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Interpretation of geomagnetic anomalies in Dronning Maud Land, East Antarctica

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Abstract: The geomagnetic field pattern in the vicinity of Georg Forster station, Antarctica, is discussed. Induced magnetization is assumed to model the regional minimum in the total field intensity (MAGSAT) located here, and an associated anomalous body at a depth of 50 km is calculated and interpreted. This model is, however, discounted in favour of a cross section derived from a meridional ground magnetic profile recorded over a distance of about 200 km. The most striking features of the profile are positive anomalies over the ice shelf which are explained by dykes of basic rocks emanating from the lower crust and from the mantle. The derived crustal structure reflects a transition from continental crust to transitional type crust.

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Introduction

Since 1979 German scientists have carried out a special geomagnetic programme at Schirmacher Oasis (70°6'17"S, 11°52'20"E), Dronning Maud Land, Princess Astrid Coast, using a geomagnetic station with a modern range of instrumentation for the measurement and recording of the total field intensity (T) and of the three components of geomagnetic variations (D, H, Z). The Schirmacher Oasis with its regional geological position in the transition zone from continental crust to transitional type crust (Bormann *et al.* 1986) offers excellent possibilities for geomagnetic mapping and deep sounding. The stationary measurements of the total field magnetic intensity are used as a datum for field measurements in the Schirmacher Oasis and its surroundings, as well as for investigations of secular variation.

The contribution of this programme to the International Global Transect Programme (IGTP) is the exploration of the structure, composition and development of the crust, of central Dronning Maud Land, by complex geophysical (deep seismic, geomagnetic, gravimetric), geodesical, geological, structural, geochemical and petrological investigations.

In October 1988, the installation of a magnetometer chain was initiated along a meridional N-S line from the Humboldt Mountains (71°25'40"S, 11°32'36"E) to the ice shelf edge (70°00'39"S, 12°25'35"E). In 1990, four three component stations were operational, each about 85 km from the base line with data recorded at a rate of every 1or 2.5 minutes. Since 1980, oversnow geomagnetic mapping has been carried out in the Schirmacher Oasis and its surroundings; so far about 1000 stations have been measured with proton magnetometers. A south-westerly elongated negative anomaly in the western part of the oasis, is of regional geologic importance. We are of opinion that this decrease of the total field intensity reflects a drop in the level of the continental crust. The anomaly covers a relatively large area and continues under the inland ice. In its centre and on its eastern flank, this NE–SW striking anomaly coincides with the two marked shear-type lineations, identified both from aerial photographs and during geological field mapping. They have the character of deep reaching fault zones (Bormann *et al.* 1986), (Fig. 1).

On the whole, the Schirmacher Oasis as well as the Wohlthat Massif lie in the region of an intense regional geomagnetic minimum covering part of the East Antarctic platform (Fig. 2).

Interpretation of the MAGSAT minimum

A total field anomaly map of Dronning Maud Land derived from MAGSAT measurements (Ritzwoller & Bentley 1983) was given in Bormann *et al.* (1986). A nearly circular minimum with an amplitude of about -6 nT is evident from an average satellite altitude of 470 km (Fig. 2). At first we tried to understand this anomaly as a basis for the interpretation of a ground-based meridional profile recorded over a distance of 200 km along 12° E. As for the interpretation of the MAGSAT Oslo Kiev maximum (Lindner *et al.* 1988) an induced magnetization and some major simplifications were assumed:

(1) homogeneous induced magnetization without remanence, and
(2) homogeneous total field intensity of 40980 nT and an inclination of -63°.

The anomalous ΔT field has been simultaneously modelled by solution of the forward problem for a 3 dimensional

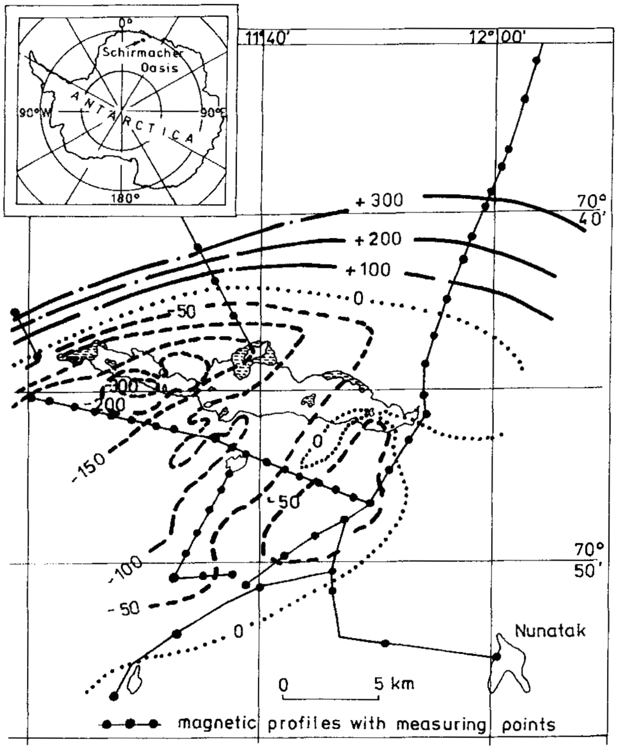

Fig. 1. Map of total field intensity ΔT in nT for the Schirmacher Oasis and its surroundings.

rectangular prism. A susceptibility contrast of Δk= -0.15 (SI) has been assumed in accordance with measurements on exposed rock sequences and experience obtained by modelling of magnetic profiles. This value characterizes the contrast between the Proterozoic gneisses and the more basic rocks, e.g. pyroxene granulites.

The following parameters are calculated for this simple model (Fig. 3):

(1) depth of the upper boundary: 40 km
(2) depth of the lower boundary: 50 km
(3) length N–S: 700 km, width E–W: 500 km

The calculated total field adequately approximates to the MAGSAT minimum. Consequently the crust is interpreted as being depressed by about 10 km. This result may be explained either by a structural difference at the crust/mantle boundary (Mohorovicic discontinuity — MOHO) with an increase in thickness of weakly low magnetic crust (Model A in Fig. 3), or by a region of lower magnetization within the crust without any structural differences (Model B in Fig. 3).

In general, positive magnetic anomalies in the MAGSAT map of Antarctica are associated with old stable shields or platforms, i.e., with areas of a relatively stationary thermodynamic regime.

According to seismic investigations (Kogan & Stroev 1972) the depth of the MOHO for this region of the East Antarctic platform is about 38–40 km. The relation of the magnetic anomalies to sources down to depths of 40–50 km can only be interpreted as an updoming of the recent Curie

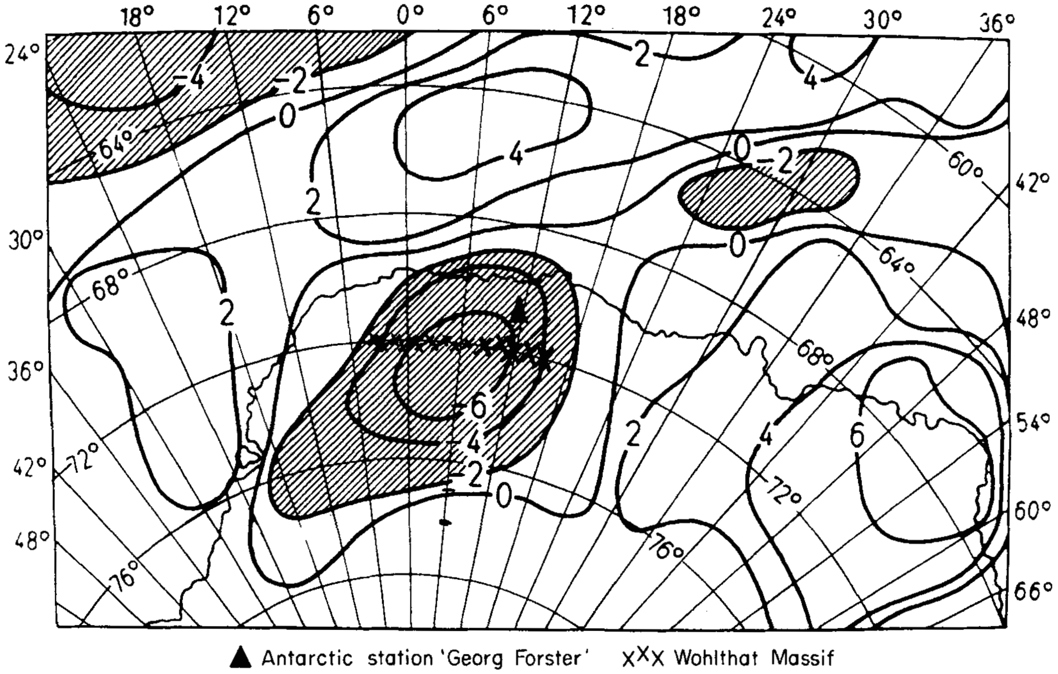

Fig. 2. MAGSAT total field intensity map over Dronning Maud Land (compiled from Ritzwoller & Bentley 1983). Units are nT, and the average satellite altitude is 470 km. ▲ Georg Forster Station, xxxx Wohlthat Massif.

isotherm in contrast to the neighboured platform area (Model B in Fig. 3). This suggests geothermal gradients of 13–15°C km^{-1}, values comparable with data from the Baltic shield and the East European platform (Cermak & Rybach 1979, Buntebarth 1980). Therefore an interpretation of the anomaly as being due to a region of weakly magnetized crust is favoured.

Anomalous satellite data, arising from the process of electromagnetic induction by the magnetic secular variation in large scale electric conductivity anomalies of the upper mantle, can be discounted as a possible source since this is corrected for in the MAGSAT data processing.

Interpretation of ground-based geomagnetic profiling

The geophysical investigations in the vicinity of Georg Forster station were located within the above mentioned regional MAGSAT anomaly. Therefore, the long wavelength MAGSAT anomaly is not expected to affect the interpretation of geomagnetic profiling. The interpretation of these observations provides information on relatively small-scale structures. Two dimensional magnetic susceptibility modelling was performed for a meridional ΔT profile from the Humboldt Mountains in the south to the ice shelf edge in the north, over a distance of about 200 km (Fig.4), using similar assumptions to those mentioned above. The whole profile was recorded with a station spacing of ~2.5 km, during a period from November 1988 to January 1989. A normal regional field of 5 nT km^{-1} (Lastochkin 1967) has been removed from the data. It should be emphasized that this rough approximation does not exclude mistakes in the description of the anomalies. This will be especially important at the southern end of the profile because of the regional trend, where the interpretation of deep crustal regions is open to other explanations. The position of the MOHO has been fixed in accordance with the results of the deep seismic soundings discussed by Kogan (1972) (Fig. 4). The recorded profile features two E–W trending positive anomalies with amplitudes of about +500 nT and +1200 nT over the ice shelf, which were observed in earlier magnetic records (Kogan & Stroev 1972) and Schäfer *et al.* (1984).

It is assumed that these anomalies are caused by geological structures similar to those described by Kogan (1972), and Bormann *et al.* (1986), i.e. in the presented cross section (Fig. 4) the deeply extending fracture zones at 94 and 142 km are drawn as dykes of basic rocks from the upper mantle. Since the magnetic anomalies in the Schirmacher Oasis have a dominant NE–SW strike and do not extend significantly beneath the adjacent ice shelf, a younger thermotectonic reactivation must be assumed, as has been discussed by Bormann *et al.* (1986).

Relatively high susceptibility contrasts of about +0.1 (SI) against the exposed gneisses have to be considered in order to reproduce the recorded magnetic field pattern. This is consistent with a density contrast derived from the seismic

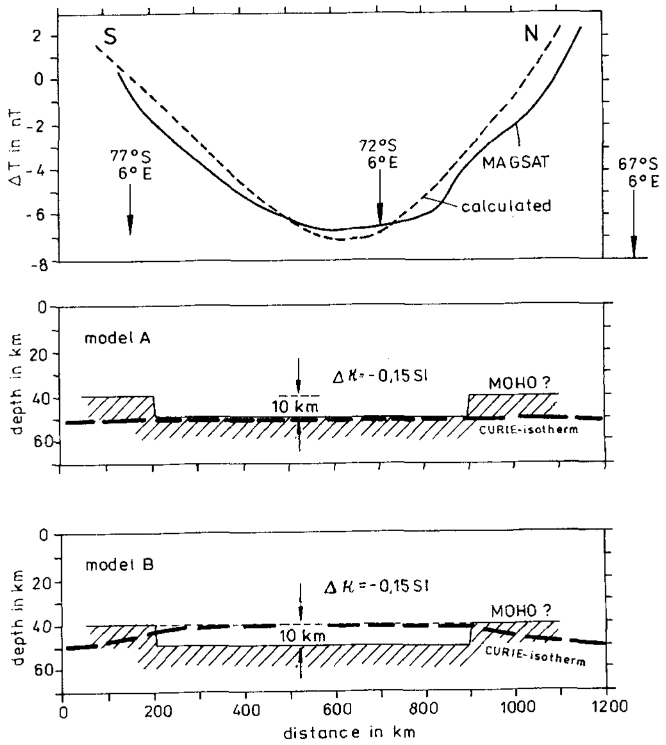

Fig. 3. Results of magnetic modelling for the MAGSAT minimum over Dronning Maud Land, East Antarctic platform. Top: measured and caluculated MAGSAT anomaly. Model A: model of the crust s structure with a depression of 10km and a length (N–S) of 700 km. Model B: MAGSAT minimum caused by an updoming of Curie isotherms.

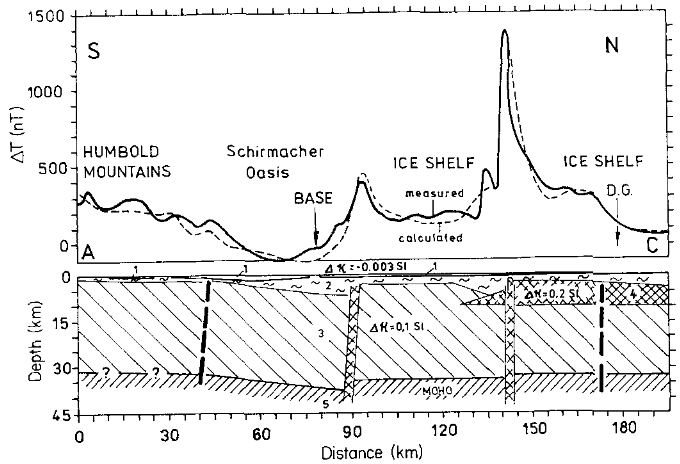

Fig. 4. Results of magnetic modelling for a 200 km ground-based meridional profile A C (see fig. 5a.) from Humboldt Mountains to the shelf ice edge.

D.G. - Indian Antarctic station, Dakshin Gangotri;1 - ice cover; 2 - gneiss series of the upper crust; 3 - lower crust with more basic rock series; 4 - intrusive basic rock series; 5 - upper mantle

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velocity–depth distribution discussed by Kogan & Stroev (1972). The density of the basement is 2800 kg m^{-3} and it increases to 3070 kg m^{-3} within the crust. This implies average P-velocities from the surface down to the seismic boundaries in the lower crust of between 6.35 and 6.42 kms^{-1}. This is probably an indication of the transition to the Archaean lower crust. The susceptibility of +0.2 SI for the crustal region beneath the ice shelf north of the Schirmacher Oasis at a depth of about 2–10 km indicates an increasingly basic composition within the crust and probably characterizes a transitional domain intruded by dolerites and gabbros. Bodies 2, 3 and 4 are determined from magnetic anomalies only.

The effect of the ice cover was calculated separately (Fig. 5) but has not been taken into consideration of the magnetic modelling for the ground-based profile A–C. In an extreme case the maximum amplitudes are less than 80 nT for a vertical ice edge with a thickness of about 1500 m and Δk = -0.003 SI. The small locally confined anomalies would appear to indicate superficial influence. Since the measurements were made at 2.5 km intervals, the influence of anomalies at the glacial margins is less important to the regional geological interpretation deduced from geomagnetic profile records.

Conclusions

German geophysicists have undertaken a systematic investigation of both the Schirmacher Oasis and the Wohlthat Massif along Princess Astrid Coast, Dronning Maud Land. A special geomagnetic programme was carried out by scientists of the Adolf Schmidt Observatory for Geomagnetism at Niemegk in the vicinity of the Schirmacher Oasis. MAGSAT data shows that this region lies within an intense regional negative magnetic anomaly covering the East Antarctic platform. We regard this anomaly as a regional background for the interpretation of ground-based measurements. As a simple model we calculated a depression of the earth crust from about 40 km to 50 km in depth with a susceptibility contrast of Δk = -0.15 SI. However, on the basis of seismic investigations we favour an interpretation of the anomaly as being due to a region of low magnetization levels within the crust/mantle, without invoking a crustal depression. We interpret this anomaly as an up-doming of the recent Curie isotherm compared to the neighboured platform area.

We also modelled a geological cross section from ground magnetic profiling within the area of the regional MAGSAT anomaly. This first S–N crustal cross section, from the Humboldt Mountains to the ice shelf edge, supports the presence of deeply extending fracture zones and features of the transition from continental to transitional type crust.

The southern continental crust is relatively acid, whereas the transitional crust is of increasingly basic composition (magnetic high). The geophysical investigations can best be interpreted in terms of an intensively dissected and down faulted crust, thinning from the south (some 50 km beneath the mountain range) to the north (less than 25 km north of the ice shelf edge). Whereas Phanerozoic uplift and erosion have dominated in the continental crust, to the south, subsidence and sedimentation characterize the transitional type crust beneath and beyond the ice shelf in the north (Bormann *et al.* 1986) .

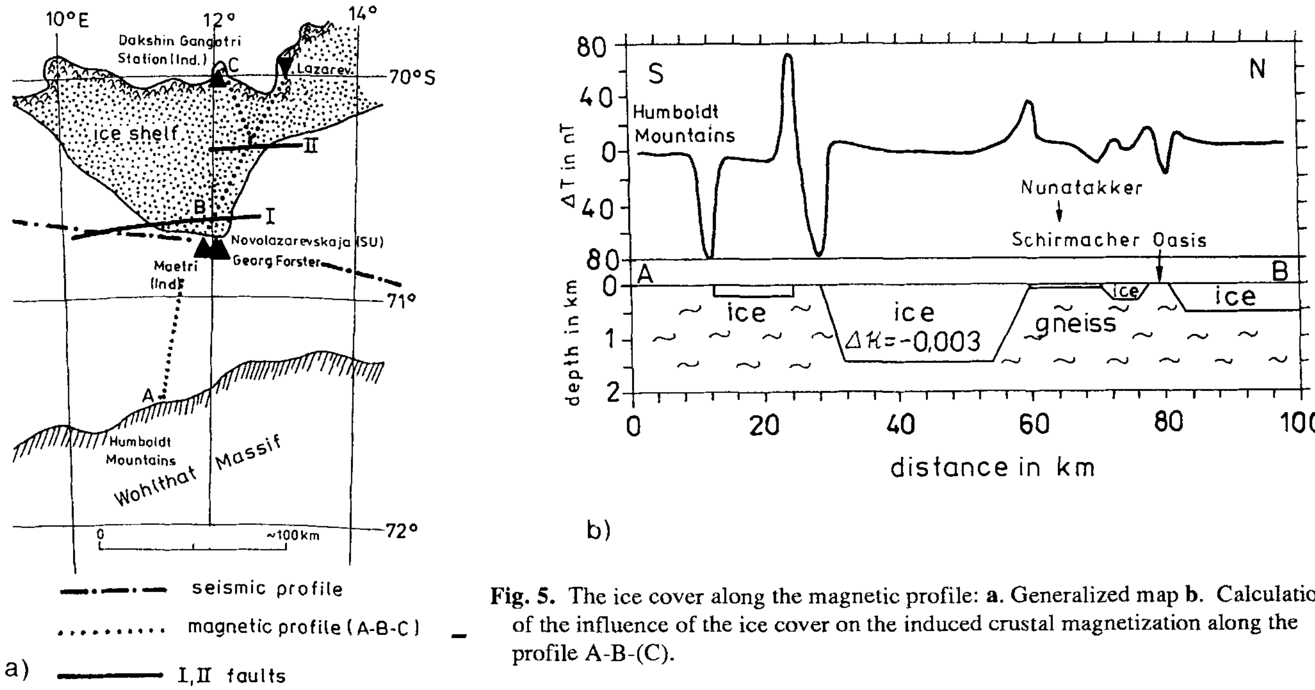

Fig. 5. The ice cover along the magnetic profile: **a.** Generalized map **b.** Calculation of the influence of the ice cover on the induced crustal magnetization along the profile A-B-(C).

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