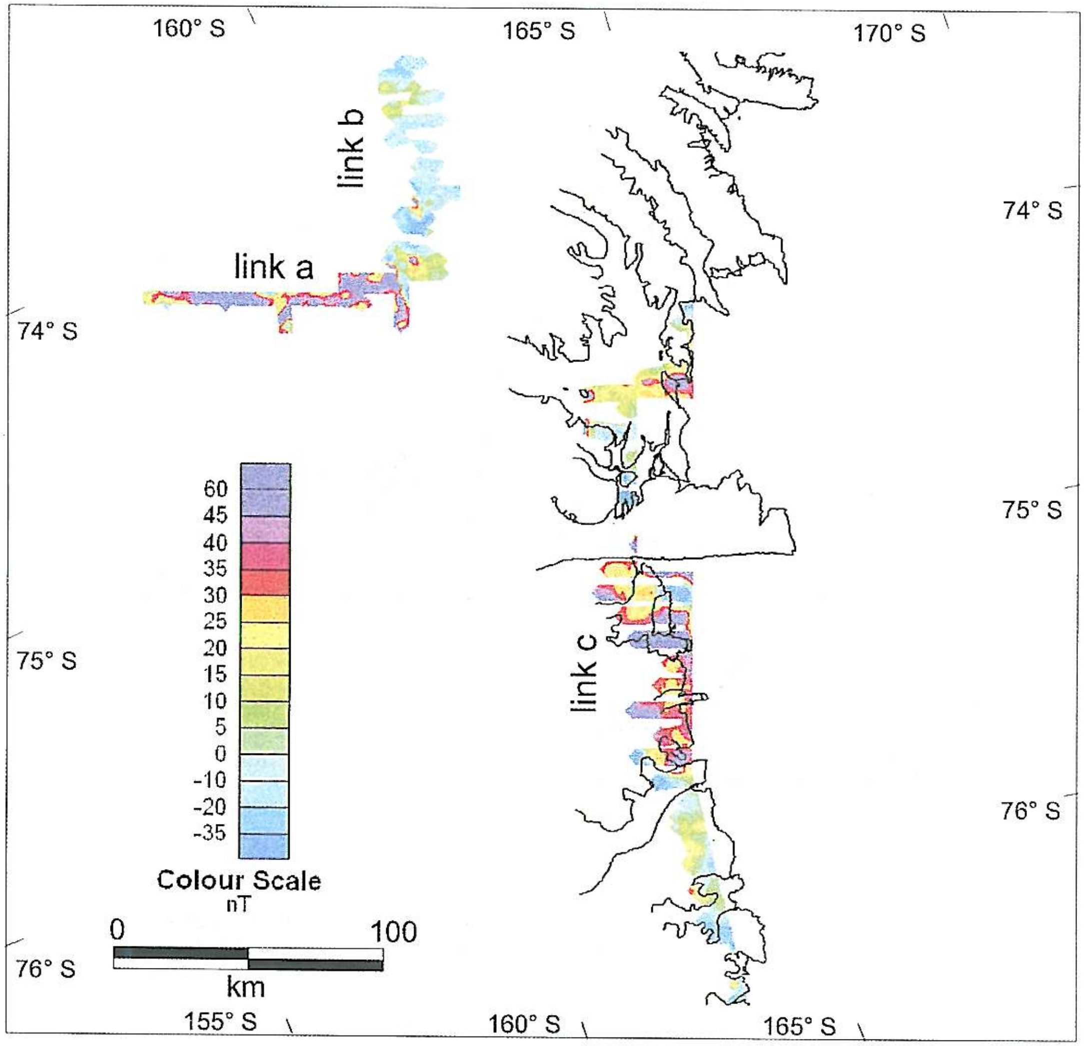

Fig. 6a-c. Overlap grids at LINK-a, -b and -c respectively. The location of the grids is indicated in fig. 3.

some GANOVEX profiles also outside the areas of overlap was necessary since in several sections the old data set was quite noisy. Microlevelling in the frequency domain was also applied, thus improving the signal-to-noise-ratio as was the case for the more recent GITARA surveys (Ferraccioli *et al.*, 1998). The final aeromagnetic grid was obtained by simply applying grid corrections to the individual microlevelled data sets as shown in fig. 8. The result is quite good with no obvious mismatches. An analysis of the results of our first integration is shown in more detail in fig. 9a-c. At LINK-a, the plateau section has been shifted to a higher level, while along the adjacent GITARA profile some anomalies have been slightly smoothed owing to the

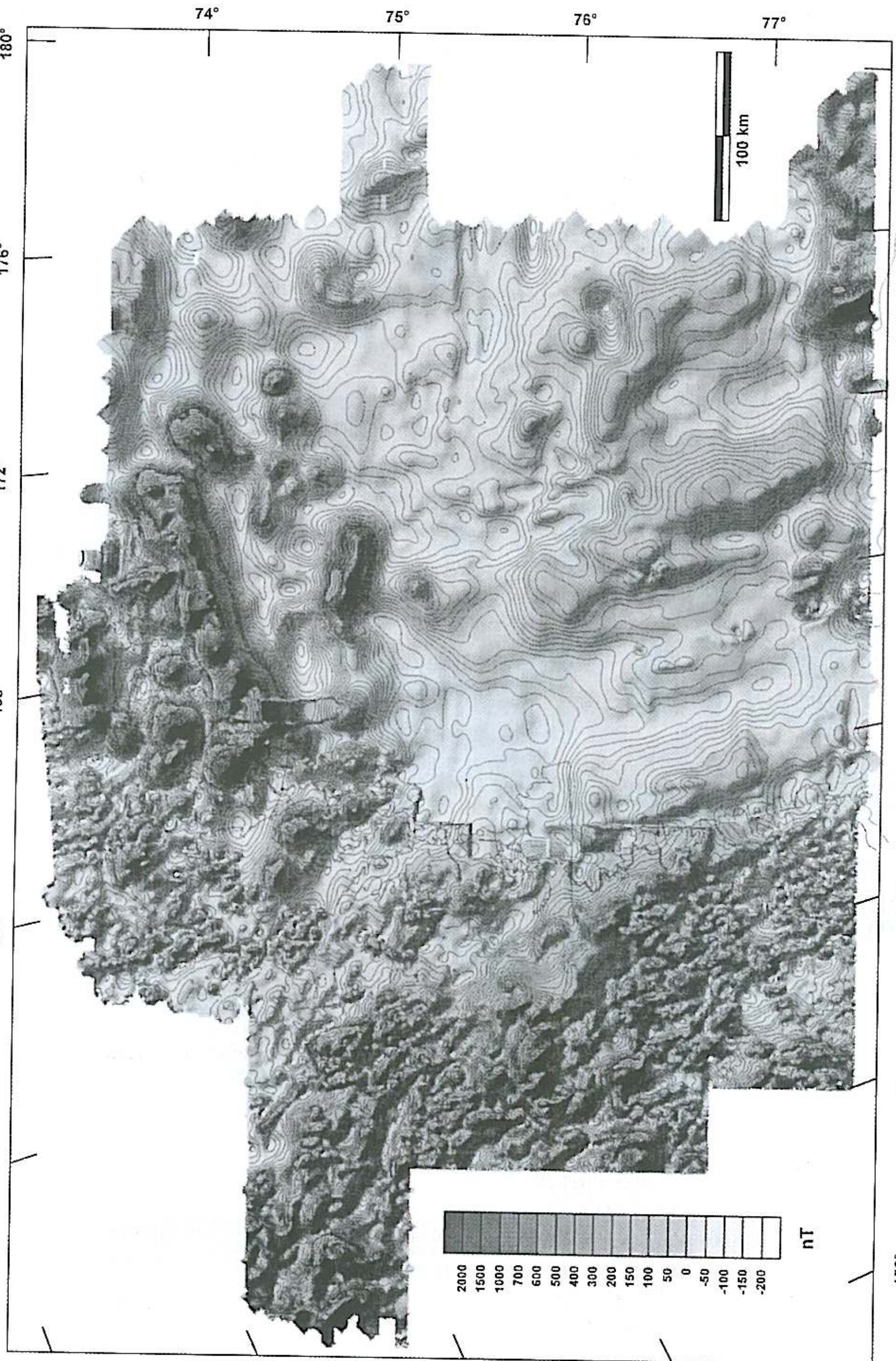

Fig. 7. Magnetic anomaly map obtained by continuation of the original data sets to a common altitude (2700 m).

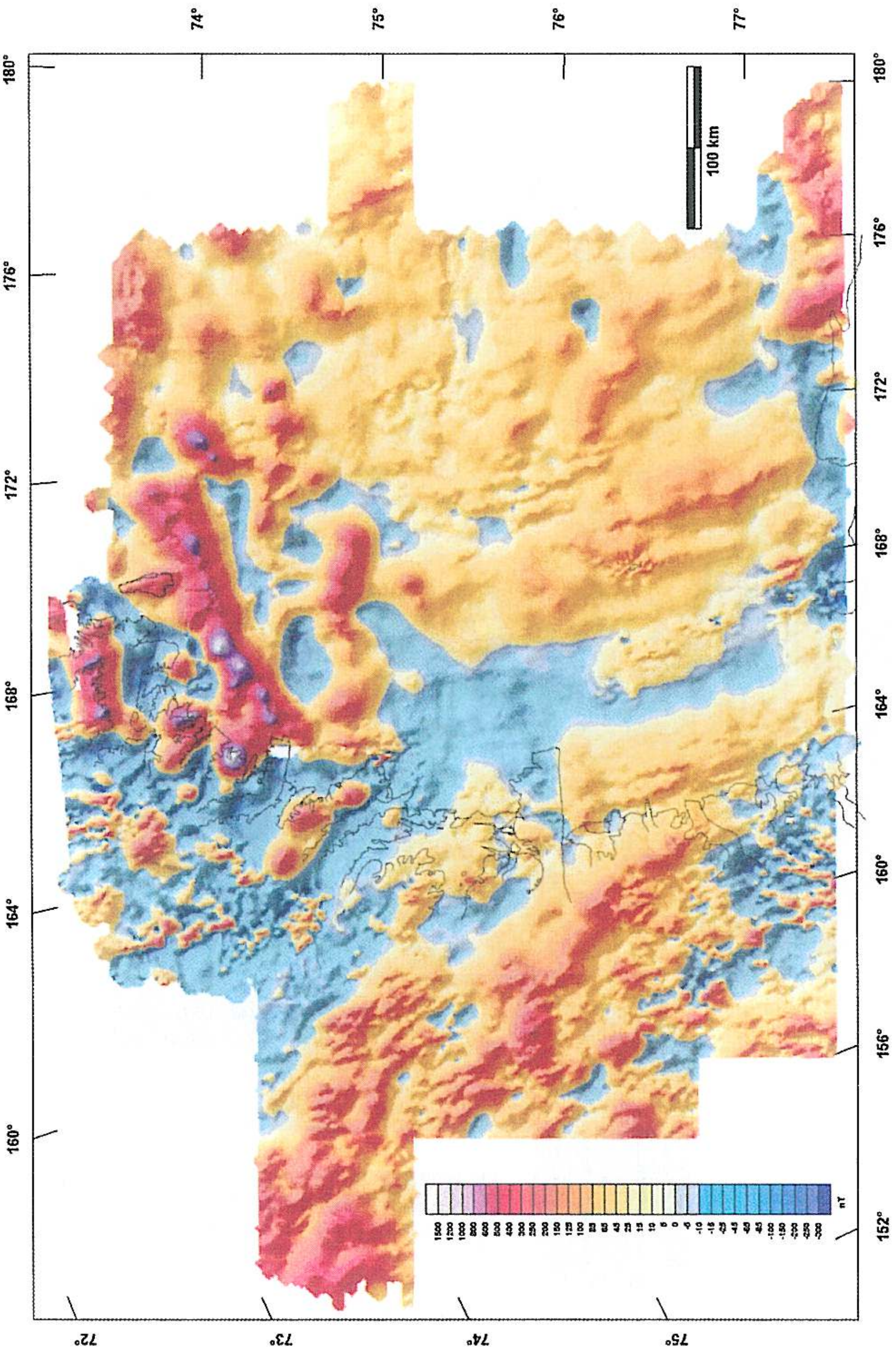

Fig. 8. Shaded relief magnetic anomaly map obtained by smoothing out differences at overlapping grids and microlevelling individual data sets.

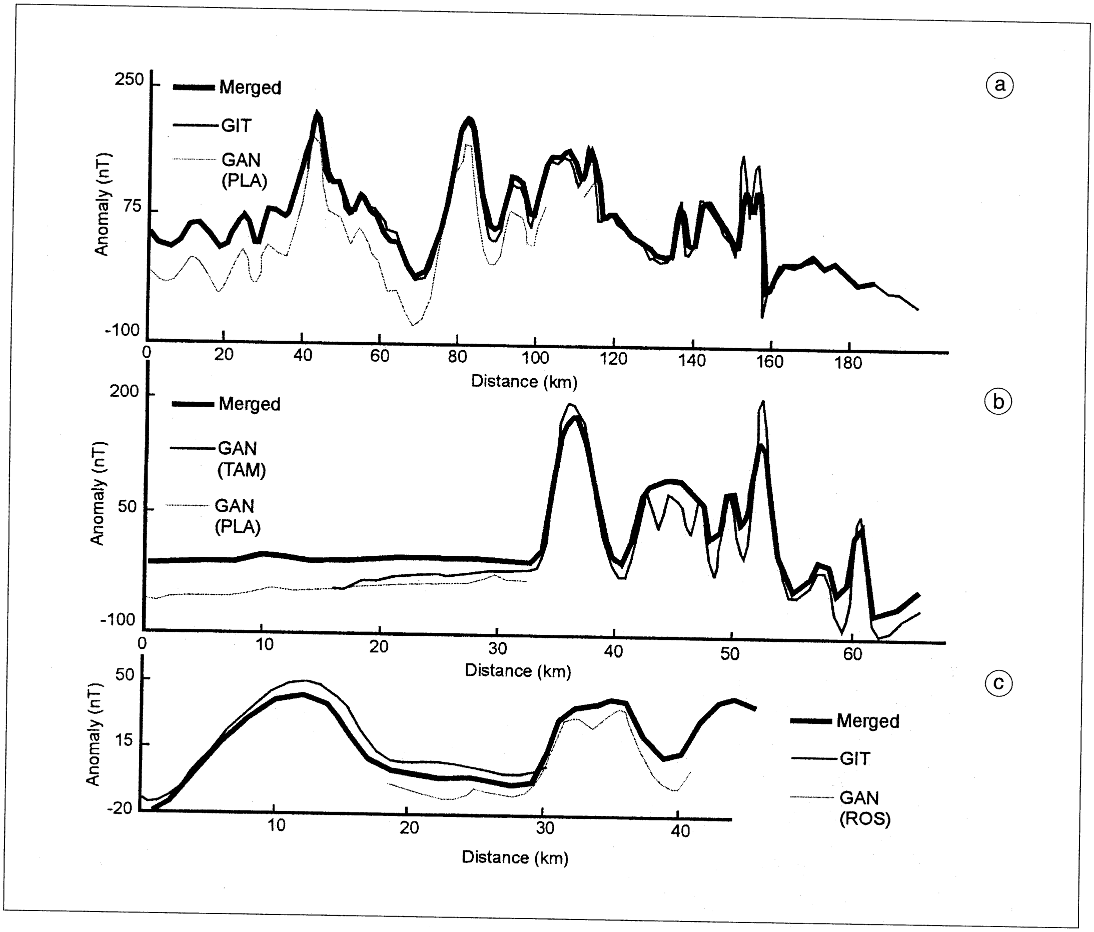

Fig. 9a-c. Results of magnetic integration along profiles at LINK-a, -b and -c.

re-levelling and merging. At LINK-b, the TAM section has been shifted to a higher level. Some high frequency anomalies of the TAM seem to have been excessively smoothed. At LINK-c, the Ross Sea section has been shifted to a higher level.

It should be noted that at the time of the analysis described in the present paper, we had not developed any software procedure to appropriately determine the weighting of one grid against the other or to adequately distribute the corrections in the region of overlap. It was thus decided to also carefully re-inspect the profiles in the region of overlap and re-level the surveys, where necessary, rather than simply relying upon the correction grid. A further effort was devoted to integrating ground magnetic data with the aeromagnetic data set. To perform this effort the ground magnetic grid was sampled along the aeromagnetic profiles. Only individual ground magnetic anomalies differing in amplitude, but showing a high degree of coherency both in terms of wavelength and phase with the aeromagnetic data were selected and included in the database. The resulting grid is shown in fig. 10.

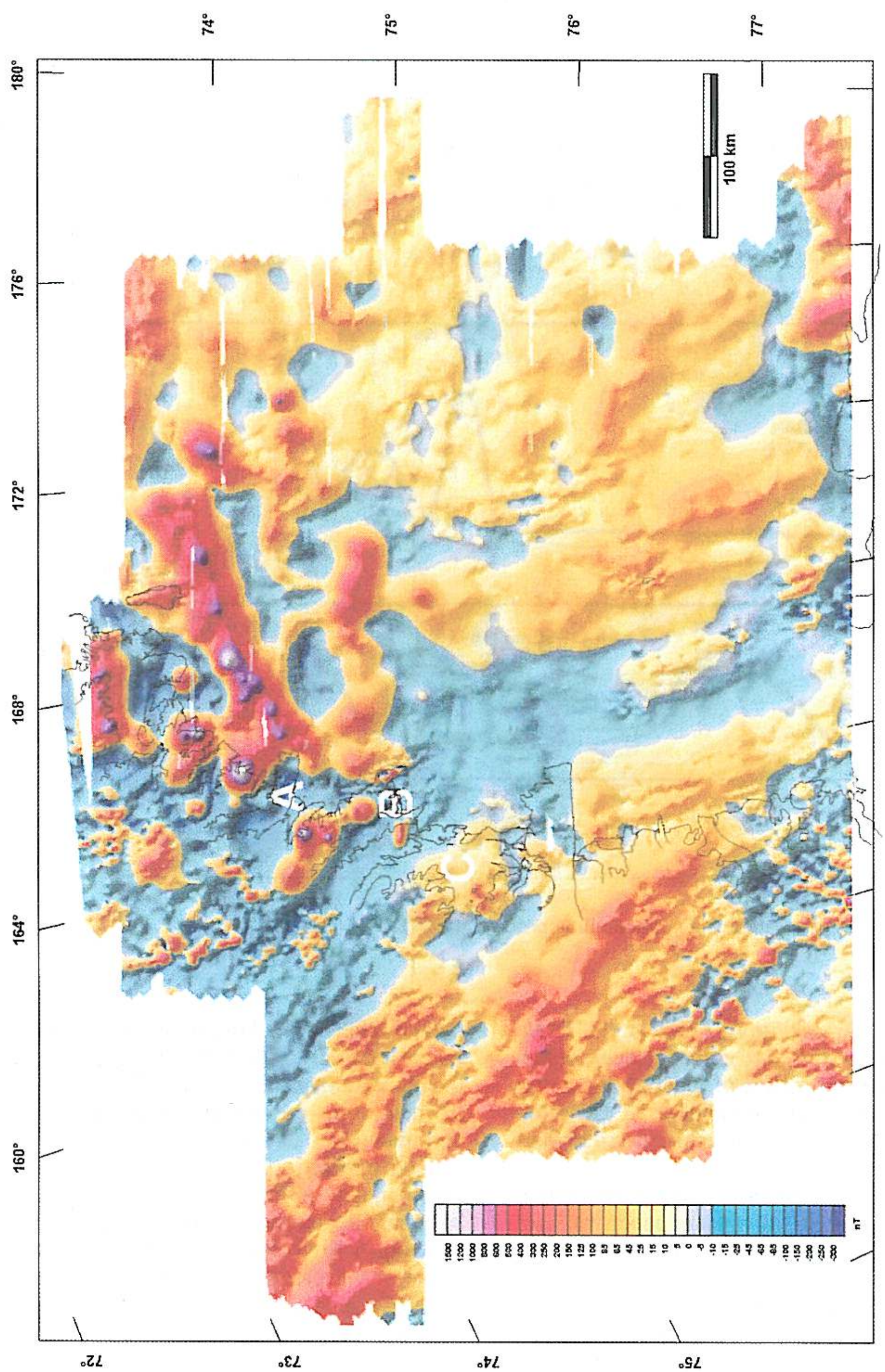

Fig. 10. Final magnetic anomaly map obtained by re-levelling profiles and sampling of ground magnetic anomalies at locations A, B and C.

5. Discussion

This study is a first attempt towards magnetic anomaly compilation in the Ross Sea Area as a contribution towards ADMAP. Though only a small sector has been compiled, the final micro-levelled grid we produced is a fundamental tool for regional interpretation of the main tectonic and geologic features of this sector of Victoria Land and adjacent Ross Sea.

In general, the INTRAMAP sector is a key region for understanding the complex geologic evolution of Antarctica from the Precambrian to the present day. Many of the geologic issues that can be addressed with a magnetic anomaly compilation in this region are of considerable interest also outside the Antarctic community. These include the study of major modern continental rifts, their tectonic and magmatic patterns and their relationship to pre-existing structure.

Much more work is obviously needed to complete the INTRAMAP effort. What we have learned from this first compilation of GANOVEX and GITARA data is that careful re-inspection of profiles, though tedious, is highly profitable to improve upon the older datasets. This step should be carried out prior to the merging of the interpolated data (grids). Our preliminary effort to integrate the re-levelled data sets was found to be very time consuming. It thus appears that there is a great need for programmes to automatically or interactively merge re-processed data sets into a coherent grid (*e.g.*, Johnson *et al.*, 1999).

Work is already underway to find solutions regarding two other large concerns that have become apparent for our efforts to compile the magnetic anomaly map. These concerns include:

i) The choice of a suitable regional geomagnetic reference field. For example, we recognised in our study considerable level shifts even between surveys flown at the same altitude with similar layouts and processed in a similar fashion. These level shifts may well reflect errors in the geomagnetic reference field that was originally adopted.

ii) The problem of reducing the data sets to a common altitude or ideally to a common distance from shallow sources. Simple upward or downward continuation of the data sets does not seem to be a valid solution, because they seem to cause great loss in detail or considerably enhance noise, respectively.

Finally we point out that all magnetic data which will eventually be compiled within the INTRAMAP banner will also be available in standard digital formats via a dedicated Web site. Restrictions will apply following the SCAR/ADMAP protocol that is 3 years after the field season for collaborative projects and 6 years for open non-commercial use of the data sets.

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