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MAGSAT MAGNETIC ANOMALIES OVER ANTARCTICA AND THE SURROUNDING OCEANS

Michael H. Ritzwoller and Charles R. Bentley

Geophysical and Polar Research Center
University of Wisconsin, Madison, WI 53706

Abstract. A procedure to select and reduce satellite magnetic anomaly data in high southern latitudes is described, and a map of Antarctica, constructed using this procedure, is shown. The map is qualitatively analyzed for error and geologic significance. Correlations are noted between magnetic anomalies and mountain ranges, subglacial basins, tectonic provinces, regional gravity anomalies, a hypothetical continental rift feature, oceanic basins, and oceanic rises. Overall, the correlation between the magnetic anomaly patterns and known geological features is good.

Introduction

The Earth's magnetic field is principally a superposition of fields generated in four regions: the core, the crust above the Curie isotherm, the ionosphere, and the magnetosphere. Isolating the crustal field at satellite elevations is difficult, especially at high latitudes, though attempts span more than a decade (e.g. Zeitz, et al., 1970; Langel, 1974; Regan, et al., 1975; Coles, et al., 1976; Coles, 1979; Coles, et al., 1979; Mayhew, et al., 1980; Langel, et al., 1980a). The difficulty arises due to the proximity to the satellite of the ionospheric and magnetospheric currents, which are amplified in auroral regions. In this paper we describe a method for extracting the crustal field from the total field measured by MAGSAT at high latitudes and give a brief interpretation of some features of the Antarctic crustal magnetic anomaly field.

Data Selection and Reduction

The crustal magnetic anomaly, ΔB, is calculated by subtracting a core field model and an external field model from the total scalar magnetic field measured by MAGSAT. The degree and order 13 spherical harmonic model MGST4/81 created by Langel, et al. (1980b) was used as the core field model. No such general external field model exists; therefore, we followed the procedure described below in filtering external field effects.

External fields primarily consist of two components: a long-wavelength, slow-varying field generated by ring currents in the magnetosphere and a shorter wavelength, faster-varying field generated by field-aligned currents in the ionosphere. The rapid variations in field-aligned currents make them difficult to model, so we deleted all passes showing signs of their effect. This was done in two ways. First, we selected data only from passes during which the planetary magnetic activity index, Kp, was less than or equal to 1^- for at least 6 hours. The extended time period was chosen because auroral ionospheric activity abates more slowly than low-latitude activity. Second, data were selected only from passes showing no sign of anomaly amplitudes greater than those theoretically expected from the crust. This was done since field-aligned currents, because of their proximity to the satellite, can generate much larger measured magnetic effects than the crust. Specifically, we have required that ΔB be no larger than 15 gammas(nT). This amplitude criterion can be applied only after the long-wavelength external field is modeled and removed. Over the 8000 km flight path we have considered, the long-wavelength field is modeled as a quadratic polynomial (e.g. Mayhew, 1979) upon which the crustal and ionospheric fields are superimposed.

An example of this procedure is given in Figure 1, in which traces A result from the measured magnetic field after the core field has been removed, traces B are the models of the field generated by the ring currents, and traces C depict ΔB, which results by subtracting B from A. The tracks of the 87 passes (out of a total of approximately 2300) over Antarctica between November 1, 1979 and April 1, 1980, that satisfied the selection criteria are shown in Figure 2.

The ΔB data from the selected passes were averaged over areas measuring 3° of latitude by 3° of longitude, and were plotted and contoured, yielding the scalar anomaly map shown in Figure 3. Anomalies on this map have not been corrected for elevation variations in the satellite path, nor have they been reduced to the pole. Both corrections will eventually be applied, since the 200 km elevation variations that occur between MAGSAT orbits alter the amplitudes even of very long wavelength magnetic anomalies by as much as a factor of two (Regan, 1979; Bhattacharyya, 1977), and since the geomagnetic latitude varies by more than 45° across the map so that fields induced in the crust by the Earth's dipole field are latitudinally dependent. At present, however, we assume that elevation variations evenly smear most anomalies and note that for most of the map, reduction to the pole will have minimal effect. Other refinements of the data planned for the near future include rectangular gridding, the incorporation of a cross-correlation selection criterion for adjacent and crossing satellite paths, and data selection based on analyzing the vector-magnetic anomaly data for field-aligned current signatures.

Accuracy of Data

Disregarding magnetometer and tracking error, the accuracy of the magnetic anomaly map in

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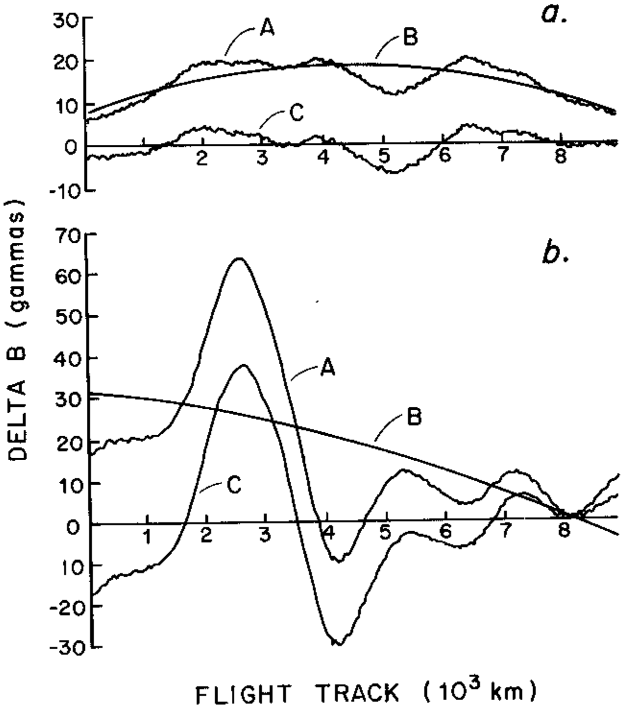

Fig. 1. Graphs of magnetic anomalies for: (a) a pass unaffected by field-aligned currents, and (b) an affected pass where A is the total-field minus the core field model, B is the quadratic polynomial model of the magnetospheric field, and C is A minus B, i.e. ΔB.

Figure 3 depends on the degree to which the core field model and the external field model are in error. We concerned ourselves chiefly with errors found in the external field models, since they are both more primitive and shorter in wavelength than the core field model. Two tests based on the time-varying nature of the external fields were performed. First, we partitioned the MAGSAT data into two successive 2½-month data sets and employed the data selection and reduction scheme described above to each. The correlation between the two maps was good, suggesting that most of the external field effects with periods less than five months were successfully filtered. Second, we compared the MAGSAT map with the POGO map of Regan, et al. (1975) covering Antarctica. The same general continental features exist on both maps, further suggesting that most external field effects with periods less than ten years were filtered out. The results of these tests are encouraging, but a more telling test, previously performed for high northern latitudes by Langel, et al. (1980a) and Coles (1979), would be to compare Figure 3 with lower altitude data continued up to satellite elevations. Until recently, data were not available from any magnetic survey over Antarctica that was large enough in area and dense enough in coverage to warrant comparison with MAGSAT. However, an aeromagnetic map soon to be published (referred to by Jankowski, et al., 1981), covering almost 10^6 km^2 in West Antarctica, will provide an excellent check of MAGSAT data.

Source of Anomalies

We expect that two major factors will contribute to continental crustal magnetic anomalies: the depth to Curie isotherm and the magnetic susceptibilities. It is still not certain to what degree continental remanent magnetization may affect long-wavelength magnetic anomalies. Some workers, at least, consider the effect negligible (M. Mayhew, personal communication, 1981); lacking better information we ignore it here. Thus we assume that the main sources of magnetic anomalies are located above the Curie isotherm and above Moho (Wasilewski, et al., 1979), and principally in the lower crustal layer where susceptibilities are greatest (Hall, 1974). Therefore, continental highs indicate either a thick crust with a deep Curie isotherm (low heat flow), or exceptionally high magnetic susceptibility in the lower crust, or both. On the other hand, continental lows imply some combination of a thin crust, a shallow Curie isotherm (high heat flow), and low susceptibilities in the lower crust.

The highest susceptibility region in the oceanic crust is in Layers 2 and 3, nearer the surface than in the continental crust, and generally well above the Curie isotherm. Therefore, oceanic magnetic anomalies should reflect regional crustal thicknesses and susceptibility differences, but probably do not reflect heat flow except in extreme circumstances. Remanent magnetization in the rocks of oceanic rift zones can also yield magnetic anomalies at satellite elevations, as can be shown by model calculations.

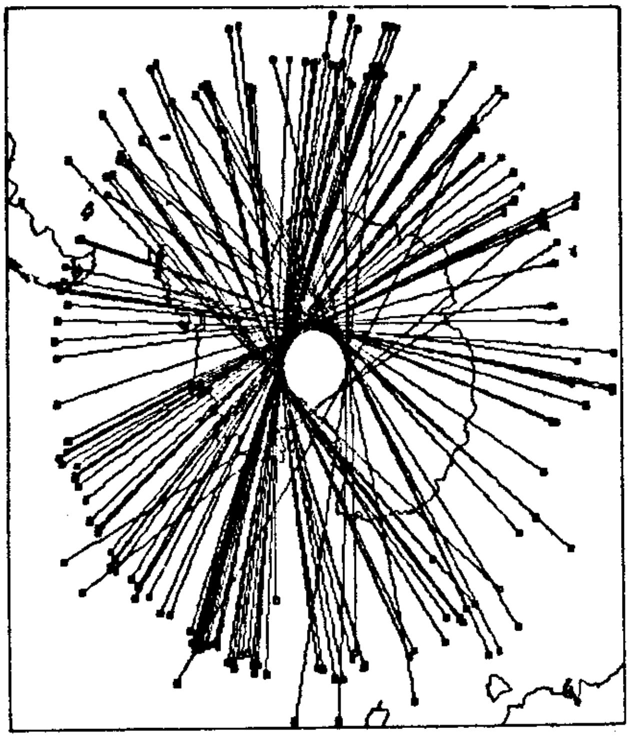

Fig. 2. Flight tracks of the 87 accepted passes over Antarctica and the surrounding oceans.

Geological Interpretation

The interpretation of satellite magnetic anomaly data is clearly ambiguous, especially over regions with little collateral data. However, the major associations between geologic features and magnetic anomalies are worth noting in both continental and oceanic regions.

Over the Antarctic continent there are magnetic anomalies associated with many topographic and geologic features. In East Antarctica, the mountains of western Queen Maud Land (magnetic low), the mountains of Enderby Land (high), the Prince Charles Mountains (low), the "Highland Massifs" beneath the ice in Wilkes Land (high)(Drewry, 1975), the Gamburtsev Subglacial Mountains (low), and the Pensacola Mountains (high) all have magnetic anomalies associated with them. Also, there is a magnetic low over a subglacial basin generally along 150°E in East Antarctica that is further characterized by a strongly negative regional isostatic gravity anomaly. This suggests that the process associated with the isostatic imbalance may be associated with high heat flow and does not support a model of cool convergence in the circulation of the upper mantle.

In West Antarctica, the Antarctic Peninsula, eastern Marie Byrd Land, and the Thurston Island region are associated with magnetic highs, whereas the Ronne Ice Shelf/Ellsworth Mountains region shows a pronounced magnetic low. Several of these anomalies seem to be closely associated with tectonic microplates suggested by D.H. Elliot (personal communication, 1981). Hayes and Davey (1975) have argued from the occurrence of a striking linear positive gravity anomaly that an actual ancient rift zone, which was probably active during the separation of Antarctica from Australia 65 m.y. ago, underlies the western Ross Sea. If so, the crust should be anomalously thin and the heat flow higher than could be normal there. A magnetic low covers much of this area, although the trends of the two features differ.

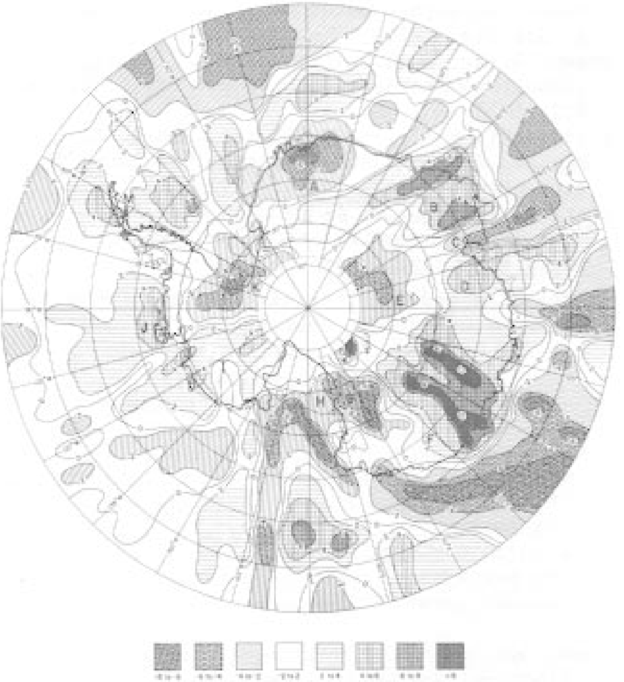
Fig. 3. MAGSAT total-field magnetic anomaly map over Antarctica. Units in gammas(nT). Capital letters indicate the approximate location of: A - Queen Maud Land, B - Enderby Land, C - Prince Charles Mountains, D - American Highlands, E - Gamburtsev Mountains, F - Wilkes Land, G - Transantarctic Mountains, H - Ross Embayment, I - Marie Byrd Land, J - Thurston Island, K - Ellsworth Mountains, L - Pensacola Mountains, M - Antarctic Peninsula.

Two continental regions that differ only in crustal thickness will tend to show different magnetic anomalies, with more positive values over the thicker crust. Bentley (1973) and Dewart and Toksöz (1964) have estimated crustal thickness to be 40 km in East Antarctica and 30 km in West Antarctica; the magnetic anomalies over East Antarctica are generally more positive.

Comparing the Gondwana reconstruction of Craddock, et al. (1970) with Figure 3 and the global magnetic anomaly map of Langel, et al. (this issue), shows that the low over the Ross Sea and the Transantarctic Mountains corresponds to the low along the Adelaide and Tasman orogens in eastern Australia, that the high in Wilkes Land is mirrored by a high in the Australian shield, and that, in fact, there is a general similarity between the magnetic appearances of Antarctica and Australia. Moreover, the Enderby Land high seems to be expressed in the Indian Shield, though this is unclear due to the latitude difference between the two regions. The Queen Maud Land low appears to correspond to a low in southern Madagascar and the Ellsworth low may be reflected in a low over the Cape orogen in South Africa. On the other hand, no feature similar to the Antarctic Peninsula high is apparent along the Andean orogen in South America. Thus, the Gondwana reconstruction seems largely consistent with the magnetic data shown in Figure 3 and Langel's map, but some discrepancies exist. A more exact comparison requires reduction of all data to the pole.

Oceanic magnetic anomalies are associated with both basins and rises. All four major ocean basins around Antarctica exhibit magnetic lows, and with the exception of the linear magnetic low along 170°W, all the oceanic negative anomalies are associated with these basins. Oceanic basin anomalies presumably are mainly negative because of the thin oceanic crust. Conversely, many of the oceanic rises in the region exhibit highs, and most oceanic magnetic highs lie above known rises. However, not all oceanic rises exhibit a magnetic high. We believe the primary cause for the magnetic highs is remanent magnetization over spreading ridges, although specific modeling has not yet been carried out.

Conclusions

Preliminary tests indicate that the primary source of the magnetic anomalies shown in Figure 3 lies within the Earth's crust. Though the data used to construct the magnetic anomaly map were not corrected for the effects of elevation and latitude variations in the satellite flight path, both continental and oceanic anomaly features show a good agreement with known geologic structures. Further research will focus on improving the quality of the magnetic anomaly map and modeling the sources of the anomalies seen.

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Geophysical and Polar Research Center, University of Wisconsin-Madison, Contribution No. 398.

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