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# A High Resolution Aeromagnetic Survey over the Mesa Range, Northern Victoria Land, Antarctica

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**Abstract:** During the GANOVEX X campaign in 2009/10, an aeromagnetic survey was carried out over the Mesa Range in northern Victoria Land. The survey was aiming to resolve the fine structure of the magnetic anomalies over the Jurassic volcanic rocks of the Mesa Range known from previous surveys by reducing the flight line separation and flying in a terrain-following mode. The survey was laid out to prove or disprove the existence of feeder dikes in the Mesa Range. It also targeted the surrounding areas of the upper Rennick Glacier and Aeronaut Glacier to detect whether the volcanics are restricted to the outcropping areas or extend underneath the ice as well as to follow postulated fault lines across and connect them to structures at the fringe of the postulated pull-apart basin, in which the Mesa Range resides centrally.

The outcome of the survey is a high-resolution map, which supports the interpretation of the Mesa Range to be the remnant of an elsewhere eroded plane of flood basalts or sills. No evidence was found for feeder dykes, which were thought to exist in some places and to be detectable through singular, round magnetic anomalies. Thus, it is likely that the sources for the volcanics are not local, but stem from regions a certain distance away from the area investigated.

The volcanics are restricted to the outcrops and there was no indication of fault lines across the neighbouring glaciers.

**Zusammenfassung:** Im Rahmen von GANOVEX X 2009/10 wurde eine Befliegung im Bereich der Mesa Range im zentralen North Victoria Land durchgeführt. Ziel der Vermessung war die Erfassung der Feinstruktur der bekannten magnetischen Anomalien über den jurassischen Vulkaniten der Mesa Range. Dazu wurden die Messlinien in engem Abstand angelegt und in einem möglichst konstanten Abstand über Grund geflogen. Die Anlage der Vermessung sollte ermöglichen, die Existenz von vulkanischen Zufuhrschloten in der Mesa Range nachzuweisen. Das Messgebiet erstreckte sich über die benachbarten Regionen des oberen Rennick Glaciers und Aeronaut Glaciers hinaus, um zu überprüfen ob und wie weit sich die Vulkanite über den aufgeschlossenen Bereich hinaus unter dem Eis fortsetzen. Störungszonen in den Randgebirgen, die das vermutete Pull-apart-Becken, in dessen Zentrum die Mesa Range aufragt, umfassen, sollten durch den eisbedeckten Bereich verfolgt werden.

Das Ergebnis dieser Befliegung ist eine hochauflösende Karte des magnetischen Feldes. Das magnetische Muster unterstützt die Annahme, dass es sich bei der Mesa Range um die Reste einer Flutbasalt-Ebene handelt. Es konnten keinerlei Hinweise auf vulkanische Zufuhrschlote gefunden werden, die nach der älteren Befliegung aufgrund zirkularer Anomalien an einigen Stellen vermutet worden waren. Danach sind die Quellen der Vulkanite nicht lokal zu suchen, sondern weiter außerhalb des Untersuchungsgebietes.

Die Vulkanite sind auf den aufgeschlossenen Bereich beschränkt und Störungszonen unter den benachbarten Gletschern konnten nicht nachgewiesen werden.

## INTRODUCTION

During the GANOVEX IV campaign in 1984/85, an aeromagnetic survey was carried out over parts of northern Victoria Land (Bosum et al. 1989, Bachem et al. 1989a, Bosum et al. 1991, Damaske 1988). The resulting map of the anomalies of the total magnetic field showed a clear signature of the volcanics of the Mesa Range with positive amplitudes of up to 500 nT directly above the outcrops, flanked by negative amplitudes of about -100 nT on both sides of the range (Fig. 1). Small circular high-amplitude anomalies were observed over the Deep Freeze Range (just north if the edge of the Priestley Glacier, see Behrendt et. al 1991) interpreted as caused by exposures of Kirkpatrick basalt. Singular, round-shaped anomalies over some parts of the Mesa Range were often discussed as being the magnetic expressions of feeder dykes for the Jurassic Ferrar dolerites and Kirkpatrick basalts (e.g. Bosum et al. 1989). On the other hand, the relatively wide separation of the survey lines (of 4.4 km) together with the relatively short distance to the magnetic sources – i.e., the volcanics of the Mesa Range – could have led to this effect. In this case, the small round-shaped anomalies (Fig. 1) would have nothing to do with any feeder dykes and are just an effect of insufficient density of survey lines in this area. An unambiguous answer can only be found in a survey with sufficiently small line separation, which is flown in a terrain-following mode. Such a survey would also address the extent of the volcanics underneath the surrounding glaciers and their "thickness", i.e. is there more volcanic material in the Mesa Range area than that of the exposed rocks?

During GANOVEX IX in 2005/06, massive dolerite dykes have been found at the eastern edge of the Aeronaut Glacier (area Mt. Carson-Runaway Hills), which could be interpreted as such feeder dykes for the basalt sheets (Viereck-Götte pers. comm. 2007). They could also relate to the postulated feeder dykes in the Mesa Range. It is also possible that the dykes follow NW-SE orientated fault lines which seem to be constituted as gaps between the Mesa Range sections such as the Pinnacle Gap between Tobin and Pain Mesa (Fig. 2).

The still unanswered major question is whether the basalt sheets in the upper Rennick Glacier area formed by local fissure eruptions or had their source outside the outcrops in the survey area (i.e. outside the Mesa Range itself). To clarify whether feeder dykes can really be observed within the basalt sheets of the Mesa Range and whether the observed fault systems can be traced through the glaciers flanking the Mesa Range, a densely spaced aeromagnetic survey was proposed for the GANOVEX X expedition.

Closely spaced surveys are still an exception in Antarctic airborne research, but their usefulness has been demonstrated in e.g. studies of the Jutulstraumen rift at 1 km line spacing by (Ferraccioli et al. (2005a, b) or in the detailed structural interpretations enabled by high resolution aeromagnetic data (Ferraccioli & Bozzo 2003).

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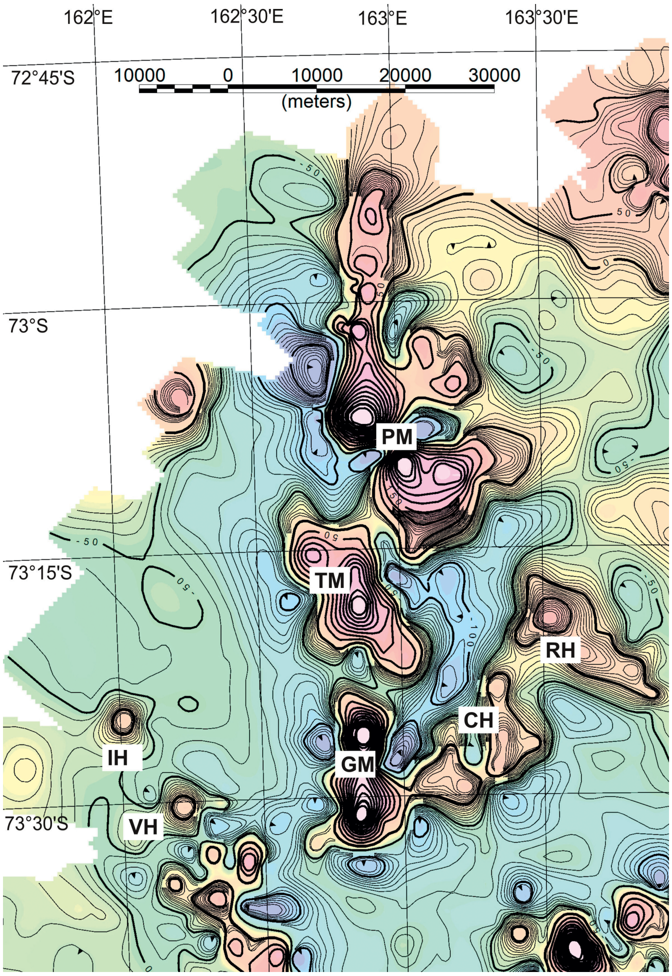


**Fig. 1:** Results from the GANOVEX IV survey (1984/85) show singular round magnetic anomalies over the Mesa Range (Pain Mesa PM, Tobin Mesa TM, Gair Mesa GM) and over neighbouring Chisholm (CH) and Runaway Hills (RH) and Deep Freeze Range (Illusion Hills IH, Vantage Hills VH).

**Abb. 1:** Die Ergebnisse der GANOVEX IV Befliegung (1984/85) zeigen einzelne runde magnetische Anomalien über der Mesa Range (Pain Mesa PM, Tobin Mesa TM, Gair Mesa GM) und den benachbarten Chrisholm Hills (CH) und Runaway Hills (RH) und der Deep Freeze Range (Illusion Hills IH, Vantage Hills VH).

## LAYOUT OF THE SURVEY

To meet the above stated requirements, i.e. closely spaced and terrain following, a helicopter is the most suitable platform to perform the survey. As in earlier high resolution surveys meeting similar requirements (e.g. Bozzo et al. 1997, Wilson et al. 2007), a line spacing of 500 m is considered to be sufficient with tie lines perpendicular to the survey lines every 5 km (ratio 1:10). An envisaged ground clearance of 500 m allows a complete coverage of the anomalies.

The survey area (Fig. 2) covers the central and southern Mesa Range completely. It includes also the Aeronaut Glacier, Runaway and Chisholm Hills in the east and the negative anomalies (mapped in the GANOVEX IV survey) over the upper Rennick Glacier in the west. The survey line orientation is the same as for GANOVEX IV (Bachem et al. 1989b) to allow direct comparison along individual lines. However, one must bear in mind that navigation in 1984/85 was less accurate and that the fixed-wing survey was flown at a constant barometric elevation.

As base for flight planning the USGS Antarctica 1:250 000 Reconnaissance Series topographic maps "Mt. Murchison" and "Sequence Hills" (Lambert conformal conic projection with standard parallels 72°40' S and 75°20' S) were used. The central meridian of 179° E (which determines the survey grid orientation) as well as the reference latitude of 74° 01' 05.2263" S, the false easting of 1123000 m, and false northing of 1444000 m were identical with projection parameters used for GANOVEX IV (Bachem et al. 1989b). Using the geodetic reference system WGS 84 (World Geodetic System) instead of WGS 72 does not make a significant difference when directly comparing the new data along a line with those of the GANOVEX IV survey lines.

## INSTRUMENTATION

An AS350B2 helicopter, owned and operated by Helicopters New Zealand (HNZ), was contracted to serve as the platform for the aeromagnetic survey. The helicopter was also used for logistic operations between the expedition's main base Gondwana Station and the survey camp in the Mesa Range. An extra fuel tank was installed to increase the range of the helicopter.

A Scintrex CS-3 caesium vapour magnetometer was utilised for the survey consisting of sensor head, cable and the sensor electronics. The sensor head was housed in a towed bird assembly and was connected to the bird's BNC connector. The bird was towed on an approximately 30 m long Kevlar reinforced coaxial cable that provided both the input DC power and the output signal at the Larmor frequency which is proportional to the magnetic field signal.

Measurements were made at a sampling rate of 10 Hz, corresponding to a ground interval of about 4 to 6 m, depending on the helicopter speed. All magnetic data were recorded in real-time to the PicoEnvirotec AGIS data acquisition system and then copied from the AGIS-XP computer to the field processing computers for quality control examination.

Position and precise time were recorded using a Novatel DL-V3 receiver with the antenna placed at the front window. At the base camp a GPS (Global Positioning System) base station was installed to obtain corrections for differential GPS post-processing.

Flight information was entered into the GPS database allowing the pilot to accurately navigate between waypoints. When flying in drape mode the elevation was controlled manually by the pilots using the helicopter's radar system and by the navigator aligning with the elevation on the neighbouring lines and tie lines.

## MAGNETIC BASESTATION

Geomagnetic activity on ground (Fig. 3) was monitored with the GEM Systems GSM-19T instrument at the Mesa Range Camp, placed about 100 m from the camp installations (Fig. 4). The station operated nearly continuously from 3 to 19 January 2010. The total magnetic field was recorded every 10 seconds. As known from earlier observations in the northern Victoria Land region (Damaske 1989, 1993) the pattern of the

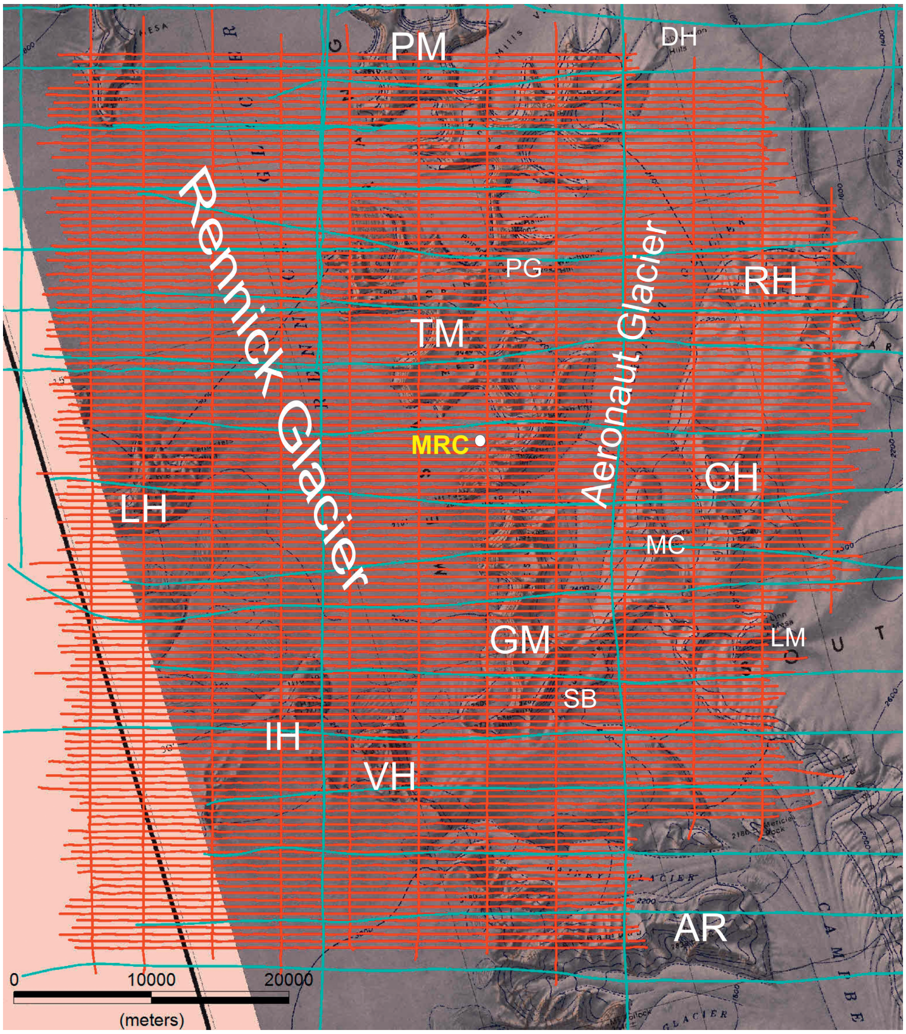


**Fig. 2:** Survey area GANOVEX X including all new survey lines (red) as well as lines flown during the surveys GANOVEX IV and GITARA V (Bozzo et al. 1998, 1999) (both light blue). All GANOVEX X survey flights were operated from the Mesa Range Camp (MRC). Feature names: Pain Mesa = PM, Tobin Mesa = TM, Gair Mesa = GM, Lichen Hills = LH, Illusion Hills = IH, Vantage Hills = VH, Runaway Hills = RH, Chisholm Hills = CH, Archambault Ridge = AR, Mt Carson = MC, Diversion Hills = DH, Pinnacle Gap = PG, Suture Bench = SB, Linn Mesa = LM. Topographic base: USGS Topographic Reconnaissance Map (250K) Mount Murchison).

**Abb. 2:** Das Befliegungsgebiet GANOVEX X mit den neuen Profillinien (rot) wie auch den Linien, die während GANOVEX IV und GITARA V geflogen wurden (beide in hellblau). Alle GANOVEX X -Messflüge wurden vom Mesa Range Camp (MRC) durchgeführt. Geländebezeichnungen: Pain Mesa = PM, Tobin Mesa = TM, Gair Mesa = GM, Lichen Hills = LH, Illusion Hills = IH, Vantage Hills = VH, Runaway Hills = RH, Chisholm Hills = CH, Archambault Ridge = AR, Mt Carson = MC, Diversion Hills = DH, Pinnacle Gap = PG, Suture Bench = SB, Linn Mesa = LM. Kartenbasis: USGS Topographic Reconnaissance Map (250K) Mount Murchison).

daily variations is characterized by a high level of magnetic activity in the local morning hours until after midday. The less disturbed period and thus the most favourable time of the day to perform survey flights ranges from 19 to 4 h (6 to 15 h UT) "local" time LT (i.e. the time stations in the western Ross Sea and Victoria Land use, corresponding to New Zealand summer time). A period of 3 hours on either side of this interval still appears to be acceptable for survey flights.

Also, the daily pattern of the magnetic activity exhibits a clear diurnal variation with a maximum around 15 h UT. This long wave daily trend, however, is of no concern with regard to the selection of survey times since it can be easily accounted for in the process of correcting the flight data with the base station data.

## FIELD OPERATIONS AND SURVEY FLIGHTS

After completion of the major logistic tasks at the beginning of the expedition and prior to moving to the Mesa Range area one of the expedition's helicopters was equipped with the aeromagnetic survey system and flight tested in the vicinity of Gondwana Station. The equipment was installed at the Italian Mario Zucchelli Station where a helicopter hangar provided optimal conditions. The helicopter and the aeromagnetic survey team moved to the Mesa Range Camp (Fig. 5) on 31 December 2009. There, a fuel depot had been previously established with the help of a Twin Otter chartered by the Italian Antarctic Programme.

Unfavourable weather conditions delayed the first survey flight until 3 January 2010. Altogether 26 survey flights were carried out until 19 January 2010. There were 6 days with 3 flights, 2 days with 2 flights and 4 days with only one survey flight, each flight lasting about 2 hours. It was mostly due to adverse weather conditions that restricted survey flights. Not only cloud coverage, but also strong winds, in particular over the western section of the survey area with frequent katabatic winds or turbulences close to the steep flanks of the Mesa Range tabular mountains (Fig. 6) made survey flights difficult on some days.

The majority of the survey flights took place within the "magnetic window" when a relatively "quiet" magnetic field could be expected. However, due the necessity to compromise with the working times of other groups based in the Mesa Range Camp, some flights started as early as 13 h LT. The survey helicopter was also partially used for other tasks, i.e. moving other groups to and from their sample sites and to support moving the remote geological field camps in the lower Rennick Glacier area.

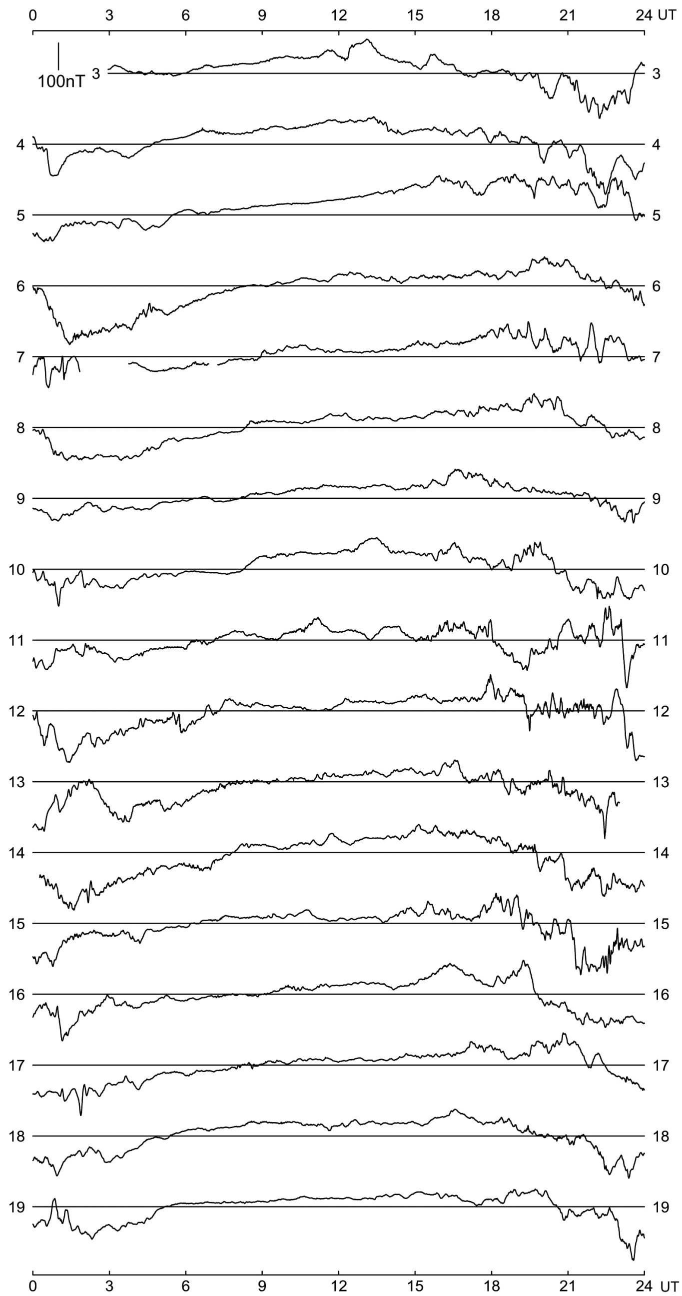


**Fig. 3:** Diurnal variations at Mesa Range Camp for the survey period from 3 to 19 January. Baseline value for all 24 hour UT-days is 64 000 nT.

**Abb. 3:** Magnetischer Tagesgang am Mesa Range Camp während der Befliegungen vom 3. bis 19. Januar. Die Basislinie an allen 24 UT-Tagen entspricht einem Wert von 64 000 nT.

A total of 7,400 km survey lines over an area of 3,300 km$^2$ were flown, using 56 ½ hours helicopter-time. After a final quality control of the data the survey was concluded on 20 January. Still in camp the aeromagnetic equipment was removed from the survey helicopter to return it to other logistic tasks of the expedition.

## DATA PRE-PROCESSING AND QUALITY CONTROL

Preliminary processing for every survey flight took place immediately or at least after the last flight of the day. Using the

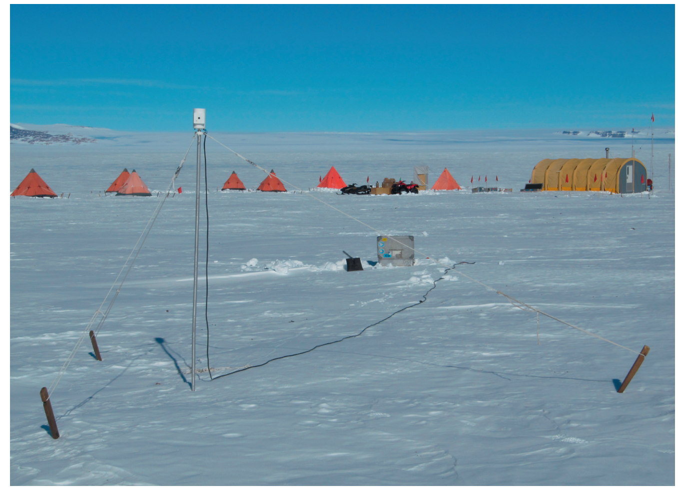

**Fig. 4:** Base station for the recording of the diurnal variations at Mesa Range Camp.

**Abb. 4:** Basisstation am Mesa Range Camp zur Aufzeichnung der täglichen Schwankungen des Erdmagnetfeldes.

**Fig 5:** Mesa Range Camp (elevation 2137 m) in front of the 3099 m high Mt Frustrum. Note the black layer of high magnetic basalts on top of the mountain.

**Abb. 5:** Das Mesa Range Camp (Höhe 2137 m) vor dem 3099 m hohen Mt. Frustrum. Die schwarze Auflage auf dem Gipfel besteht aus stark magnetischem Basalt.

PicoEnvirontec PEIView program the original PicoEnvirontec binary flight data files were converted into the binary Geosoft GBN format for use with OasisMontaj data processing software.

For each flight separately, the GBN formatted data were read into a new database of Geosoft GDB format in which a line header was edited and the flight number assigned to all lines of the flight. If necessary lines were renamed, empty or faulty rows eliminated. Also new projected x,y-channels, calculated from the geographic coordinates using the projection chosen for the survey (see above), were needed since the AGIS PEIconvert program used for navigation apparently calculated slightly different coordinates for the Lambert conformal projection, thus leading to slightly shifted lines. To reduce the amount of data only the most important data base columns, i.e., latitude, longitude, (GPS-)altitude, the new x,y coordi-

**Fig. 6:** Survey flights occasionally suffered from air turbulences occurring at the steep flanks of Mesa Range (Gair Mesa western side facing towards Exposure Hill).

**Abb. 6:** Die Messflüge wurden gelegentlich von Turbulenzen an den Steilhängen der Mesa Range (Gair Mesa westlich Richtung Exposure Hill) beeinflusst.

nates, (GPS-)time and the raw value of the recorded total magnetic field were exported to an ASCII-file forming the base for further quality control.

The ASCII-files from each survey flight were now imported into a single Geosoft GDB database to hand-edit (shorten) every single line and tie line at both ends to avoid multiple crossings for single lines. If possible only straight-line ends were kept. A preliminary IGRF processing was performed using IGRF2005, line date, and GPS altitude. The resulting magnetic anomaly was processed for a preliminary anomaly plot for each flight and also for the entire survey to obtain a first overview of the magnetic field pattern. After completion of the tie-line flights a preliminary analysis of crossover errors (altitude and magnetic anomaly values) was carried out to judge whether lines or sections of lines need to be re-flown (which was not the case).

Some sections in a number of lines show regular "wiggles" (Fig. 7). They are typically of 10 to 12 seconds width. The amplitude (peak-to-peak) varies from 1 nT to 5 nT, in most cases the amplitude is within the 2-3 nT range with a few exceptions of up to 10 nT amplitude. They are visually detectable only in the relatively "flat, quiet" sections of a line. They seem to be of higher amplitude at the beginning of lines and sometimes also at the end of lines. If they occur in the middle of lines they seem to be of lower amplitude and more regularly. This suggests an effect of sensor orientation: In the beginning of a line, the pilot often struggled to keep elevation or the helicopter was not perfectly aligned, yet. Thus, helicopter manoeuvres forced the bird to swing around and this may account for strong wiggles close to the start of a line, dying out when the flight was stabilized. Wind during the flight may have triggered swinging of the bird producing the wiggles also in middle sections of a line. It should be noted, that the wiggles seem to start during the fourth flight, but there were no wiggles detected before that flight. Since we do not have proof observations of the environmental conditions during the flights, we cannot further judge on this effect.

## DATA PROCESSING

### *Removal of diurnal variations*

The original 10-second recordings of the Mesa Range Camp magnetic base station were low-pass-filtered to remove the short period variations, which may not be representative over the whole survey area. In contrast to previous surveys in Victoria Land stretching over more than 100 km away from a base, the Mesa Range survey covered a relatively close area with a maximum distance of a survey point from the location of the magnetic base station of less than 60 km. Thus it was possible to use a relatively short filter as compared with the older surveys (see MASLANYJ & DAMASKE 1986). Different filter lengths have been tested and compared directly along single survey lines as well as in form of an anomaly map over the whole survey area: Applying a 5-minute filter or applying no filter at all showed best results. To smooth any artificial noise at the camp and the high frequency natural noise at the base station we decided to apply the 5-minute filter. These base values were then interpolated to 10 Hz intervals ($T_{base}$) and subtracted from the flight data ($T_{air}$) as follows:
$T_{cor} = T_{air} - T_{base} + BASE$ where BASE = 64 000 nT (mean base value over all days).

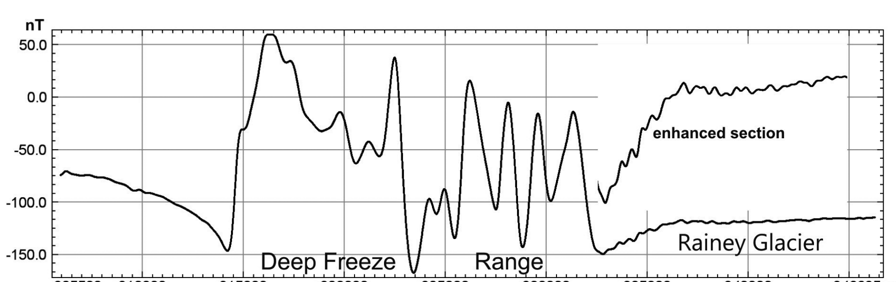


**Fig. 7:** Typical example for "wiggles" along a flight line. This line L990 runs west – east from the Deep Freeze Range (DFR) across outcrops south of the Vantage Hills to the upper Rainey Glacier, which runs along the Archambault Ridge on its northern side. The anomaly pattern typical for the dolerites of the DFR runs into a "flat" magnetic pattern over the Rainey Glacier. The appearance of "wiggles" at exactly this point (to better demonstrate the "wiggles" this section has been enhanced) can – in this case – clearly be attributed to strong katabatic winds dropping from the high plateau of the DFR to the low lying Rainey Glacier causing oscillations of the bird.

**Abb. 7:** Typisches Beispiel für Störungen entlang einer Fluglinie. Die Linie L990 verläuft in West-Ost-Richtung von der Deep Freeze Range (DFR) über Aufschlüsse südlich der Vantage Hills bis zum oberen Rainey Glacier, der nördlich längs zur Archambault Ridge verläuft. Das für die Dolerite der DFR typische Anomaliemuster schwächt sich über dem Rainey Glacier ab. Die gerade hier auftretenden Störungen (zur Verdeutlichung wurde dieser Bereich hervorgehoben) sind eindeutig auf starke katabatische Winde vom Plateau zurückzuführen, die den Flugköper in seitliche Schwingungen versetzten.

*A possible dependence on flight direction*

After base station correction the magnetic anomaly map shows artefacts that seem to be related to flight direction (Fig. 8a). The distinct step-wise appearance of steep gradients can be removed by the introduction of a lag correction. A series of different lag corrections were tried over 05, 10, 15, 20, 25 and 30 fiducials (one fiducial corresponds to 1/10 of a second and thus approximately 5 m with a survey speed of close to 100 knots). Applying this correction considerably improves the data (Fig. 8b). Since a 15-fiducial lag is definitely not sufficient to remove the effects at some edges and a 30-fiducial overcompensates the effect at some places, a 20-fiducial lag corresponding to about 90 m was chosen as the optimal shift to account for this flight direction dependent effect.

Another small "heading" effect was accounted for by removing the mean over all lines in W-E lines (90° course) from the individual W-E lines and the mean over all E-W lines (270° course) from the individual E-W lines. A small improvement in the anomaly map justifies the correction.

*Removal of a reference field*

Before obtaining a map of the anomalies of the crustal magnetic field, regional and global components of earth' magnetic field need to be removed. It is also advisable to remove these components before "levelling" the data since it makes it easier to judge on this processing step. Removal was done by first computing the International Geomagnetic Reference Field (IGRF) at all survey points at the respective survey altitude and then subtracting these values from the survey's total magnetic values. The IGRF 2005 coefficients were used to calculate the reference field values for a mean date (11 January 2010). Since these values are independent of the measured (and corrected) data they can later be added again and subsequently replaced with a more suitable reference model (e.g. the IGRF 2010, which was not available at the time of data processing).

*Levelling*

To remove effects of diurnal variations not accounted for by the base station correction, a "levelling" procedure, in which the differences at intersections of profile and tie lines are minimized, was carried out. Smoothing the data is necessary due to noise on some lines. To do this prior to levelling reduces also the effect of wrong values at intersections being used as discrepancies.

Low pass filters of 18 sec, 12 sec, and 6 sec lengths have been tested. Clearly an 18 sec filter significantly modifies shape and position of real anomalies. It does remove some of the artificial wiggles mentioned above and observed in parts of a number of lines, but not all. The 12 sec filter (corresponding to about 500 m (at 80 knots), thus the spacing of the lines) removes or at least reduces the wiggles to some part. However, there are a number of real anomalies for which the amplitudes are altered (their position is changed by less than 25 m which would be considered within positioning error), but more seriously, there are cases where obviously the shape of the anomaly has been

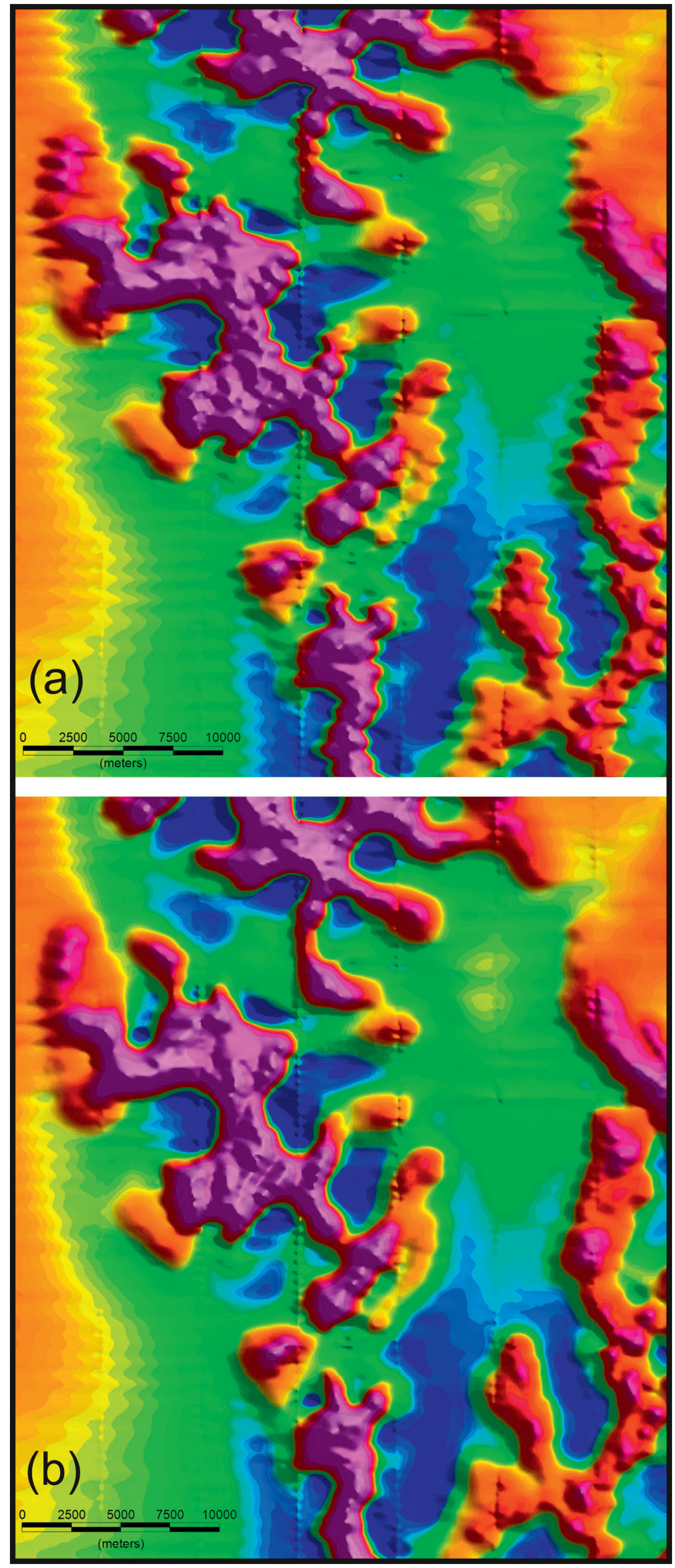


**Fig. 8:** (a) Section of the anomaly map after correcting for diurnal variations. Apparent over all lines is a possible dependence on the flight direction; (b) after applying a lag correction of 2 sec the "line-effects" are greatly reduced, especially in high gradient areas. Colour scale and shadowing as in Figure 9.

**Abb. 8:** (a) Ausschnitt aus der Anomalienkarte nach Abzug der täglichen Schwankungen des Erdmagnetfeldes. Sichtbar wird auch eine mögliche Abhängigkeit von der Flugrichtung; (b) nach „lag"-Korrektur von 2 sec sind die Linieneffekte weitestgehend reduziert, insbesondere in Gebieten mit großem Gradienten. Farbskala und Schatteneffekte wie in Abbildung 9.

modified. A 6 sec filter corresponds to about half the line spacing. Using this filter hardly changes the positioning of the anomaly peaks and changes in their amplitude are within an acceptable limit of less than 5 nT or less than 1.5 % of the peak-to-peak amplitude. Most important, there are no changes in the shape of the anomalies any more.

Applying the 6 sec filter does not remove the artificial wiggles at all, but a lot of very high frequency, low amplitude (<1 nT) noise including small spikes are removed. During levelling special attention was given to intersections lying in sections with "wiggles".

Levelling was done in two steps. First, a normal statistical levelling was applied. This involved an initial constant shift of each tieline with respect to the mean crossover difference with the profile lines, followed by the same procedure now reversed, i.e. lines shifted against the mean crossover difference of the tie lines. Since very large discrepancies in places of steep gradients of anomalies occur, a relatively large number of intersections had to be excluded. The result is an improvement in areas of "flat" magnetic field, but not in parts of high gradients. Taking these results now as a base and removing a linear trend in the tie lines and subsequently applying higher order trends along profile lines lead to a definite improvement in all the areas of a "flat" magnetic field. In the areas of high amplitudes, line effects are still very obvious. The normal "statistical levelling" approach cannot be continued there.

As a second step, a "pseudo-tie-line" method was developed (since the standard levelling methods and also a microlevelling approach (Ferraccioli et al. 1998) did not prove to be successful), in which only the profile lines are considered. Instead of the 5 km spaced original tie lines artificial tie lines spaced only 1 km are calculated and intersected with the profiles. Along these new tie lines a 4 point (i.e., over 4 profile lines) low pass filter (after experimenting with a number of different filters and filter lengths) was run. Calculating now differences at the intersections and using these for a correction (using the "careful levelling" option of the OasisMontaj levelling package with a tensioned spline) of the profiles – adjusts neighbouring profiles in such a way that line effects are greatly reduced. Again, this works best in "flat" (i.e. low gradient) areas. As before, large intersection differences have been excluded when applying this step over the whole survey. High gradient areas have been treated individually in separate steps in a similar way but now using also larger intersection differences.

The result of this second levelling step is a map which shows only a very few small line effects remaining. To include also the original, measured tie-lines in the final data-base, we used the "careful level" OasisMontaj application to adjust these now to the – per definition – perfect lines.

## FIRST RESULTS

### *Anomaly description*

The most distinct features in the anomaly map (Fig. 9) are strong positive amplitudes over the mesas. In most cases, the anomalies mimic almost exactly the topographically visible expression of the table mountains and ridges that rise above the ice (Fig. 10). The magnitude of the anomalies over flat mountain tops is about 400-700 nT but locally amplitudes up to 1200 nT and more occur. The other areas as there are the Runaway Hills, the Chisholm Hills, the Suture Bench, the Linn Mesa and the Lichen Hills – Illusion Hills – Vantage Hills as well as a plateau west of Archambault Ridge have lower positive amplitudes (mostly less than 250 nT).

The large glacier areas and particularly the Rennick Glacier appear nearly everywhere magnetically quiet. There are only a few exceptions from this observation. At the eastern end of Pain Mesa south of Diversion Hills, a 5 km long anomaly extends under the Aeronaut Glacier in SE direction and might be connected to a similar anomaly extending NW from the Runaway Hills under the glacier. The western part of Archambault Ridge seems to cause no magnetic anomaly but the flight altitude was higher than over the unnamed plateau west of it.

There is one area where weak to intermediate amplitude anomalies (up to 250 nT) occur over a wide ice and snow surface. This is west of Illusion Hills, Vantage Hills and the south-western continuation of these outcrops to Archambault Ridge. Flight altitude was low over this smooth surface and the snow and ice cover might be thin.

### *Modelling*

Nearly all structures and particularly the mesas have a very irregular shape and can hardly be represented with two-dimensional models. Nevertheless, we tried to model one cross-section by a two-dimensional geometry with bodies limited in y-direction ($2^1/_2$ and $2^3/_4$ dimensional, GM-SYS modelling program) to get a first impression of the relationship between possible source bodies and magnetic anomalies. True 3D models will later be necessary to explore the data in more detail. Modelling was done for the original survey line L1110.

We used the ASTER Global Digital Elevation Model (GDEM) (https://wist.echo.nasa.gov) to describe the topography for the modelled cross section. The GDEM seems to be correct over most parts of the survey area but also contains areas with large errors over the ice and snow surface. By comparison with the topographic map (Fig. 2) we hand-edited the altitude values for the model line. Errors in that procedure are mostly not very important because nearly always the surface of the glaciers is concerned that does not represent a magnetic model surface.

Line L1110 (Figs. 10, 11) crosses the Gair Mesa at its greatest width. The western part of the line runs from just north of the Illusion Hills (IH) over the magnetically quiet ice surface in the southernmost part of the Rennick Glacier (Figs. 9, 10). To the east, Suture Bench (SB) is crossed while Linn Mesa (LM; see also Fig. 2) is just touched at its southern tip. The first simple model in Fig. 12a uses only model bodies for the topographically visible parts of Gair Mesa and Suture Bench. The bodies are restricted in their width (y-direction perpendicular to the line direction) to only 1 to 3 km simulating coarsely the irregular shape of the table mountain. Magnetization values were chosen to fit the anomaly at the given topography but are

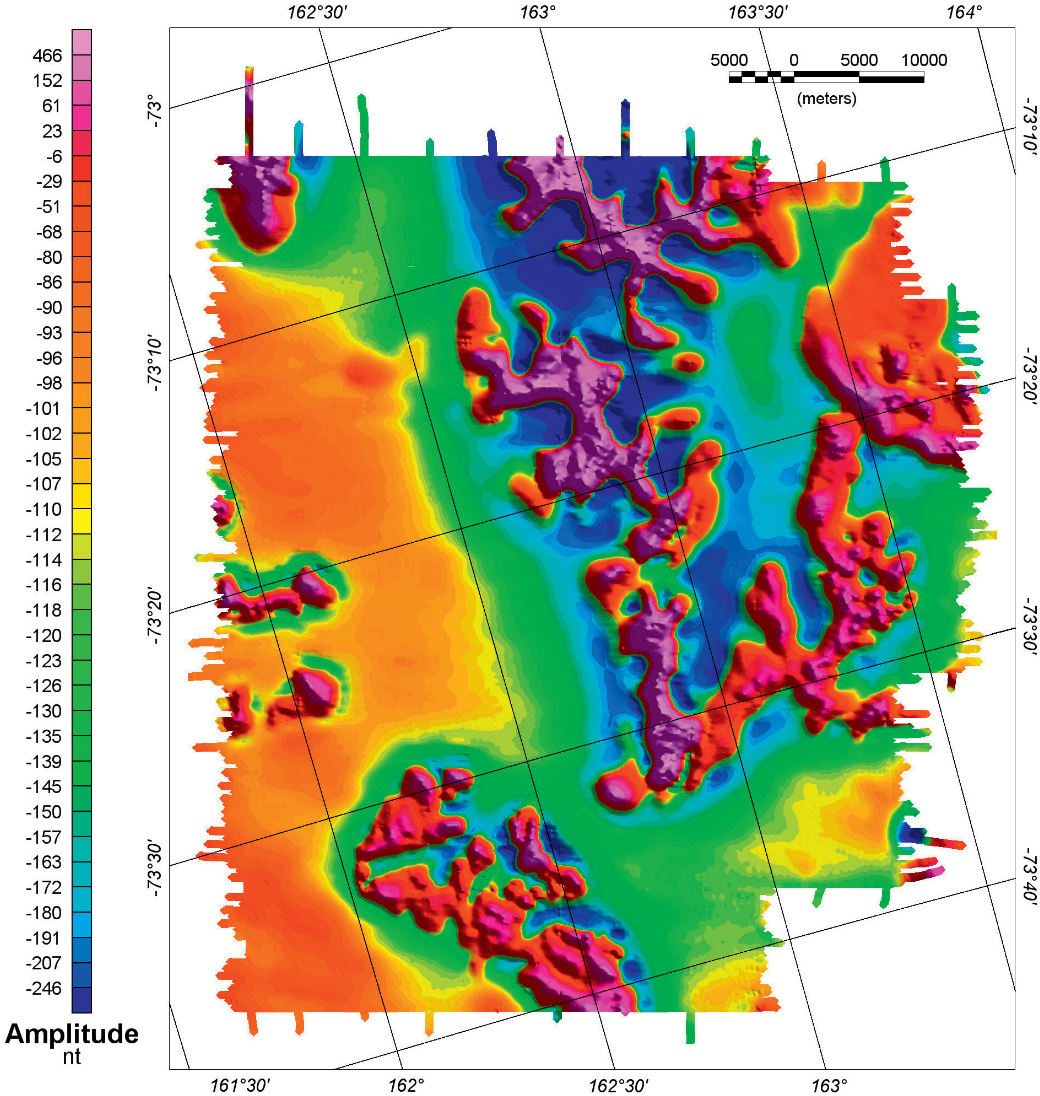


**Fig. 9:** Map of the anomalies of the total magnetic field after levelling. Colour scale is equal-area and shadowing direction from 45°.

**Abb. 9:** Anomalienkarte des Magnetfeldes nach dem Levelling. Farbskala ist „equal-area", Schattenwurf hier aus Richtung 45°.

in agreement with paleomagnetic investigations in the Mesa Range by McIntosh et al. (1986). Total magnetization values that combine remanent with induced magnetization at the inclination of the present field (-84°) are used as no information about the Königsberger ratio and magnetization directions are available. The Gair Mesa was subdivided into a lower part of about 700 m thickness with 3 A/m and an approximately 200 m thick cap with 5 A/m. These values seem to be reasonable for extrusive basalt flows from which the mesas in the survey area are built up. McIntosh et al. (1986) report NRM values for 15 samples from the Mesa Range that range from below 1 A/m to more than 10 A/m with an overall average of 4.1 A/m.

Fig. 12a shows that the magnetic anomaly can easily be modelled when only the topographically visible parts of Gair Mesa are regarded as magnetic bodies.

In Fig. 12b we tried to introduce a 500 m thick "root" below the higher parts of Gair Mesa on the expense of a reduced magnetization value for nearly the entire body. This is also in agreement with McIntosh et al. (1986) who report many samples with NRM values around 2 A/m. However, a very deep root with a much lower magnetization would necessarily reduce the steepness of the anomaly flanks. Thus we conclude that by far most of the anomaly is caused by the visible parts of Gair Mesa.

In order to investigate the question whether more magnetic bodies can be hidden under the ice in the glaciated areas Fig. 12b also contains two purely hypothetical source bodies below the surface of the Rennick Glacier. One of them may represent a 1 km wide dike ending about 500 m below the surface of the ice. The other body is a 5 km wide and 1 km thick block covered by 3 km thick ice. Their magnetization is assumed to be as strong as that of the main Gair Mesa body (2 A/m). The presence of these bodies causes distinct positive anomalies, which should be detectable in the smooth magnetic field over the glaciers. They therefore establish a minimum depth and maximum volume for significant basaltic source bodies under the glaciated areas.

Figs. 12c-e show the Gair Mesa in more detail. In Fig. 12c it is modelled with a uniform magnetization value for the whole body. It was chosen to fit the main part of the anomaly includeing its 'edge' anomalies which are typical for this and all other mesas (Fig. 9). The additional "peak" anomaly on top of the Gair Mesa needs special consideration because it is not adequately modelled. Fig. 12d uses a hypothetical 1 km wide

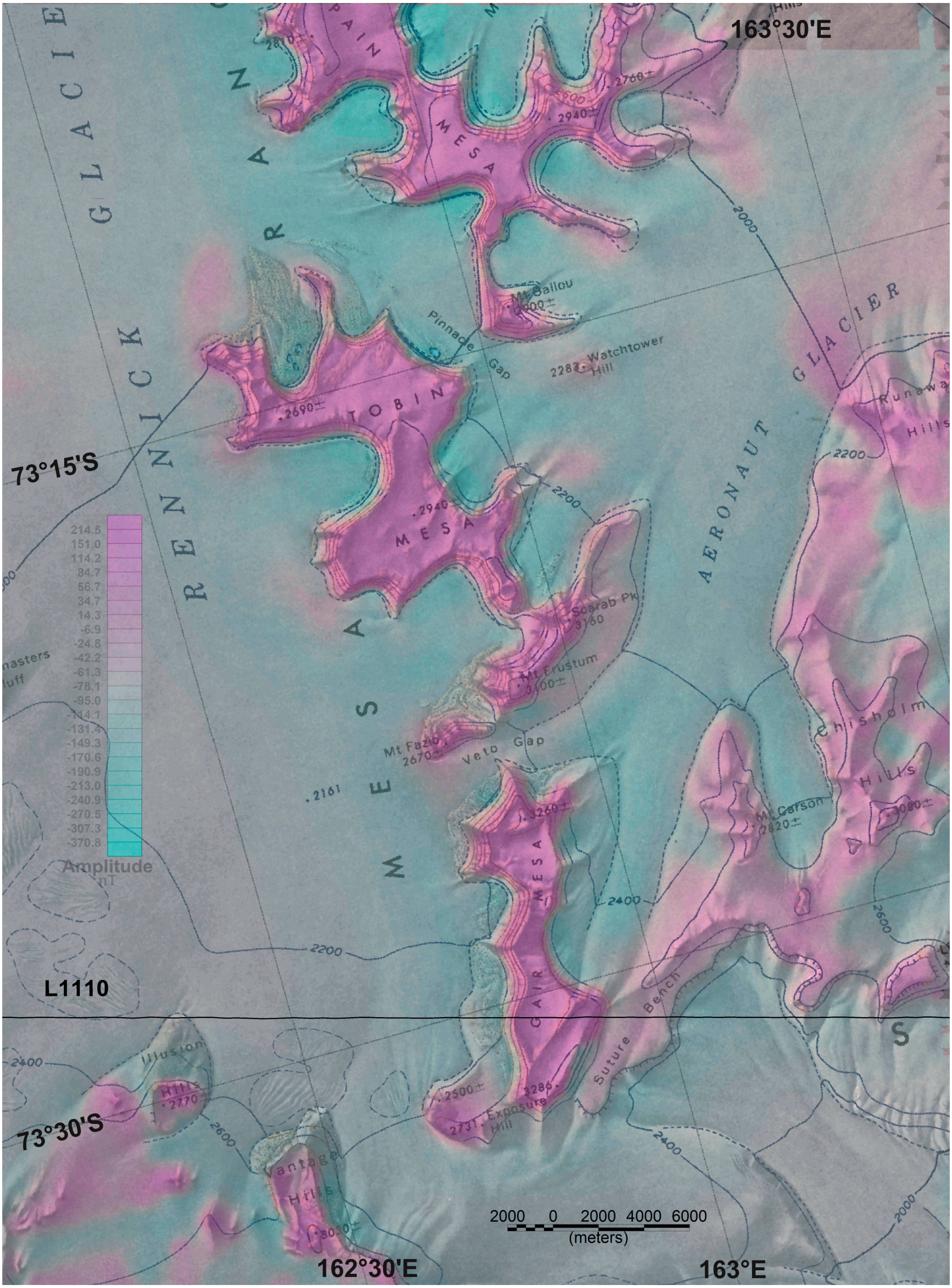


**Fig. 10:** The anomalies of the total magnetic field superimposed on the topographic map (section of the USGS Topographic Reconnaissance Map (250K) Mount Murchison). Colour scale is equal-area. The flight path for line L1110 is marked.

**Abb. 10:** Anomalienkarte des Magnetfeldes über topographischer Karte (Ausschnitt der USGS Topographic Reconnaissance Map (250K) Mount Murchison). Farbskala ist „equal-area". Der Flugweg für Linie L1110 ist markiert.

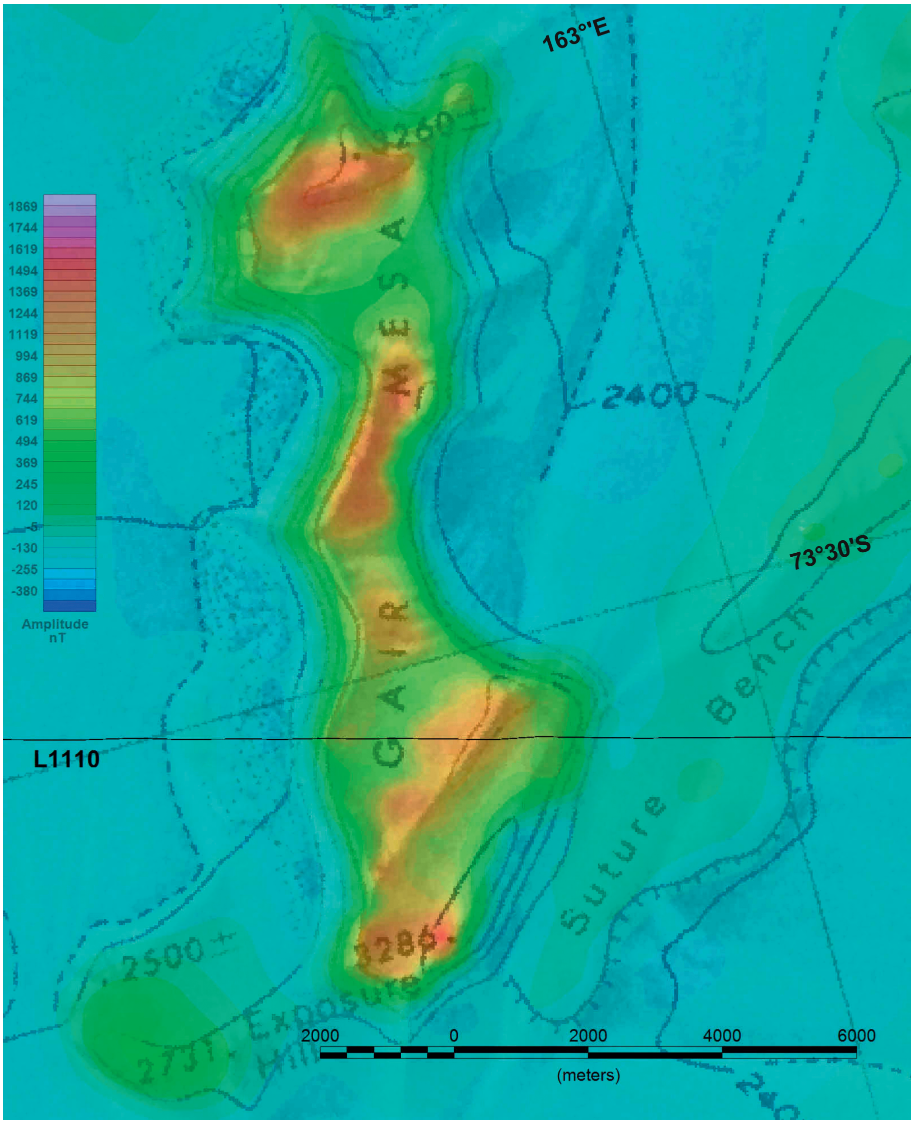


**Fig. 11:** Magnetic anomalies of the Gair Mesa. A linear colour scale was chosen to illustrate the magnetic pattern directly over the top of the mesa. The flight path for line L1110 is marked.

**Abb. 11:** Magnetische Anomalien der Gair Mesa. Eine lineare Farbskala wurde zur Verdeutlichung des magnetischen Musters direkt über dem Mesa Plateau gewählt. Der Flugweg für Linie L1110 ist markiert.

"feeder channel" and a slightly higher magnetization value to fit the observed anomaly. Another possibility is shown in Fig. 12e where the "peak" anomaly is caused by a small topographic ridge on top of the Gair Mesa combined with a higher magnetization value for the top of the Mesa. The ridge and the magnetic "peak" anomaly seem to be related to each other everywhere across the southern Gair Mesa plateau (Fig. 11). Therefore, we favour this model over that in Fig. 12d because the visible ridge and its connected anomaly provide a more natural explanation for the "peak" anomaly making a hypothetical "feeder dike" unnecessary. Consequently, this modelling approach was used in our preferred interpretation in Fig. 12a.

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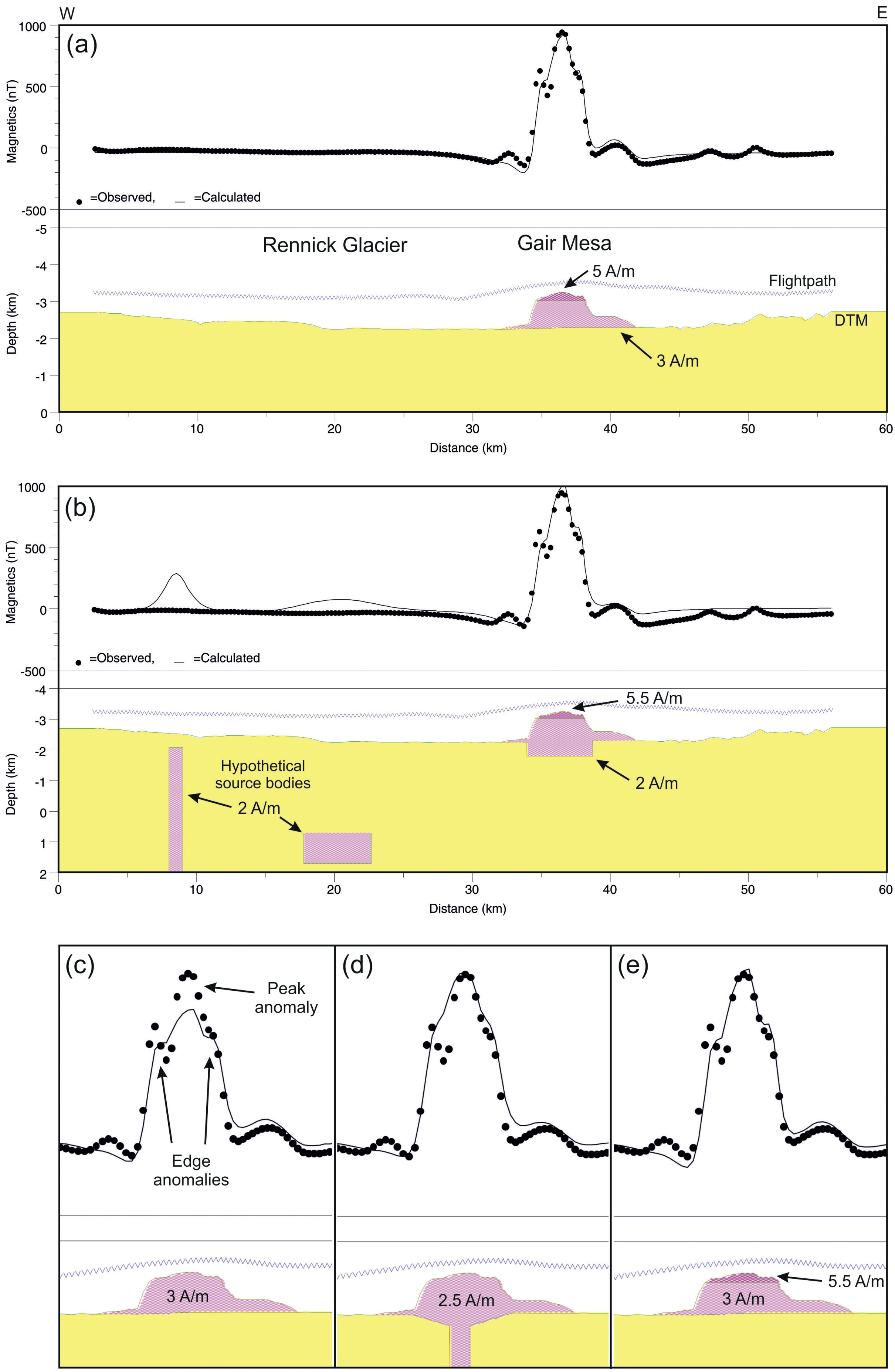
**Fig. 12:** Magnetic model calculation for flight line L1110 over the Rennick Glacier and the Gair Mesa. The anomalies are calculated for the draped flight path from GPS. Purple bodies are magnetized, yellow bodies denote non-magnetic rocks and ice. Their upper surface is defined by the ASTER Global Digital Elevation Model (GDEM) (https://wist.echo.nasa.govhttps://wist.echo.nasa.gov). Magnetic source bodies are limited in the y-direction perpendicular to the profile line (2 ½ dim). (a): Preferred model that explains the anomalies by topographically visible parts of the Mesas. (b): Alternative model using an additional "root" body for the Gair Mesa at reduced magnetizations. Two hypothetical bodies under the Rennick Glacier demonstrate that the presence of volcanic sources below most parts of the glacier areas are unlikely. (c)–(e): Detailed view of the Gair Mesa area. (c): Uniform magnetization of the Gair Mesa reproduces the "edge" anomaly of the main Gair Mesa body but fails to explain the peak on its top. (d): A feeder dike (1 km wide) below the Mesa may explain the "peak" anomaly. (e): "Peak" anomaly modelled by a topographic ridge on top of the Gair Mesa using a higher magnetization (approximately equivalent to (a)).

**Abb. 12:** Magnetische Modellrechnung für Linie L1110 über dem Rennick Gletscher und der Gair Mesa. Die Anomalien wurden für die mit GPS gemessene Flughöhe berechnet. Lila stellt magnetisches, Gelb nicht-magnetisches Gestein und Eis dar. Die Topographie stammt aus einem ASTER-Geländemodell (ASTER Global Digital Elevation Model (GDEM) (https://wist.echo.nasa.gov)). Magnetische Quellen senkrecht zu den Profillinien (2 ½ dim) in y-Richtung begrenzt. (a): bevorzugtes Modell, das die Anomalien durch die sichtbare Topographie der Mesas erklärt. (b): alternatives Modell mit einem zusätzlichen „Wurzelkörper" für die Gair Mesa bei geringerer Magnetisierung. Zwei angenommene Quellkörper unter dem Rennick Gletscher machen deutlich, dass solche Körper unter den Gletschergebieten praktisch ausgeschlossen werden können. (c)–(e): Detailansichten der Gair Mesa. (c): Gleichförmige Magnetisierung der Gair Mesa reproduziert die Randanomalien der Gair Mesa aber nicht das zusätzliche magnetische Hoch. (e): Mit einer stärkeren Magnetisierung des obersten Teils der Gair Mesa kann das magnetische Hoch erklärt werden (entspricht mit leichten Abweichungen dem Model in (a)).


W
E
(a)
Magnetics (nT)
1000
500
0
-500
=Observed,
=Calculated
Rennick Glacier
Gair Mesa
5 A/m
Flightpath
DTM
3 A/m
Depth (km)
-5
-4
-3
-2
-1
0
10
20
30
40
50
60
Distance (km)
(b)
Hypothetical
source bodies
2 A/m
5.5 A/m
2 A/m
(c)
Peak
anomaly
Edge
anomalies
3 A/m
(d)
2.5 A/m
(e)
3 A/m
5.5 A/m

Indications for a highly magnetized top of the lava stack of the Mesa Range do exist. The more northerly Tobin Mesa near our Camp shows distinctively different darker basalt layers on the top, which were also recognized and sampled by McIntosh et al. (1986). They report for this "thick black, glassy flow" on the top of Pain Mesa a mean NRM intensity of 10.9 A/m (4 samples). These rocks seem also to be present on the northernmost edge of Gair Mesa but so far there are no indications for that flow variety on available photos from the usually snow-covered top of the southern Gair Mesa in the vicinity of our modelled line. The topographic ridge on top of the Gair Mesa is flanked on both sides with snow-covered depressions. If the snow cover in these depressions would have a significant thickness then the GDEM does not represent a magnetic surface and the true magnetic interface would have a more pronounced topography and the magnetic anomaly could be modelled using a lower magnetization value.

## INTERPRETATION

The magnetic map in Fig. 9 shows that the anomalies can be subdivided into three main categories. (1) Areas with smooth, low amplitude appearance over glacier areas, (2) moderate anomaly amplitudes over some mountain areas and (3) distinct high amplitudes over the mesas.

(1) For the first category of the smooth magnetic field over the glaciers two possible explanations may apply: Either the lack of magnetic material in these areas or a greater source depth due to a thick ice cover in these areas or a combination of both. Unfortunately, ice thickness measurements are not available for the survey area. Ice thicknesses of more than one to two kilometres are unlikely but it cannot be excluded that the depth of the ice layer exceeds these values. Our hypothetical model (Fig. 12b provides arguments that any highly magnetized body like that of the Mesas must be located much deeper than it would be expected assuming a reasonable ice thickness. Thus any rocks, which might be present directly below the base of the ice are very likely not composed of Mesa Range basalts.

(2) The area with moderate anomalies seems to be underlain by weakly magnetized sedimentary, metamorphic and/or granitic rocks that sometimes may contain smaller amounts of intruded volcanic material (dikes and sills). It is also possible that this basement type underlies the glacier areas discussed above but due to the ice cover the magnetic pattern appears "flat".

(3) The high amplitudes over the mesas can obviously be explained by the topographically visual mesas if they have magnetization values that are typical for basalts. Deeper bodies are not necessary (see above).

## CONCLUSION

One of the main questions, which this project was based on, was whether – in addition to the topographically visible expression of the basaltic mesas or the dolerite outcrops around – more volcanic material might be hidden under the ice. Clearly, only little volcanic material can be expected in the depressions of the Rennick Glacier and Aeronaut Glacier. It also appears that the gaps between the mesas and the areas directly adjacent to the mesa flanks do not contain volcanic material (at least not enough to produce a visible effect in the magnetic anomaly map). This supports the interpretation of the Mesa Range (and the Monument Nunataks further to the northwest) to be remnants of an elsewhere eroded plane of flood basalts or sills. The volcanic sequence of the mesas probably does not reach much below the present glacier level in agreement with earlier observations of outcropping Beacon sediments at the foot of some mesas.

The new magnetic map does not show any indications of circular anomalies, which might be associated with feeder dikes. Thus, we conclude that the previously discussed quasi-circular anomalies in the GANOVEX IV map were just artefacts of insufficient line spacing combined with low terrain clearance over the Mesa Range. It is thus likely that the basalt sheets forming the Mesas have their sources outside the upper Rennick area.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The major part of this survey was conducted from a remote field camp in the Mesa Range. Without the help of many members of the expedition and the logistic support of the Italian Mario Zucchelli Station this camp – vital to our survey – would not have been established or functioning. In particular, we would like to express our thanks to the Helicopters New Zealand team and their constant support of this survey and to Maurice Conway who managed the camp during the entire field campaign in his professional and cheerful way. We would like to thank John C. Behrendt and Fausto Ferraccioli for their comments, which helped to improve the manuscript.


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