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Final Report

submitted to

Goddard Space Flight Center
National Aeronautics & Space Administration
Greenbelt Road
Greenbelt, MD 20771

on

APPLICATION OF MAGSAT TO LITHOSPHERIC MODELING IN SOUTH AMERICA: PART I - PROCESSING AND INTERPRETATION OF MAGNETIC AND GRAVITY ANOMALY DATA

(Contract No. NAS 5-26287)

by

William J. Hinze, Lawrence W. Braile, Ralph R.B. von Frese
(in conjunction with G.R. Keller, University of Texas at El Paso, and E.G. Lidiak, University of Pittsburgh)

Department of Geosciences
PURDUE UNIVERSITY
WEST LAFAYETTE, IN 47907

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ABSTRACT

MAGSAT scalar magnetic anomaly data reduced to vertical polarization and long-wavelength-pass filtered free-air gravity anomaly data of South America and the Caribbean are compared to major crustal features. Many interesting relationships are observed. The continental shields generally are more magnetic than adjacent basins, oceans and orogenic belts. In contrast, the major aulacogens are characterized by negative anomalies. Spherical-earth magnetic modeling of the Amazon River and Takatu aulacogens in northeastern South America indicates a less magnetic crust associated with the aulacogens which is compatible with previous studies over the Mississippi River aulacogen and the Rio Grande rift in North America. Spherical-earth modeling of both positive gravity and negative magnetic anomalies observed over the Mississippi Embayment indicate the presence of a non-magnetic zone of high density material within the lower crust associated with the aulacogen.

MAGSAT scalar magnetic anomaly data and available free-air gravity anomalies over Euro-Africa indicate several similar relationships and some important differences. Rift zones and aulacogens tend to be magnetically negative. The Precambrian shields of Africa and Europe exhibit varied magnetic signatures. The reduced to vertical polarization magnetic anomaly map shows a marked tendency for northeasterly striking anomalies in the eastern south Atlantic and adjacent Africa, which are coincident to the tracks of several hotspots for the past 100 million years. Comparison of the radially polarized anomalies of Africa and Europe with similar satellite magnetic anomaly maps of the Western Hemisphere show correlative anomalies across the (closed) Atlantic Ocean adding support to the Mesozoic reconstruction of the continents.

INTRODUCTION

This report summarizes research activities performed on MAGSAT scalar data over South America, Central America and adjacent marine areas under grants provided to Purdue University and the University of Texas at El Paso. Research at Purdue University was conducted by L.W. Braile, W.J. Hinze and R.R.B. von Frese and their students. In the later stages of the project, they were joined by R. Olivier of the Institute of Geophysics of the University of Lausanne, Switzerland. Master of Science theses at Purdue University were prepared by Mark B. Longacre and Jeffrey R. Ridgway. Research at the University of Texas at El Paso was conducted by G.R. Keller working with E.G. Lidiak of the University of Pittsburgh. Master of Science theses were written by D.W. Yuan and K. Scott Remberger respectively at the University of Pittsburgh and the University of Texas at El Paso. A no-cost extension to the original contracts was provided to January 1, 1984 to expand our studies into the Euro-African region.

As of this date, research involved with these grants has resulted in the publication of three papers (Hinze et al., 1982; Longacre et al., 1982; von Frese et al., 1982), three expanded abstracts (Olivier et al., 1982; von Frese, 1982; Yuan et al., 1982) and eight published abstracts (Longacre et al., 1981; von Frese et al., 1981; von Frese and Hinze, 1982; von Frese, 1983; Hinze et al., 1983; Lidiak et al., 1983; Olivier et al., 1983; von Frese et al., 1983). In addition, several presentations regarding the research results were presented at MAGSAT investigator meetings and academic seminars. Master of Science theses were prepared with the support of these grants by D.W. Yuan, "Relation of MAGSAT and Gravity Anomalies to the Main Tectonic Provinces of South America", at the University of Pittsburgh under the supervision of Prof.

E.G. Lidiak, by K. Scott Remberger, "A Crustal Structure Study of South America", at the University of Texas at El Paso under the supervision of Prof. G.R. Keller, by Mark B. Longacre, "Satellite Magnetic Investigation of South America" at Purdue University under the supervision of Prof. W.J. Hinze, and a M.S. thesis is currently in the final stages of preparation by Jeffrey R. Ridgway, "The MAGSAT Scalar Magnetic Anomaly Map of South America", under the supervision of Prof. W.J. Hinze at Purdue University.

DISCUSSION OF RESULTS

Detailed discussions of the research results are presented in the three published papers, three expanded abstracts, and eight abstracts which are provided in Appendix A. Additional information is provided in four graduate theses and new research results will be presented in publications which are currently being prepared.

South America, Central America and adjacent marine areas include some of the most geologically significant regions of the Earth. A primary objective of this research program was to demonstrate the geologic utility of magnetic satellite anomalies by focusing on the spherical-earth interpretation of scalar MAGSAT data, in combination with ancillary geological and geophysical (free-air gravity, seismic, etc.) data, to obtain lithospheric models for these regions related to their contemporary crustal dynamic processes, geologic history, current volcanism and seismicity, and natural resources. Purdue University (L.W. Braile, W.J. Hinze and R.R.B. von Frese) was responsible for processing of the MAGSAT data and preparation of the magnetic and gravity anomaly maps, the University of Texas at El Paso (G.R. Keller) provided the data on seismic investigations of the crust, and the University of Pittsburgh (E.G. Lidiak) assembled the data and prepared the tectonic/geologic maps of South America. All these data were used by the investigators in an integrated interpretation.

As the investigator tapes were made available nearly a year later than originally scheduled, a substantial amount of effort performed under the auspices of this research program was based on an analysis of the preliminary <2°> MAGSAT anomaly data.

Tectonic, gravity anomaly and crustal structure data have been gathered, synthesized, and interpreted for comparison to magnetic anomalies mapped by the MAGSAT satellite over South America. The correlation of reduced-to-pole magnetic and gravity anomalies (Longacre et al., 1981; Hinze et al., 1982) at 350 km elevation with tectonic provinces are shown in Figures 1 and 2 respectively. A map of crustal thickness (Remberger, 1983) is shown as Figure 3. This map represents a compilation of previous results as well as a major effort analyzing Rayleigh wave dispersion data. The non-satellite data have numerous limitations because of the sparse data available in the many remote areas of the continent. The magnetic anomalies mapped as part of the MAGSAT project provide more uniform coverage of the South American continent, but these data are also of an averaged nature. Furthermore, magnetic and gravitational field measurements are sensitive to lithological variations in the crust (and upper mantle) which are not necessarily related to either the crustal thickness or the tectonic features of South America. Nevertheless, numerous interesting relationships exist between the variations in crustal thickness and average crustal shear velocity, the magnetic and free-air gravity anomalies, and the major tectonic features of South America.

The South American Platform (Yuan et al., 1982) is the oldest tectonic province and contains the only known Archean rocks of the continent. The basement of the platform is exposed in three major shields--Guyana, Central Brazilian, and Atlantic. All of these shields contain thick Precambrian metamorphic sequences and a wide variety of volcanic and intrusive rocks and are characterized by positive magnetic (Figure 1) and free-air gravity anomalies (Figure 2). Exceptions are the eastern part of the Guyana Shield which corresponds to a negative free-air gravity anomaly and the central Atlantic Shield which corresponds to a negative magnetic anomaly.

The sedimentary cover and associated volcanics of the platform, which are of Silurian or younger age, are well developed in four great synclines - Amazon, Parnaiba, Parana, and Chaco basins. These basins are filled with a thick sequence of non-magnetic and Bouguer gravity anomalies. An exception is the Parana basin in which positive magnetic anomalies occur which are associated with a thick sequence of Parana basalts. In general, grabens or aulacogens, underlying the large basins (Amazon and the southern part of Chaco basins) or in the shield (Takatu rift valley), are characterized by magnetic minima and gravity maxima (Figures 1 and 2).

The central and southern portion of the South American platform is undistinguished by any notable variations in crustal thickness. The average thickness of the crust throughout this region is approximately 42 km, which is typical of stable platform and shield areas; the crust may thicken slightly to the north. (The crust beneath the Chaco basin and surrounding areas has not been sampled adequately, however.) The average regional crustal shear wave velocity falls within a range of 3.65 to 3.70 km/s. The pattern of filtered free-air gravity anomalies across the central and southern platform indicate that the entire region is broadly in isostatic equilibrium, as would be expected in a large area of uniformly thick crust. Strongly positive magnetic anomalies occur over the Central Brazilian shield and over the northern and southern Atlantic shield; an intense negative magnetic anomaly occurs over the

Central Atlantic shield. The southern portion of the platform is characterized by an irregular pattern of slightly negative magnetic anomalies. The pattern of magnetic anomalies over the southern and central South American platform does not seem to be associated with variations in crustal thickness, but appears to be related to lithological variations within the crust of the platform. The intense magnetic anomaly over the central Atlantic shield may, for instance, be attributable to thermo-tectonic reactivation of the crust prior to or during the rifting of South America from Africa.

Two major trends in crustal thickness dominate the crustal structure of the northern South American platform (Figure 3). An east-west trending zone of thickened crust (slightly thicker than 50 km) exists beneath nearly all of northern Brazil. This crustal zone is characterized by average crustal shear wave velocities of at least 3.81 to 3.95 km/s, which implies that in addition to being thick, the crust is more dense than average. The northwestern lobe of the South American platform is underlain by a hook-shaped zone of thinned crust (slightly thinner than 35 km) that roughly parallels the curve of the Andean Cordillera. The average crustal shear wave velocity in this region is poorly defined, but probably falls within the range of 3.70 to 3.77 km/s. The pattern of filtered free-air gravity anomalies over the northeastern platform is very similar to that of the central and southern platform. However, unlike the other intracratonic basins of the South American platform, the Amazon basin is not characterized by a distinct free-air low, although it correlates with a negative Bougüer anomaly where data are available. The slight negative anomaly which lies over the eastern lobe of the Guyana shield is also unusual. A distinctive pair of interconnected magnetic lows covers part of the northeastern platform. One of these anomalies is centered over the eastern Amazon basin and extends out into the Atlantic Ocean; the other is centered over the intersection of the trend of the Takatu aulacogen with the central Amazon basin and cuts across much of the southern Guyana shield (particularly the eastern lobe). The area covered by these negative magnetic anomalies corresponds with the zone of thickened crust beneath northern Brazil, suggesting that a relationship exists between the two features. Perhaps the zone of thickened crust (and low elevation) represents a subsided rift cushion.

A ridge-like free-air gravity high (greater than 40 mGals) covers much of the low-lying, sedimentary rock-covered transition zone between the Andean Cordillera and the Amazon basin and Guyana shield, over the northwestern South American platform. The western lobe of the Guyana shield is also characterized by a slight free-air gravity high. These anomalies could be a reflection of the zone of thinned crust mapped beneath the area. A distinctive negative magnetic anomaly lies over the central part of the transition zone, at the intersection of the trend of the Amazon basin with the Andean Cordillera. The relationship of this anomaly to the zone of thinned crust is not clear. The magnetic anomaly could be due to the extensive sedimentary cover of the region, to a fundamental lithological difference in the crust, or to remnant thermal activity.

The Andean Cordillera constitutes the entire western margin of South America with rocks dating from the Precambrian to recent time. It is a region of strong seismicity and volcanism. A relatively narrow belt of thick crust is present beneath the trend of the Andean Cordillera along the western coast of South America. This belt thins gradually southward beneath the Central Andes, and rather abruptly northward beneath the Northern Andes. The crust thickens dramatically beneath the bend in the mid-Central Andes at latitude 18° South, reaching thicknesses greater than 70 km. The crust also thickens beneath the Northern Andes of western Colombia. Positive free-air gravity anomalies are related to the Andean Cordillera. The most intense of these anomalies is correlative with the sharp bend in the Central Andes. The relationship of the MAGSAT scalar anomalies to the Andes is much less definitive, but a major magnetic minimum is associated with the above mentioned positive anomaly. This is the portion of the Andes with the maximum regional uplift of the surface, the greatest Moho depths and steepest dip of the Benioff zone associated with subduction of the Nazca plate. It also coincides with the location of major recent volcanism. The smaller free-air gravity high over the mid-Northern Andes does not seem to be related either to the elevation of the cordillera or the presence of a crustal root. The anomaly may, however, be caused by the zone of dense, shallow oceanic crust that lies between the Central Cordillera and the Pacific coast of Colombia.

Longacre et al. (1981) and Hinze et al. (1982) show statistically that the magnetic data over the continental areas of South and Central America are more magnetic and magnetically more variable than the adjacent marine areas. The former observation is compatible with evidence that suggests that the seismic Moho is a magnetic boundary and that the upper mantle is only weakly magnetic. The more variable magnetization of the continents reflects their long and complex geologic history which has led to strong horizontal magnetic polarization variations in the crust.

The Caribbean Sea and the Gulf of Mexico are underlain by prominent magnetic minima (Lidiak et al., 1983). Within these oceanic areas, linear magnetic highs correlate with topographic ridges which separate the Gulf of Mexico, the Colombian Basin, and the Venezuelan basin. The boundaries of the Caribbean plate occur along magnetic gradients. The gradients are particularly sharp along the northern and western margins of the plate, but are gradational along the southern margin where they merge with anomalies associated with the Andean Cordillera.

To obtain further insight concerning the relationships between regional South American tectonic features and geopotential field satellite anomalies, the Euro-African MAGSAT data were investigated. Specifically, satellite (MAGSAT) scalar magnetic anomaly data were compiled and differentially reduced to radial polarization (Figure 4) for comparison with tectonic data of Africa, Europe and adjacent marine areas (Olivier et al., 1982 and 1983; Hinze et al., 1983; von Frese et al., 1983). These studies demonstrated a number of associations to constrain analyses of the tectonic features and geologic history of the region. Rift zones and aulacogens, for example, tend to be magnetically negative. The most intense positive anomaly of the region is the Bangui anomaly which has been interpreted as due to a deep crustal positive magnetization source. There are no near-surface sources which will explain this anomaly. By contrast, the next most intense positive anomaly is over the Kursk region in the Russian Ukraine. This anomaly extends 450 km in a northeasterly direction and is roughly 150 km wide, and is caused according to aeromagnetic anomaly interpretations by near-surface, intensely magnetic ferruginous quartzites. Apparently, there is sufficient long-wavelength energy in the superimposed near-surface anomalies for them to be observed at satellite elevations. The Precambrian shields of Africa and Europe exhibit varied magnetic signatures. All shields are not magnetic highs and, in fact, the Baltic shield is a marked minimum. The reduced to the pole magnetic map shows a marked tendency for northeasterly striking anomalies in the eastern Atlantic and adjacent Africa, which is coincident to the track of several hot spots for the past 100 million years. However, there is little consistency in the sign of the magnetic anomalies and the track of the hot spots. Comparison of the radially polarized anomalies of Africa and Europe with other reduced to the pole magnetic satellite anomaly maps of the Western Hemisphere (Figure 5) support the reconstruction of the continents prior to the origin of the present-day Atlantic Ocean in the Mesozoic Era.

To illustrate the utility of satellite magnetic data in characterizing the properties and structure of the lithosphere, magnetic modeling of the Amazon River and Takatu aulacogens in northeastern South America (Longacre et al., 1982) and the Mississippi Embayment (von Frese, 1982 and 1983) were undertaken. For the Amazon River and Takatu aulacogens, reduction of MAGSAT scalar magnetic anomaly data to an equivalent condition of vertical polarization shows these tectonic features generally correlated with magnetic anomaly minima. Surface gravity data demonstrate a correlative positive anomaly. Spherical earth modeling of the magnetic data indicates a less magnetic crust associated with the aulacogens which is compatible with previous studies over the Mississippi River aulacogen and Rio Grande rift in North America.

For the Mississippi River aulacogen, spherical earth inversion analysis of free-air gravity, U.S. Naval Oceanographic Office aeromagnetic, and satellite (POGO, MAGSAT) magnetometer data show the Embayment to be characterized by regionally positive gravity and negative magnetic anomalies. Incorporating constraints developed from seismic refraction and surface-wave dispersion studies of the region with Gauss-Legendre quadrature potential field modeling suggests that the regional gravity and magnetic anomalies may be related to a rift zone along the axis of the Embayment which defines a non-magnetic block of high density material within the lower crust. The decreased magnetization of this component may be due to reversed magnetic remanence, an intra-lithologic variation, or an upwarp of the Curie isotherm.

To assess the crustal component in satellite data, POGO and preliminary MAGSAT magnetometer data were compared with the scalar aeromagnetic data obtained by the U.S. Naval Oceanographic Office (NOO)--Vector Magnetic Survey of the conterminous U.S.A. (von Frese et al., 1982; von Frese and Hinze, 1982). POGO and preliminary MAGSAT data demonstrate remarkable consistency, but the NOO data spherically upward continued by equivalent point source inversion are dominated by long-wavelength (≈ 1000-3000 km) anomalies which are not present in the satellite anomaly data. However, upon removal of these long-wavelength anomalies from the upward continued NOO data, a close comparison observed between the anomalies verifies that satellite magnetic anomalies do portray the crustal component within a range of wavelengths from roughly 1000 km down to the resolution limit of the observations.

Finally, to avoid potential problems and smoothing of the MAGSAT scalar anomaly data by using the 2° averaged data, a scalar anomaly data set of South America has been prepared directly from the investigator tapes. The procedure used which was developed with resources independent of this contract involved selecting orbital profiles observed when K_p values were 3 or less. In addition, the magnetic effect of the equatorial electrojet was minimized by screening profiles for a large "y" component and using only dawn profiles. Furthermore, the NASA ring current correction was applied to the data. Finally, all data were wavenumber filtered between 0.25 deg^{-1} and 0.02 deg^{-1} with a Butterworth filter. Analyses of 25 sets of 3 essentially coincident profiles showed that maximum correlation of coincident, redundant, profiles was obtained using a minimum low-cutoff of 0.02 deg^{-1}. The resulting data set minimizes geologic anomalies which have dimensions exceeding roughly 2900 km, but it also has minimum disturbance from temporal variations in the geomagnetic field. The data set has been processed by equivalent point source inversion (Longacre et al., 1981; Hinze et al., 1982) taking into account the variable elevation of the data points. The resultant map is shown in Figure 6. This map will be used in subsequent analysis of MAGSAT scalar magnetic anomalies over South America, Central America and associated marine areas.

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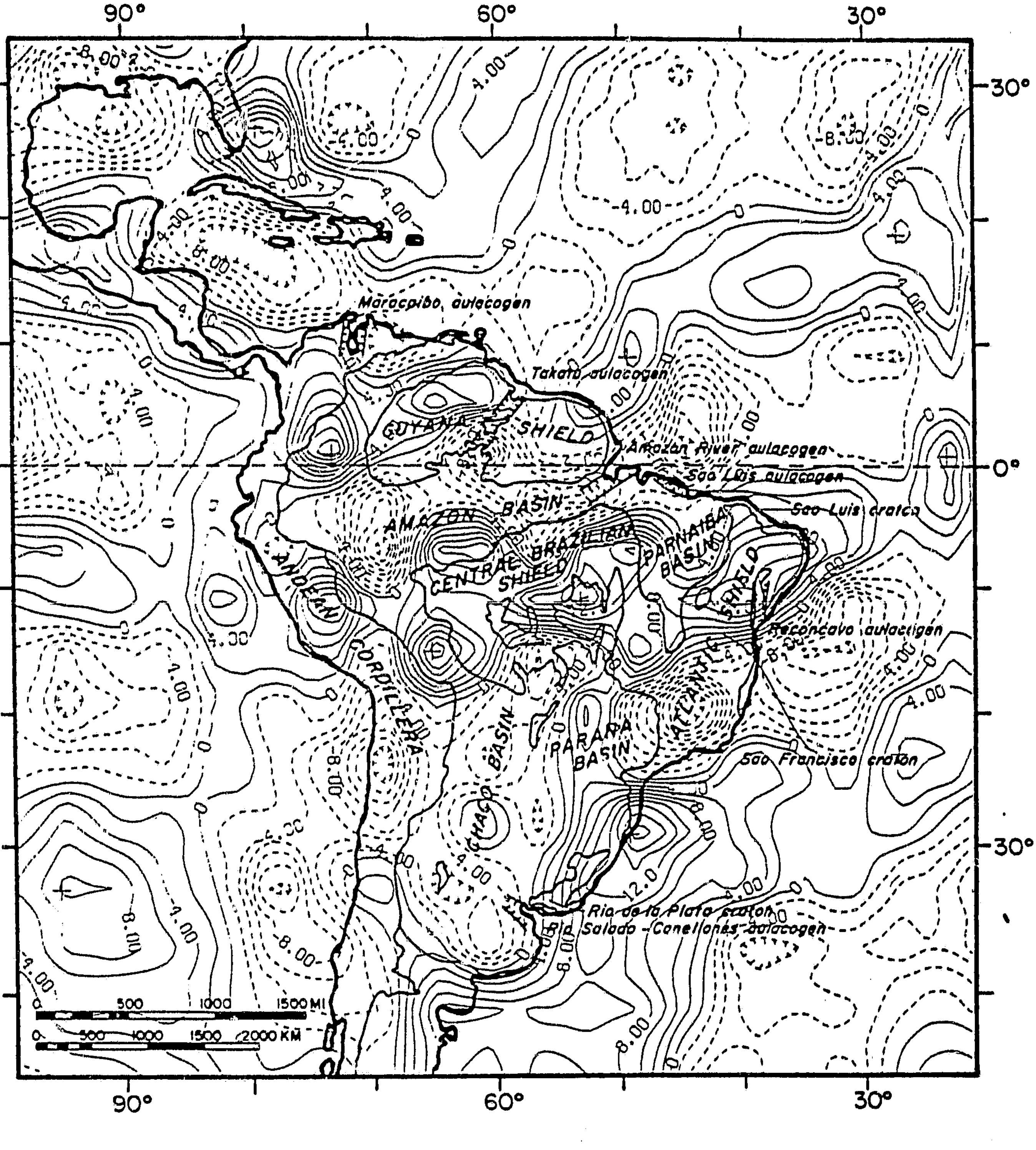

Figure 1. Reduced-to-pole MAGSAT scalar magnetic anomalies at 350 km over South America with major tectonic features. Contour interval is 2 nT.

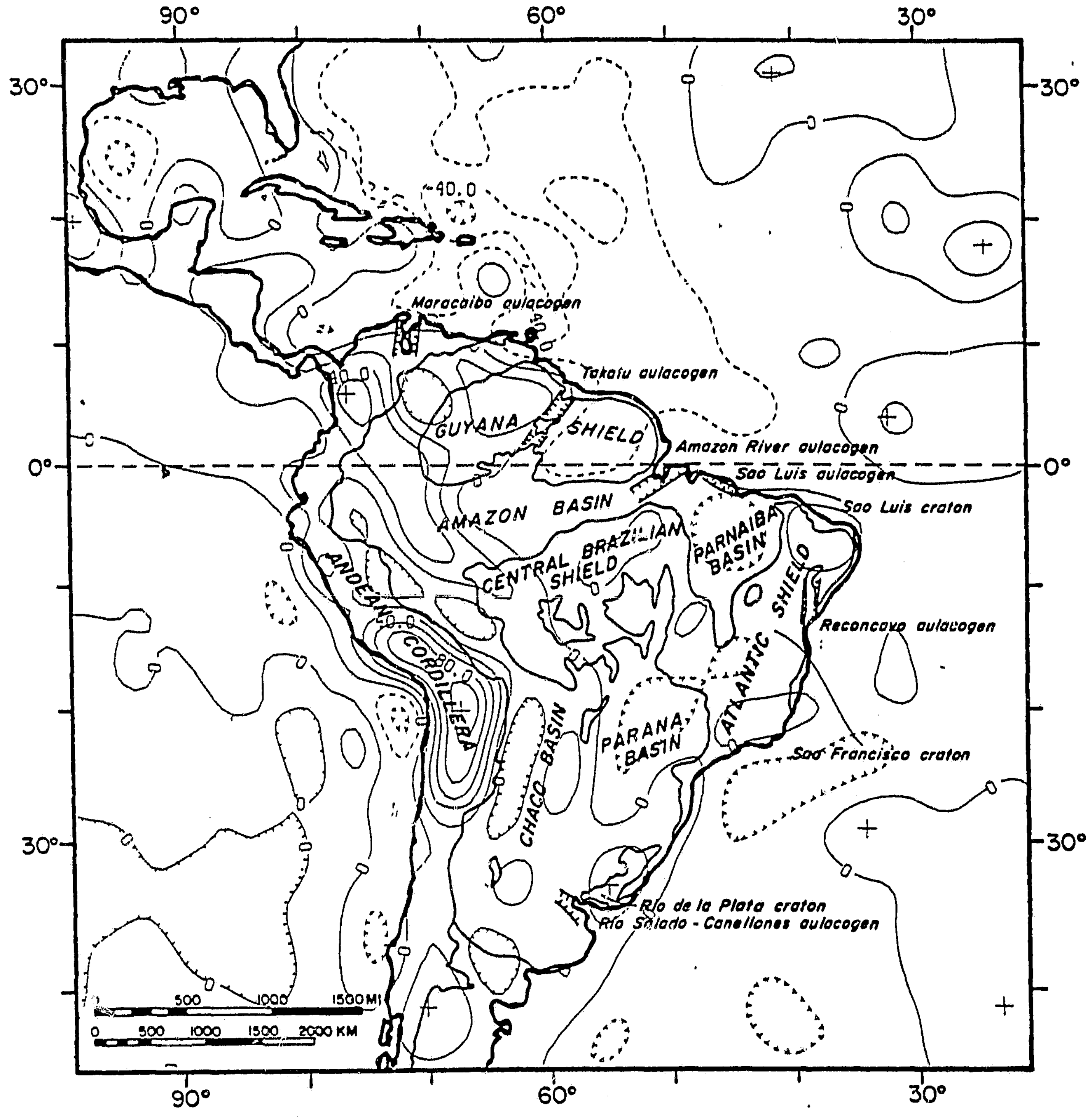

Figure 2. Free-air gravity anomaly at 350 km over South America with major tectonic features. Contour interval is 20 mGal.

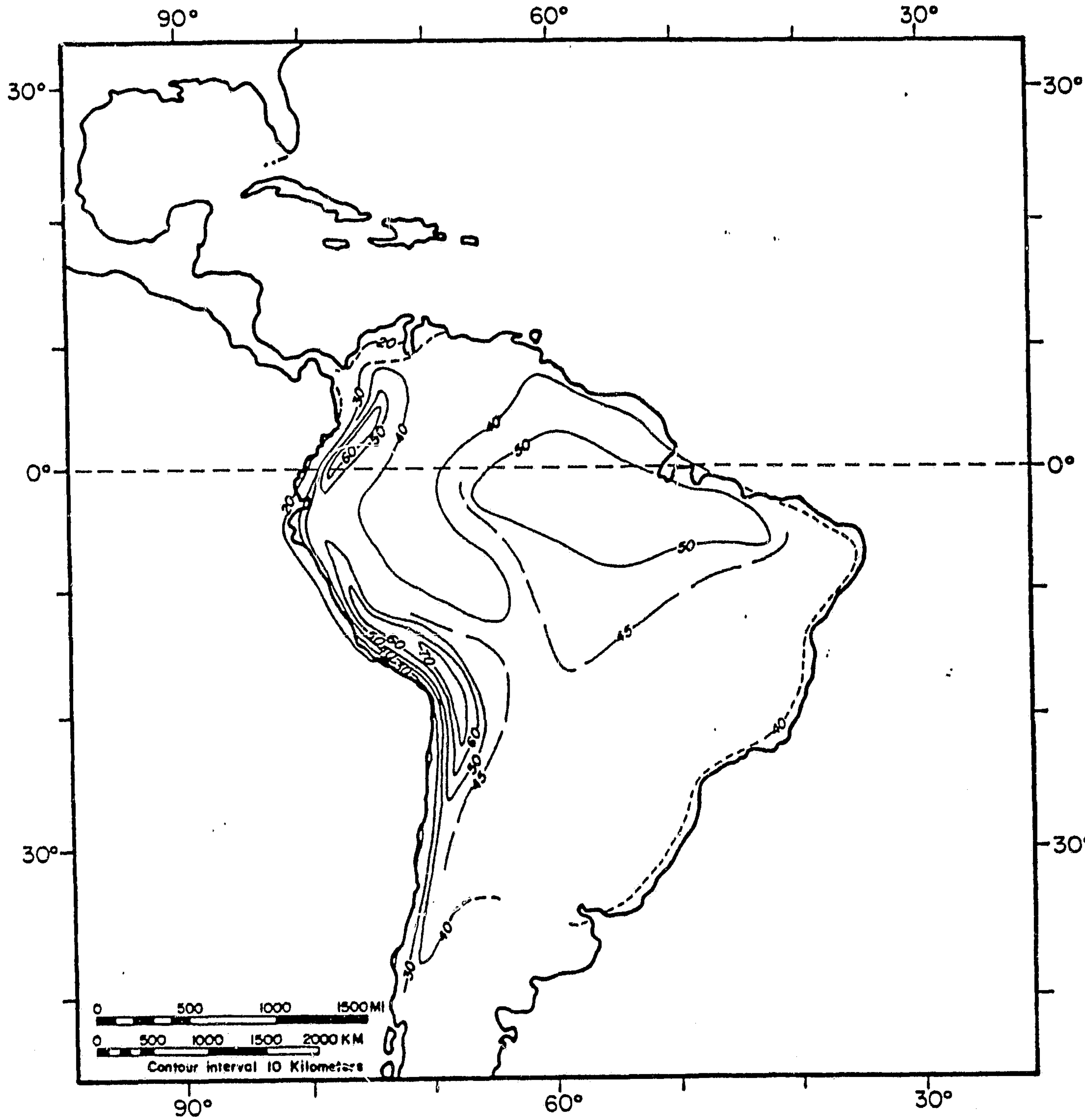

Figure 3. Depth to Moho from published data and surface-wave analysis. Contour interval is 5 and 10 km.

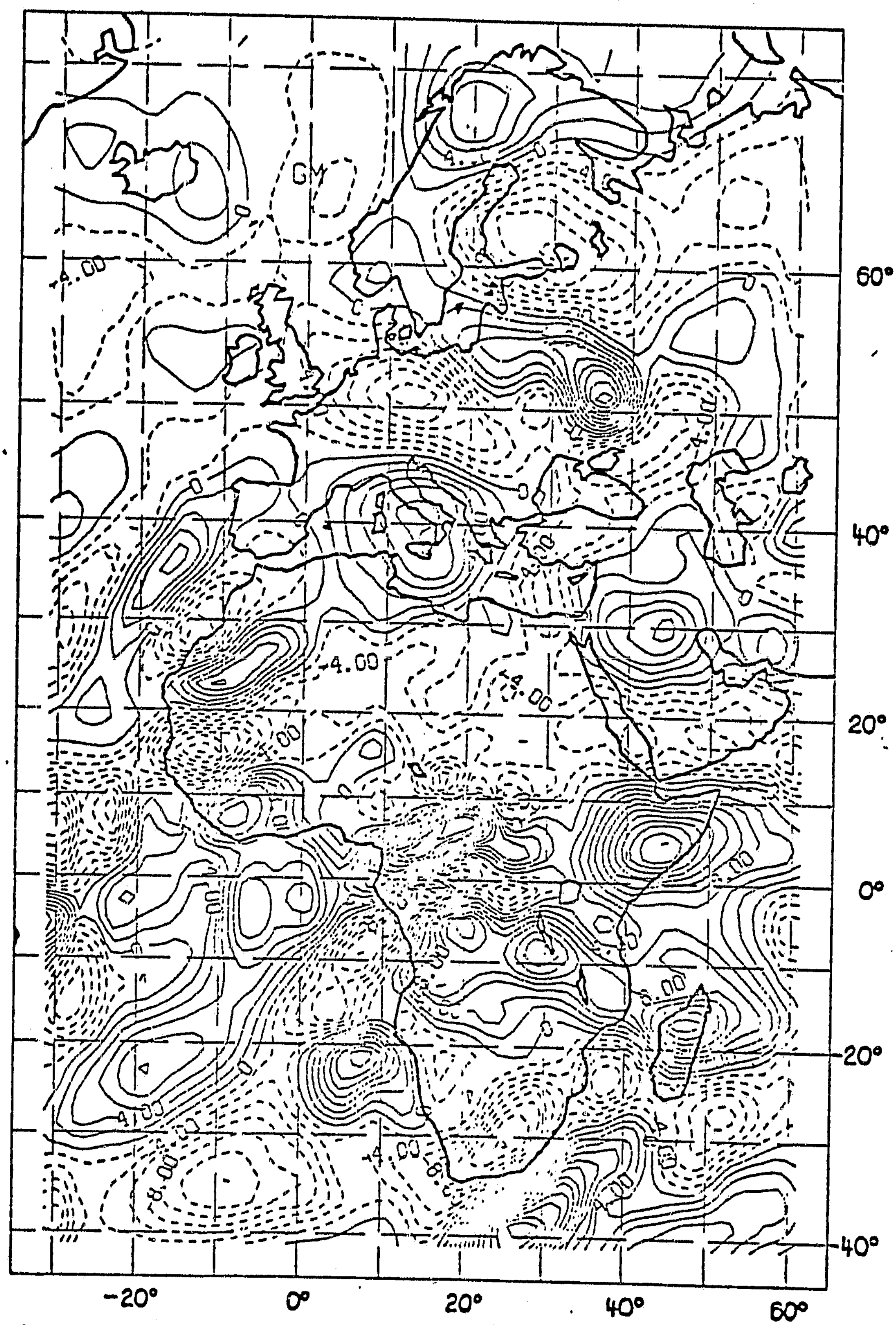

Figure 4. Reduced-to-pole MAGSAT scalar magnetic anomalies at 400 km elevation over Euro-Africa. Contour interval is 2 nT.

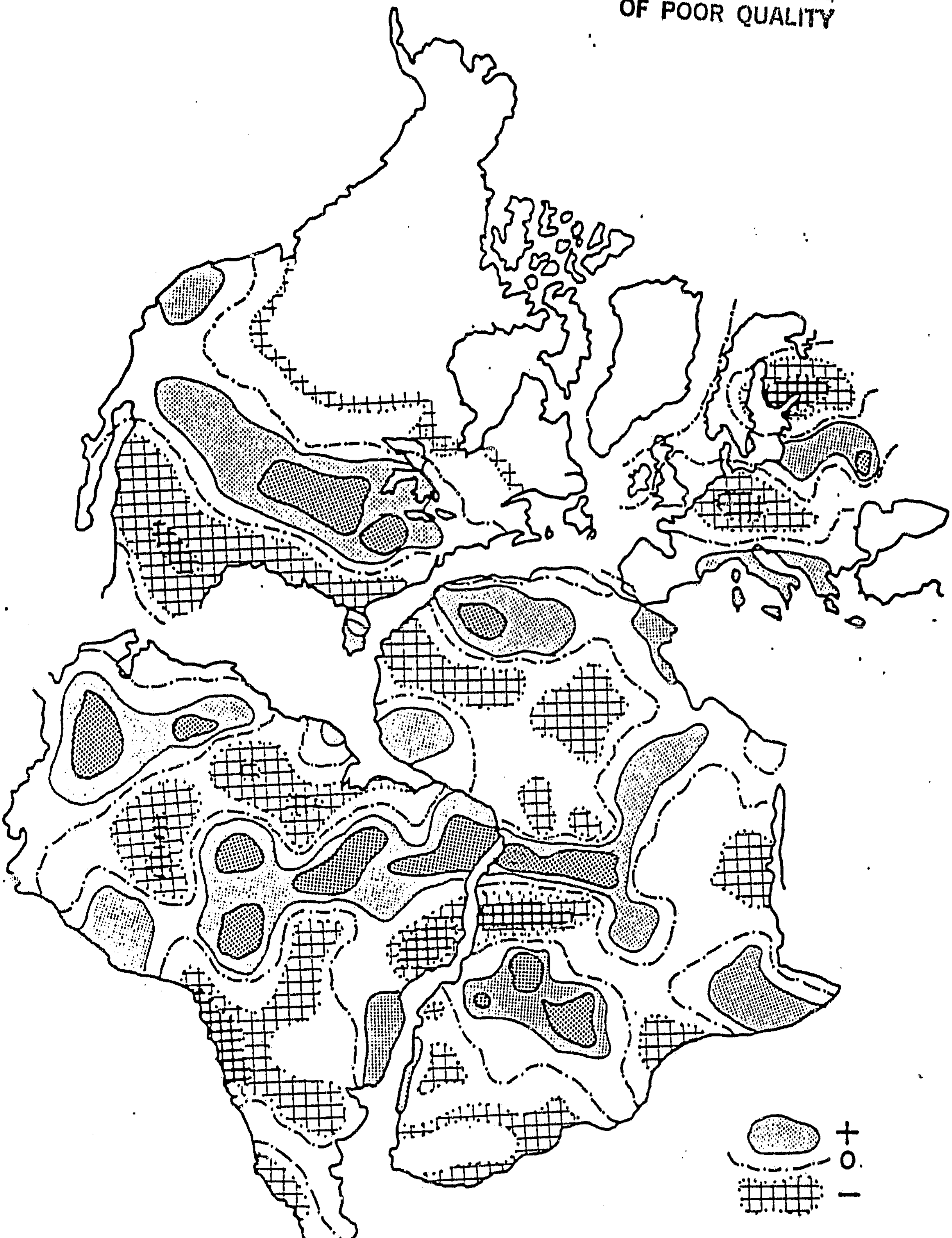

Figure 5. Partial reconstruction of the continents using reduced-to-pole satellite scalar magnetic anomalies.

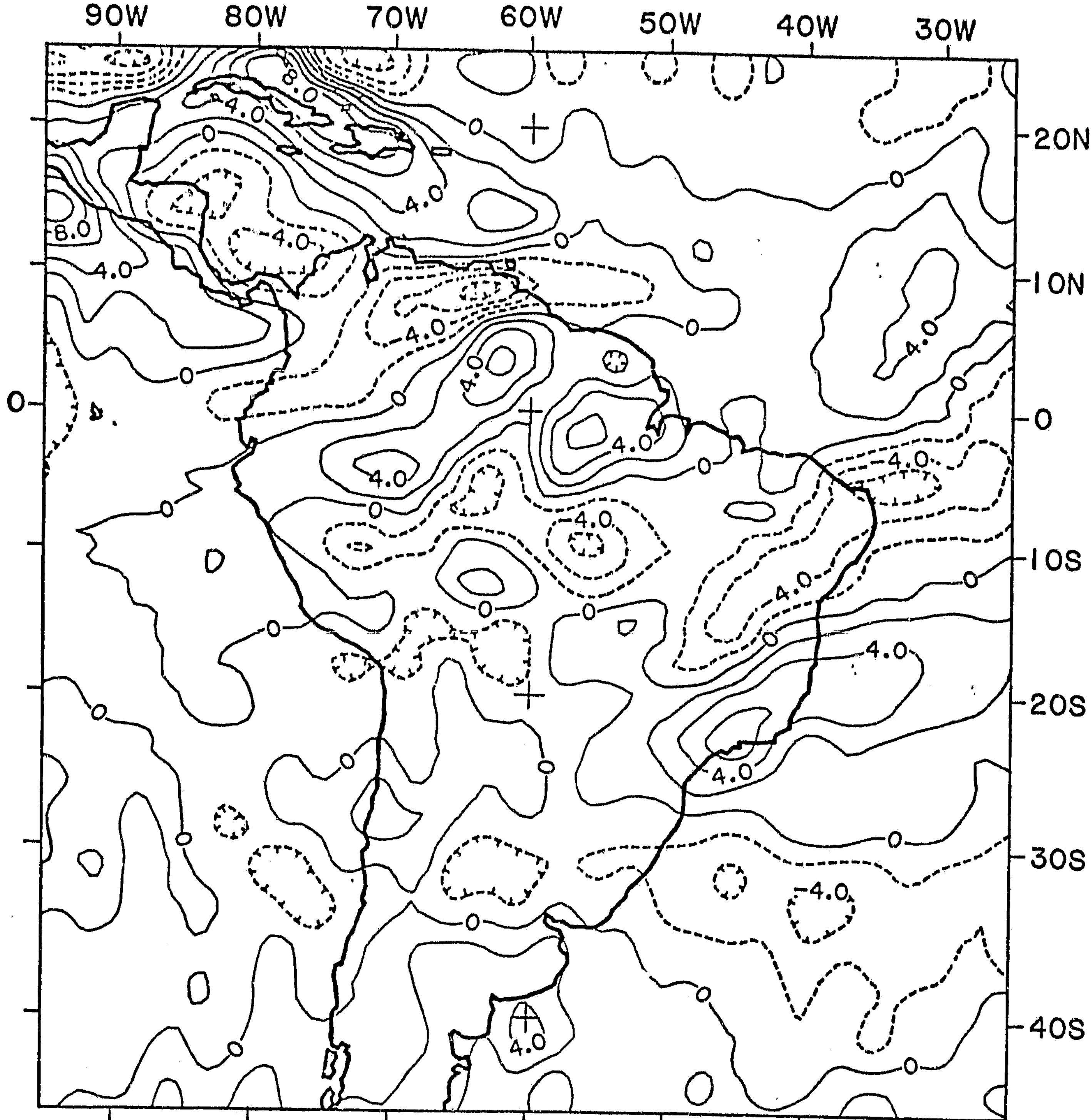

Figure 6. Bandpassed filtered (4° < λ < 50°) MAGSAT scalar magnetic anomalies at 350 km over South America. Contour interval is 2 nT.

APPENDIX A

Reprints of published articles,
expanded abstracts and abstracts.

GEOPHYSICAL RESEARCH LETTERS, VOL. 9, NO. 4, PAGES 314-317, APRIL 1982

REGIONAL MAGNETIC AND GRAVITY ANOMALIES OF SOUTH AMERICA

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Abstract. Preliminary satellite scalar magnetic anomaly data (MAGSAT) reduced to vertical polarization and long-wavelength-pass filtered free-air gravity anomaly data of South and Central America are compared to major tectonic features. A number of correlations are observed, but these must be generalized because of the preliminary nature of the geophysical data and the inherent petrophysical variations within tectonic features. Statistical analysis of the magnetic data reveals that South and Central America are more magnetic and magnetically more variable than adjacent marine areas. More obvious correlations exist between magnetic anomalies and tectonic elements of the continents than in the case of oceanic areas. No obvious correlations occur between the tectonic features of the Atlantic Ocean, including the Mid-Atlantic Ridge, and magnetic anomalies. The continental shields generally are more magnetic than adjacent basins, oceans and orogenic belts. In contrast, the major aulacogens are characterized by negative magnetic anomalies. Positive free-air gravity anomalies are related to the Andean Foldbelt, but the relationship of this feature to magnetic anomalies is much less obvious. However, along the west coast of South America, the magnetic anomalies of the Pacific Ocean are separated from those of the eastern platforms by north to northwest trending anomalies. South of the equator along the Foldbelt, gravity maxima are related to magnetic minima, a relationship analogous to the situation observed in the Rocky Mountain Cordillera. North of the equator in Columbia, gravity and magnetic maxima roughly correlate along the Foldbelt.

Introduction

A wide variety of significant geologic problems are represented by the complex geological-geophysical setting of South and Central America and adjacent marine areas. This region includes tectonically active areas, a number of lithospheric plates, advancing and trailing plate margins, hotspots, aulacogens, strong contemporary seismicity and volcanism, well-delineated metallogenic zones in the Cordillera, and a complex mineral-rich Precambrian shield.

Long-wavelength magnetic and gravity anomalies and their correlations provide the opportunity to investigate the regional relations of these features. For the South America region, potential field anomaly compilations are especially important to megatectonic investigations because of access problems which limit surface geologic and geophysical mapping.

Accordingly, preliminary 2°-averaged satellite magnetic anomaly values derived from the recent MAGSAT mission are compiled for South America. These data are differentially reduced to the pole (vertical magnetic polarization) for comparison with tectonic data and surface free-air gravity anomalies upward continued to satellite elevations. Finally, visual spatial correlations between the regional magnetic and gravity anomalies and tectonic data are considered in the context of their potential geological significance.

Data Sources and Preprocessing

The satellite magnetic anomalies used in this investigation are compiled from a preliminary scalar MAGSAT data set from observations made during "quiet day" periods of low temporal magnetic variations. The data set is based upon the average areal value of data taken below 400 km with an average elevation of approximately 350 km. An average of 12 data points with a range from 3 to 32 points per 2° area were used to calculate the average values. The preliminary geomagnetic reference field model MG680982 developed by NASA-GSFC was used to remove the geomagnetic core field component of the data. Comparison of this preliminary MAGSAT data set with POGO magnetic anomalies [Langel, 1979] shows excellent consistency over South America. A subset of these preliminary global MAGSAT data was compiled for the region (99°W-21°W), (45°S-33°N) and differentially reduced to the pole by least squares matrix inversion [von Frese et al., 1981a] on a spherical earth using the IGS-75 field updated to 1980 and an inducing field of 60,000 nT (Fig. 1).

Surface 1°-gridded free-air gravity anomalies for the South America region were compiled from measured and predicted continental data, satellite derived oceanic values, shipborne measurements and interpolated values. Continental values were obtained from the free-air gravity map of South America provided by the Defense Mapping Agency Aerospace Center which includes observed

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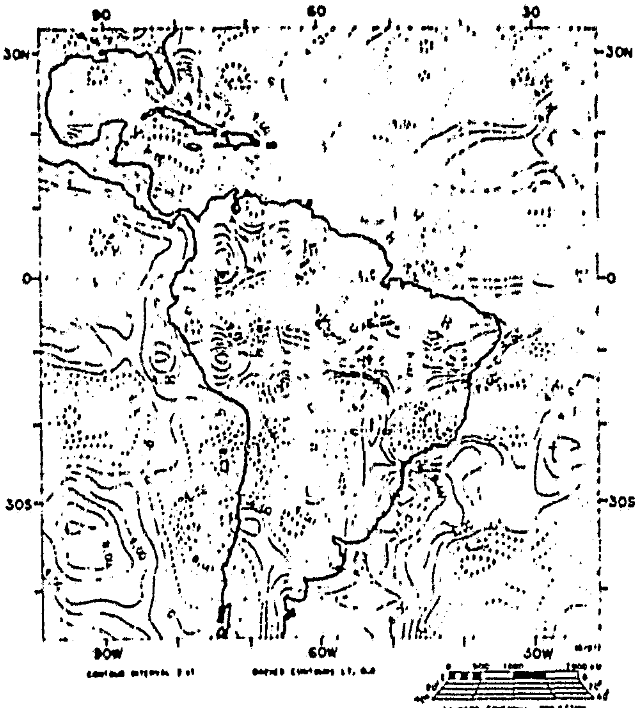

Fig. 1. Equivalent point source field approximation of 2°-averaged scalar MAGSAT magnetic anomaly data differentially reduced to radial polarization at 350 km elevation. The normalized amplitude for the polarizing induction field is 60,000 nT. Contour interval is 2 nT.

values, as well as some predicted values [Woollard and Strange, 1966] largely based on geologic and topographic considerations. Oceanic free-air gravity values were derived principally from GEOS-3 geodetic satellite altimetry data converted to gravity values [Rapp, 1979].

To enhance the longer wavelength components of the 1°-gridded free-air gravity anomalies, as well as to facilitate subsequent inversion processing, the data set was long-wavelength-pass filtered for wavelengths greater than roughly 8° (Fig. 2). For comparison with the satellite magnetic anomalies, the filtered gravity data set was upward continued to 350 km elevation (Fig. 3) by equivalent point source inversion.

To facilitate comparisons between potential field anomalies and tectonic features, a regional tectonic map of Latin America is presented in Figure 4 which emphasizes features with wavelengths of the order of 200 km or greater [Longacre, 1981]. The South American Platform, the largest and geologically oldest of the major tectonic subdivisions, includes continental terrain east of the Andean Foldbelt and north of about 35°S latitude. It consists of Precambrian basement rocks which in places are overlain unconformably with sedimentary and volcanic rocks of Silurian and younger age. The Patagonian Platform with basement rocks of Middle Paleozoic age includes the continental region of South America south of roughly 35°S and east of the Andes. These basement rocks are largely masked by a volcanic-sedimentary rock cover that developed after the Carboniferous. The Andean Cordillera constitute the entire western margin of South America with the northern portion merging into the Caribbean tectonic complexes. This foldbelt consists of rocks dating from the Precambrian to recent time and contains areas of strong seismicity and volcanism, as well as some of the richest metallogenic zones in the world.

Magnetic and Gravity Anomaly - Tectonic Observations

A number of interesting associations between regional tectonic features and magnetic and free-air gravity anomalies are evident by comparing Figures 1 through 4. However, the correlations are seldom exact and are not universal because of the limited resolution and potential imprecision of the averaged and preliminary nature of the magnetic data set, the limited gravity observation coverage and the inherent petrophysical variations within the tectonic elements. In the most regional sense there appears to be a relationship between satellite magnetic anomalies and continental areas (Fig. 1). The magnetic anomalies of the continent are observed to be more positive and more variable than the oceanic anomalies. This is particularly evident in Central America. In an attempt to quantify this subjective observation, the continental and oceanic magnetic data sets were separated and statistically analyzed. The frequency distribution of the oceanic and continental magnetic anomaly amplitudes (Fig. 5) reveals the mean of the oceanic anomalies is -0.9 nT and that of the continents, including the continental shelf, is +0.7 nT, with the continents having a higher standard deviation. A variance test (F test) and a mean test indicate that the oceanic and continental anomalies represent two signifi-

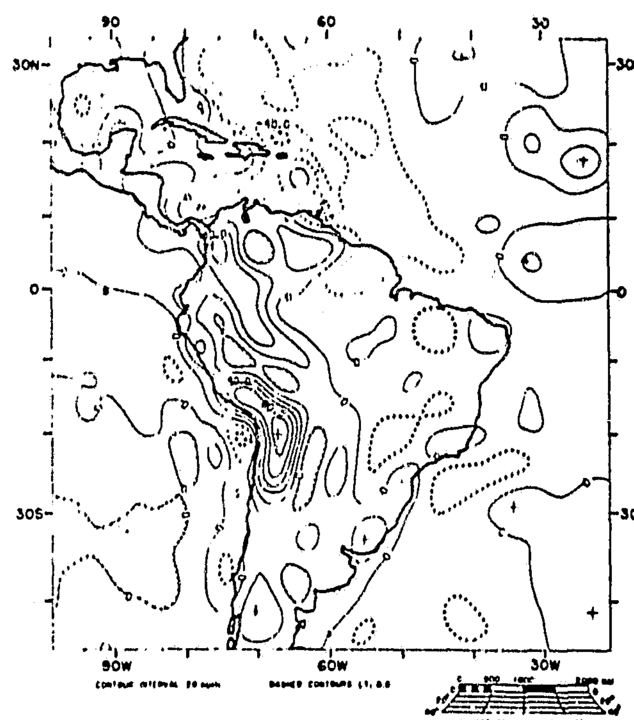

Fig. 2. Long-wavelength-pass ($\lambda \geq 8°$) filtered, surface free-air gravity anomaly map of South America and adjacent areas. Contour interval is 20 mgals.

cantly different populations at the 99% and 99.9% level of significance respectively. Thus, these preliminary results suggest that the continents are more magnetic and variable in their magnetization than the oceans. The former is compatible with the conclusions reached by Wasilewski et al. [1979] that the seismic Moho can be a magnetic boundary and the upper mantle only weakly magnetic. The more variable magnetization of the continents presumably reflects their long and complex geologic history which has led to strong horizontal magnetic polarization variations in the crust.

The strikes of the smoothed surface free-air gravity anomalies (Fig. 2) generally are consistent with tectonic trends. However, at 350 km elevation the gravity data (Fig. 3) have a decidedly north to northwest trend which reflects the dominating effects of the Andean Foldbelt and the features of the eastern margin of the Caribbean Plate at the longer wavelengths. The satellite magnetic data (Fig. 1) by contrast exhibit prominent east-west trends which, although consistent with tectonic features, may also be related to processing noise derived from data reduction efforts to correct for external magnetic field effects, especially in equatorial latitudes [Regan et al., 1981]. In both geophysical data sets, the leading edge of the South American Plate marks an effective boundary between Pacific anomalies of the Nazca Plate and continental anomalies of South America. The trailing edge, by contrast, is characterized by gravity and magnetic anomalies which commonly extend across the eastern continental margin of South America into the Atlantic Ocean.

The major shield areas of South America - Guiana, Central Brazilian, Sao Luiz Craton, Sao

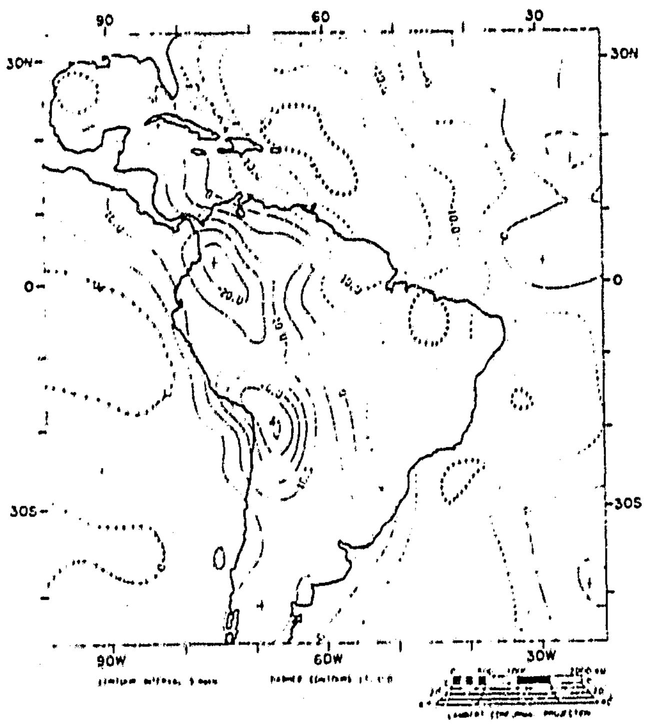

Fig. 3. Free-air gravity anomaly map of South America (Fig. 2) upward continued to 350 km elevation by equivalent point source inversion. Contour interval is 5 mgals.

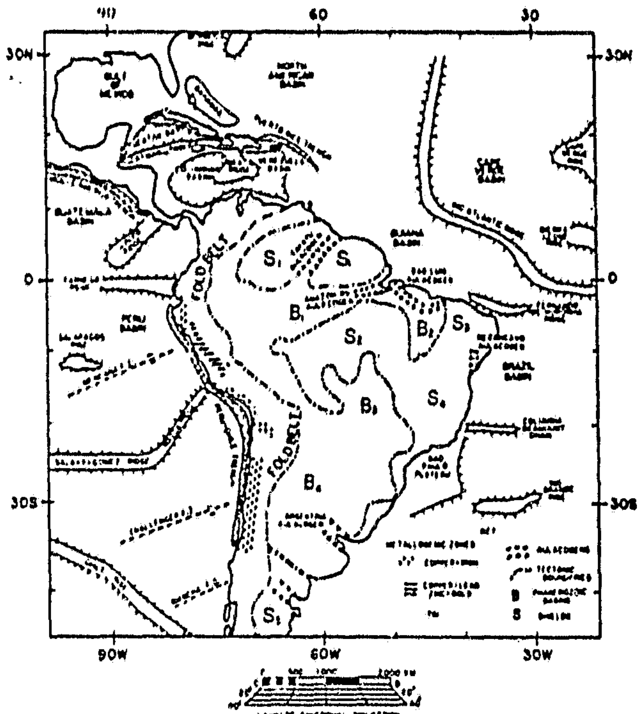

Fig. 4. Generalized tectonic divisions of South America and adjacent areas. S_1 - Guiana Shield, S_2 - Central Brazilian Shield, S_3 - Sao Luiz Craton, S_4 - Sao Francisco Craton, S_5 - Patagonian Platform, B_1 - Amazon River Basin, B_2 - Parnaiba Basin, B_3 - Parana Basin, and B_4 - Chaco Basin.

Fransicso Craton and the Patagonian Platform (Fig. 4) - are associated with positive magnetic anomalies and no definitive gravity anomalies. In contrast, many of the intra-cratonic basins - Amazon River, Parana, Parnaiba and Chaco (Fig. 4) - are related to negative magnetic anomalies. The Takatu, Amazon River, and Sao Luiz aulacogens also are associated with negative magnetic anomalies that correlate with local positive gravity anomalies. This inverse correlation of anomalies also is observed for the Mississippi Embayment aulacogen where the source of these anomalies has been attributed to either an intra-layer lithologic variation or upwarp of the Curie isotherm in the lower crust [von Frese et al., 1981b]. The major tectonic break between the Chaco Basin and the Patagonian Platform to the south appears as a linear magnetic high which extends into the Andean Foldbelt.

The Andean Foldbelt is dominated by positive gravity anomalies (Figs. 2 and 3). The correlation of magnetic anomalies (Fig. 1) with this tectonic zone is much less obvious and more variable. However, in a general way the magnetic anomalies of the eastern Pacific Ocean are separated from those of the eastern platforms by north to northwest anomaly trends. South of the equator an inverse relationship exists between positive gravity and negative magnetic anomalies. This relationship is consistent with observations by von Frese et al. [1982] for the North American Cordillera, where this inverse correlation may result from regionally higher temperature associated with geodynamic processes which produce thinned crust, mantle intrusives and an inflated elevation that

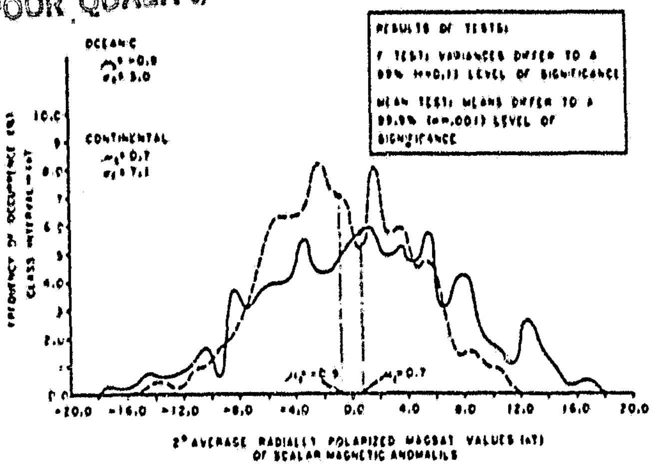

Fig. 5. Frequency distributions for oceanic and continental radially polarized MAGSAT magnetic anomaly data at 350 km elevation for South America and adjacent areas.

may not be isostatically compensated. A parallel zone of negative gravity and positive magnetic anomalies occurs along the eastern flank of the Andean Foldbelt. Similar inverse relationships, observed for continental regions east of the North American Cordillera are shown by seismic evidence to be characterized by thickened crust [von Frese et al., 1982]. This zone is bordered farther eastward by a less obvious linear trend of positive gravity and negative magnetic anomalies that includes the western flank of the Central Brazilian Shield.

Potential field anomalies along the Andean Foldbelt and Central America roughly north of the equator, in general, show direct correlation between positive gravity and magnetic anomalies. The large positive free-air gravity anomaly over Columbia correlates with a linear ophiolite (greenstone) sequence. Seismic refraction measurements in western Colombia indicate higher velocities and density for the rocks associated with this gravity anomaly [Meyer et al., 1973]. Further evidence for the mafic character of these rocks is suggested by the corresponding positive satellite magnetic anomaly which characterizes the region as a zone of enhanced magnetization.

The adjacent marine areas also demonstrate a variety of associations between potential field anomalies and tectonic features that can be useful for understanding the geologic characteristics and history of the area. The Pacific Ocean region, for example, generally exhibits a pattern of inverse correlations between the potential field anomalies with ridges and rises occurring along the flanks of the regional anomalies. The Gulf of Mexico and the Caribbean Sea are gravity and magnetic minima, although the correlation is inexact particularly because of a gravity ridge which separates the Columbian and Yucatan Basins. Potential field anomalies over the Atlantic Ocean adjacent to South America are inconsistent and lack correlation to trends of tectonic features including the Mid-Atlantic Ridge.

Although these complicated anomaly patterns mirror a complex assortment of crustal structures and lithological variations, they also undoubtedly reflect the preliminary character of the data sets used in this study. Efforts currently are underway to develop an improved set of MAGSAT scalar and vector magnetic anomaly data for geologic analysis and modeling. In consideration of the correlations demonstrated by this preliminary investigation, these efforts are anticipated to significantly enhance our understanding of the structure, dynamics and geologic history of the crust and upper mantle of South America.

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EURO-AFRICAN MAGSAT ANOMALY-TECTONIC OBSERVATIONS

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Preliminary satellite (MAGSAT) scalar magnetic anomaly data are compiled and differentially reduced to radial polarization by equivalent point source inversion for comparison with tectonic data of Africa, Europe and adjacent marine areas. A number of associations are evident to constrain analyses of the tectonic features and history of the region. Rift zones and aulacogens, for example, tend to be magnetically negative. The most intense positive anomaly of the region is the Bangui anomaly which has been interpreted as due to a deep crustal positive magnetization source. There are no near-surface sources which will explain this anomaly. By contrast, the next most intense positive anomaly is over the Kursk region in the Russian Ukraine. This anomaly extends 450 km in a northeasterly direction and is roughly 150 km wide, and is caused according to aeromagnetic anomaly interpretations by near-surface, intensely magnetic ferruginous quartzites. Apparently there is sufficient long-wavelength energy in these near-surface anomalies for them to be observed at satellite elevations. The Precambrian shields of Africa and Europe exhibit varied magnetic signatures. All shields are not magnetic highs and, in fact, the Baltic shield is a marked minimum. The reduced to the pole magnetic map shows a marked tendency for northeasterly striking anomalies in the eastern Atlantic and adjacent Africa, which is coincident to the track of several hot spots for the past 100 million years. However, there is little consistency in the sign of the magnetic anomalies and the track of the hot spots. Comparison of the radially polarized anomalies of

Africa and Europe with other reduced to the pole magnetic satellite anomaly maps of the western Hemisphere support the reconstruction of the continents prior to the origin of the present-day Atlantic Ocean in the Mesozoic Era.

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CORRELATION OF TECTONIC PROVINCES OF SOUTH AMERICA AND THE CARIBBEAN REGION WITH MAGSAT ANOMALIES

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Intensities of satellite scalar magnetic anomaly data (MAGSAT) correlate with the main tectonic provinces of South America and the Caribbean region. Magnetic anomalies of the continents generally have higher amplitudes than oceanic anomalies. This is particularly evident in Central America and in the shield areas of South America. The Caribbean Sea and Gulf of Mexico are underlain by prominent magnetic minima. Within these oceanic areas, linear magnetic highs correlate with topographic ridges which separate the Gulf of Mexico, the Colombian Basin, and the Venezuelan Basin.

South America is divisible into a broad craton of Precambrian shields and platforms separated by Phanerozoic basins, grabens and aulacogens to the east, the Phanerozoic Patagonian platform to the south, and the Mesozoic to Cenozoic Andean foldbelt and Caribbean Mountain system to the west and north. The continental shields are mainly more magnetic than continental basins and orogenic belts. This is particularly true of the Guyana shield, the Central Brazilian shield, and parts of the Atlantic shield, all of which are coincident with magnetic highs. The Amazon basin (aulacogen) in contrast is associated with large magnetic lows. Other basins coincide either with magnetic lows or magnetic gradients. Platforms, mainly covered by younger sedimentary rocks, are generally associated with magnetic gradients. Most of the anomalies associated with the Patagonian platform are positive and the gradients have higher amplitudes east of the Andean foldbelt. The northern Andes are coincident with positive magnetic anomalies, whereas the central and southern Andes are associated mainly with negative anomalies.

The boundaries of the Caribbean plate occur along magnetic gradients. The gradients are particularly sharp along the northern and western margins of the plate, but are gradational along the southern margin where they merge with anomalies associated with the Andean Cordillera. The anomalies along the western margin of the South American plate are also distinct and appear to be separate from those of the adjacent ocean basin. In contrast, eastern South America is characterized by magnetic anomalies which commonly extend into the Atlantic Ocean.

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A SATELLITE MAGNETIC MODEL OF NORTHEASTERN SOUTH AMERICAN AULACOGENS

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Abstract. Magnetic modeling of the Amazon River and Takatu Aulacogens in northeastern South America illustrate the utility of satellite magnetic data in characterizing the properties and structure of the lithosphere. Specifically, reduction of preliminary MAGSAT scalar magnetic anomaly data to an equivalent condition of vertical polarization shows a general correlation between magnetic anomaly minima and the Amazon River and Takatu Aulacogens. Surface gravity data demonstrate a correlative positive anomaly. Spherical earth modeling of the magnetic data indicates a less magnetic crust associated with the aulacogens which is compatible with previous studies over the Mississippi River Aulacogen and Rio Grande Rift in North America.

Introduction

South America is particularly significant to regional geophysical investigations because it affords opportunities for integrated analysis of a broad range of geologically interesting tectonic features. However, surface acquisition of the necessary data for these studies frequently is inhibited due to the vast areas involved and problems of access. Hence, satellite geophysical data, such as the magnetic anomaly values obtained from MAGSAT, are especially useful in providing information for developing lithospheric models of major South American tectonic features.

A preliminary set of scalar MAGSAT data is utilized to investigate the magnetic structure and properties of the Takatu and Amazon River Aulacogens in northeastern South America previously recognized by Burke [1978]. The magnetic data are derived from preliminary 2°-averaged scalar MAGSAT magnetic anomaly values which Hinze et al. [1982] have reduced to the pole (equivalent vertical polarization) by equivalent point source inversion [von Frese et al., 1981a]. This radially polarized form of the anomaly data eliminates uncertainties in interpretation caused by the inclination and intensity of the earth's magnetic field which induces magnetization in the lithosphere at depths shallower than the Curie point isotherm of magnetic minerals. This procedure assumes the anomalous magnetic field is caused only by magnetization in the direction of the earth's magnetic field and the inducing field strength is 60,000 nT.

Hinze et al. [1982] present a description of the reduced to radial polarization MAGSAT scalar magnetic anomaly map and its qualitative correlation with regional gravity anomalies and tectonic features. A number of interesting correlations are observed, but they are generalized due to the preliminary nature of the geophysical data and the inherent variations of the petrophysical properties of the tectonic features. One of the more interesting correlations is the approximate spatial coincidence between the Amazon River and Takatu Aulacogens and magnetic anomaly minima shown in Figure 1. In the original 2°-averaged MAGSAT data set, prior to reduction to radial polarization, these correlative anomalies were positive and complicated by their location near the magnetic equator and the spatially rapidly varying magnetic field.

Relationship of Aulacogens to Geophysical Data

The aulacogens (failed-rifts), which originated in late Permian-early Jurassic time during the breakup of the continent of Pangea, are characterized by deep sedimentary troughs with near vertical faulting and associated basaltic intrusions. The troughs occur roughly perpendicular to the South American platform margin. They are associated with relative positive Bouguer gravity anomalies (Fig. 2) presumably related to the basaltic intrusions.

A similar anomaly relationship is observed over the younger, still active, Rio Grande Rift. Mayhew and Majer [1980] have discussed the satellite magnetic anomaly minimum associated with this rift. They suggest that the rift, which has a correlative free-air gravity positive anomaly over the southern extent of its length, is related to a decrease in the relative thickness of the magnetic crust caused by an upwarped Curie isotherm. However, this origin for the magnetic minima in northeast South America seems unlikely because of the great length of time since the formation of the aulacogens.

A similar inverse relationship between the magnetic anomaly minimum observed at satellite elevations by the Polar Orbiting Geophysical Observatory (POGO) and positive surface free-air gravity data has been observed over the Mississippi Embayment by von Frese et al. [1981a]. The embayment is a broad, spoon-shaped basin of Mesozoic and Cenozoic sedimentary rocks which extends into the North American craton from the Gulf Coast. Ervin and McGinnis [1975] suggest on the basis of gravity, crustal seismic, and geologic data that the embayment is the site of a late Precambrian aulacogen which was reactivated in late Cretaceous time by tensional forces initiated during the formation of the present Atlantic Ocean. von Frese et al. [1981b; 1981c] present a quantitative crustal model which duplicates the observed magnetic and gravity anomalies. Several origins are postulated [von Frese et al., 1981c] for satisfying the negative magnetic anomaly including: 1) Strong reversed magnetization of intrusives into the lower crust which were emplaced during the rifting process, 2) petrologic variations be-

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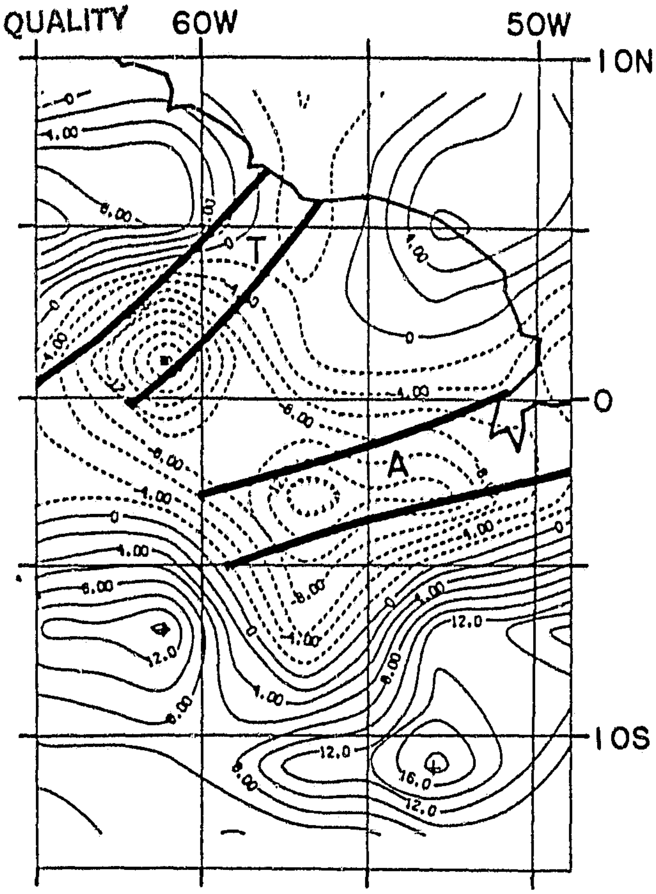

Fig. 1. Radially polarized magnetic anomaly map of northeastern South America derived from MAGSAT scalar data at an average elevation of 350 km. An inducing field of 60,000 nT is assumed. Contour interval is 2 nT. The locations of the Amazon River (A) and Takatu (T) Aulacogens are generalized from Burke [1978], de Almeida [1975] and Potter [1978].

tween the normal lower crustal rock, which is generally highly magnetic, and the intrusions into the crust from the mantle, and 3) increased temperatures in the embayment region which raises the Curie point isotherm from a normal position near the base of the crust to within the crust, thereby decreasing the overall magnetization of the crust.

In general, little evidence currently is available to support or discriminate between these hypotheses for the crustal structure of the embayment. Furthermore, other studies by Mayhew et al. [1980] in Australia and globally by Frey [1979] indicate the rifts and aulacogens are not universally represented by negative satellite magnetic anomalies. Hence, it appears that aulacogens and rifts are manifested in a variety of ways within the magnetic crust, where their variable geophysical signatures may provide clues for understanding their origin and subsequent geologic evolution.

Spherical-Earth Modeling of Aulacogens

A three-dimensional, spherical earth model of the aulacogens was developed using a Gauss-Legendre quadrature integration technique [von Frese et al., 1981b] and radially polarized scalar magnetic anomaly data. The magnetic model (Fig. 3) consists of simplified spherical prisms which produce an anomaly comparable to the observed data at 350 km elevation.

The three positive anomalies, A, D, and E, of Figure 3 represent the Guiana and Central Brazilian Shields by the prisms illustrated which have a relative anomalous magnetization of 2 A/m between depths of 10 to 50 km. These model parameters are consistent with the arguments of Wasilewski et al. [1979] that suggest sources of long-wavelength magnetic anomalies are concentrated in the lower crust which, in general, is substantially more magnetic than the upper crust. Typical estimates of deep crustal magnetization are on the order of 5 A/m [e.g., Hall, 1974; Shuey et al., 1973].

The magnetic anomaly minima associated with the aulacogens are modeled approximately by prisms B and C which respectively have relative anomalous magnetizations of -4 A/m from 20 to 40 km and -3 A/m from 25 to 40 km. However, the resolution of sources by modeling is limited, thus anomalous magnetization may be decreased with an increased prism thickness and vice versa. The same limita-

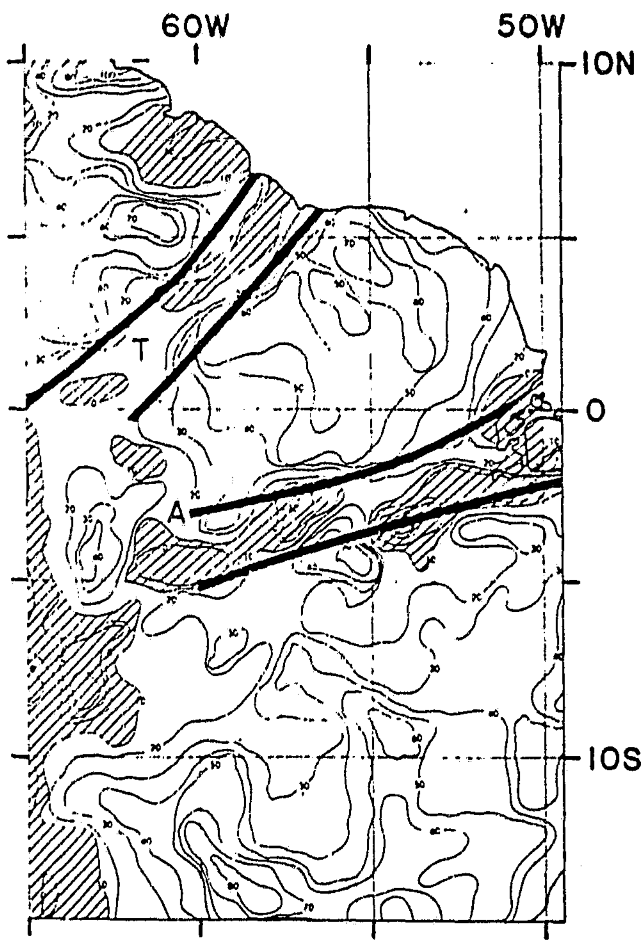

Fig. 2. Bouguer gravity anomaly map of northeastern South America [Wilcox, 1981]. Contour interval is 10 mgal, where shading indicates anomaly values ≥ -10 mgals. The locations of the Amazon River (A) and Takatu (T) Aulacogens are generalized from Burke [1978], de Almeida [1978] and Potter [1978].

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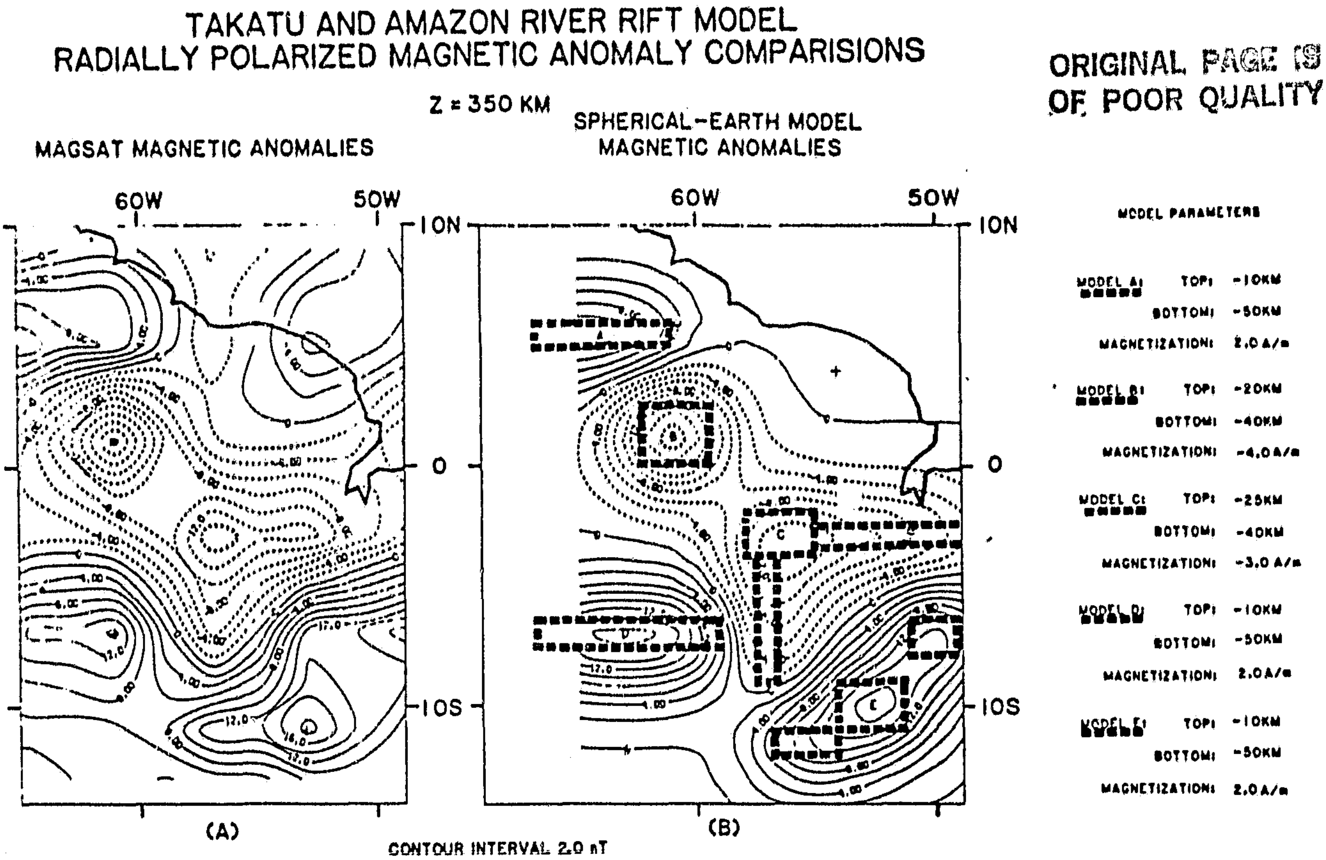

Fig. 3. Comparison at 350 km elevation of radially polarized magnetic anomalies derived from scalar MAGSAT data over northeastern South America (A) and modeled magnetic anomalies (B) which includes location and characteristics of anomaly source models. Contour interval is 2 nT.

tion is present in considering the prism sources of the positive magnetic anomalies. The sources of the anomaly minima have been modeled with prisms which approximate deficiencies in magnetization in the lower crust associated with the aulacogens similar to the model developed by von Frese et al. [1981c] for the Mississippi Embayment Aulacogen. The prism associated with the Takatu Aulacogen does not have the linear character of the aulacogen as delineated by Burke [1978] and the Amazon River Aulacogen model includes a low magnetization arm extending to the south from the Amazon River. No correlative gravity anomaly (Fig. 2) is observed with this south striking arm, suggesting that its source is probably not related to the aulacogen.

Conclusions

Modeling procedures are used with MAGSAT anomalies to investigate the Takatu and Amazon River Aulacogens of South America. Positive gravity and negative magnetic anomalies characterize these features analogous to the regional inverse correlations observed for the Mississippi River and Rio Grande Rift. Indeed, a synthesis of the preliminary 2°-averaged MAGSAT data and deep crustal magnetization information leads to a model that compares favorably with Mississippi Embayment Aulacogen model characteristics derived from POGO anomaly considerations by von Frese et al. [1981b; 1981c].

In general, the models presented here are consistent with the aulacogen hypothesis for the tectonic origins of the anomalies. These results suggest that an aulacogen may be characterized at satellite elevations by observable negative magnetic anomalies related to the rift component that defines a nonmagnetic block of material within the lower crust. It should be emphasized, however, that these models lead to a variety of interpretations which can only be discriminated on the basis of auxiliary geological and geophysical information.

Finally, although the preliminary character of the 2°-averaged MAGSAT data set used in this study obviously limits the geological implications of the models, these results clearly do indicate that the MAGSAT data provide geologically reasonable constraints for investigating the structure and properties of regional lithospheric features.

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SATELLITE ELEVATION MAGNETIC AND GRAVITY MODELS OF MAJOR SOUTH AMERICAN PLATE TECTONIC FEATURES

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Magsat scalar and vector magnetic anomaly data together with regional gravity anomaly data are being used to investigate the regional tectonic features of the South American Plate. An initial step in this analysis is three-dimensional modeling of magnetic and gravity anomalies of major structures such as the Andean subduction zone and the Amazon River Aulacogen at satellite elevations over an appropriate range of physical properties using Gauss-Legendre quadrature integration method. In addition, one degree average free-air gravity anomalies of South America and adjacent marine areas are projected to satellite elevations assuming a spherical earth and available Magsat data are processed to obtain compatible data sets for correlation. Correlation of these data sets is enhanced by reduction of the Magsat data to radial polarization because of the profound effect of the variation of the magnetic inclination over South America. The results of the modeling and correlation of magnetic and gravity anomalies are used with other regional geophysical data and geologic information to illustrate the utility of satellite magnetic data in characterizing the properties and structure of the South American Plate.

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REDUCED TO POLE LONG-WAVELENGTH MAGNETIC ANOMALIES OF AFRICA AND EUROPE

R. Olivier - University of Lausanne; W.J. Hinze - Purdue University; and R.R.B. von Frese - Ohio State University

To facilitate analysis of the tectonic framework for Africa, Europe and adjacent marine areas, magnetic satellite (MAGSAT) scalar anomaly data are differentially reduced to the pole and compared to regional geologic information and geophysical data including surface free-air gravity anomaly data upward continued to satellite elevation (350 km) on a spherical earth. Comparative analysis shows magnetic anomalies correspond with both ancient as well as more recent Cenozoic structural features. Anomalies associated with ancient structures are primarily caused by intra-crustal lithologic variations such as the crustal disturbance associated with the Bangui anomaly in west-central Africa. In contrast, anomalies correlative with Cenozoic tectonic elements appear to be related to Curie isotherm perturbations. A possible example of the latter is the well-defined trend of magnetic minima that characterize the Alpine orogenic belt from the Atlas mountains to Eurasia. In contrast, a well-defined magnetic satellite minimum extends across the stable craton from Finland to the Ural mountains. Prominent magnetic maxima characterize the Arabian plate, Iceland, the Kursk region of the central Russian uplift, and generally the Precambrian shields of Africa.

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SATELLITE MAGNETIC ANOMALIES OF AFRICA AND EUROPE

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Preliminary satellite (MAGSAT) scalar magnetic anomaly data of Africa, Europe, and adjacent marine areas have been reduced to the pole assuming a constant inducing earth's magnetic field of 60,000 nT. This process leads to a consistent anomaly data set free from marked variations in directional and intensity effects of the earth's magnetic field over this extensive region. The resulting data are correlated with long wavelength-pass filtered free-air gravity anomalies; regional heat flow, and tectonic data to investigate megatectonic elements and the region's geologic history. Magnetic anomalies are related to both ancient as well as more recent Cenozoic structural features. The anomalies associated with ancient structure primarily are caused by intracrustal lithologic variations such as the crustal disturbance associated with the Bangui anomaly in west-central Africa. In contrast, anomalies correlative with Cenozoic tectonic elements appear to be primarily related to Curie isotherm perturbations. A possible example of the latter is the well defined trend of magnetic minima that characterize the Alpine orogenic belt from the Atlas Mountains to Eurasia. Western Europe particularly is dominated by the Alpine (?) magnetic minimum. Prominent magnetic maxima characterize the Arabian plate, Scandinavia, Iceland, and the Kursk region of the central Russian uplift. A well-defined satellite magnetic minima extends from Finland across Russia to the Ural Mountains which correlates with a heat flow minimum and increased crustal thickness.

Processed preliminary satellite (MAGSAT) scalar magnetic anomaly data are useful in studying and providing constraints for the investigation of the megatectonic features and geologic history of Africa, Europe, and adjacent marine areas. These studies are facilitated by the integration of long wavelength-pass filtered free-air gravity anomalies, regional heat flow, and tectonic data with the magnetic anomalies. The scalar magnetic anomaly map shown in Figure 1 was derived from satellite observations acquired during "quiet day" periods of low temporal magnetic variations. This data set, which was provided by NASA-GSFC, is based on average 2° x 2° areal measurements obtained at an average elevation of about 400 km. The anomalous component was calculated by removing from the observed data the core field magnetic effect, as defined by the preliminary reference field model MG680982 developed by NASA-GSFC.

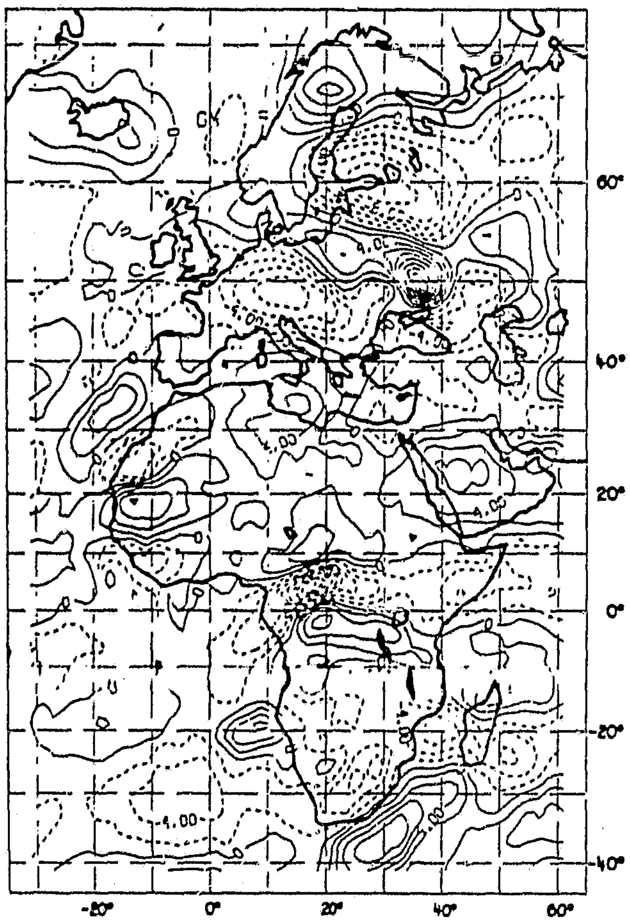

FIG. 1. Total magnetic intensity anomaly map of Africa and Europe derived from Magsat satellite 2°-mean values at an average elevation of about 400 km. Contour interval is 2 nT.

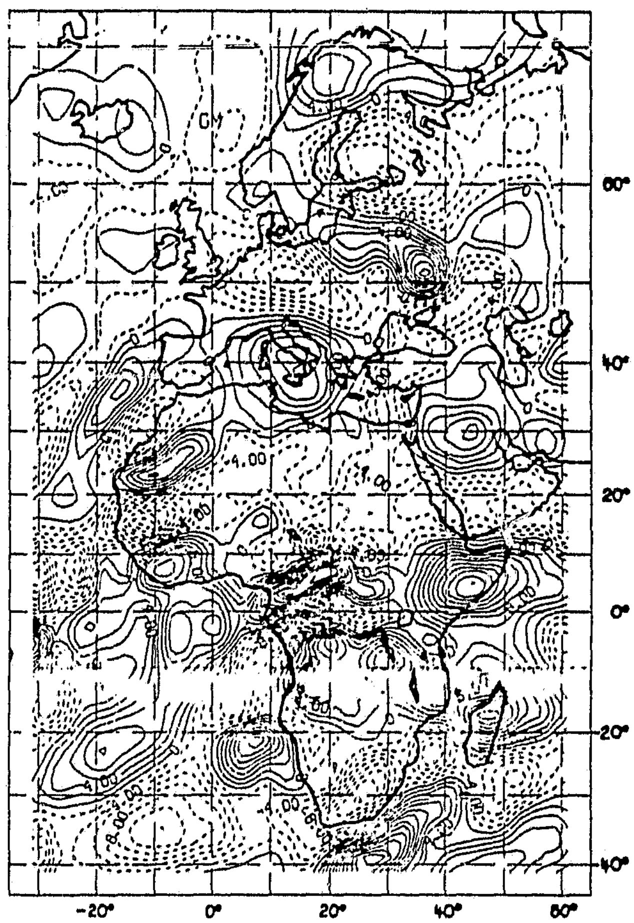

FIG. 2. Equivalent point source field approximation of 2°-averaged scalar Magsat magnetic anomaly data differentially reduced to radial polarization at 400 km elevation. The normalized amplitude for the polarizing field is 60,000 nT. Contour interval is 2 nT.

The region under investigation extends from mid-southern to high northern latitudes and thus shows a wide range of geomagnetic field strength, inclination, and declination. Hence, magnetic anomalies caused by induction in the earth's magnetic field will have signatures considerably different from the same source characteristics. To remove the effect of the highly variable magnetic field, the data used to prepare Figure 1 were differentially reduced to vertical (radial) polarization by equivalent point source inversion.

Least-squares matrix inversion was used to determine the magnetizations of a spherically orthogonal array of dipoles, oriented in the magnetic field defined by the updated IGS 1975 geomagnetic field model, that will duplicate the observed scalar magnetic anomalies. The dipoles were located on a 4 degree grid over the entire study region. To process this large array and make the problem more tractable, the inversion was performed on two independent sets of equivalent point sources. The process, which may be termed boot-strap inversion, was initiated with inversion of point sources over the southern half of the study area. The residual magnetic field obtained by subtracting the model field from the anomaly field was then inverted over a distribution of point dipoles in the remaining half of the data set. This procedure yielded 744 point dipole sources that model the anomalies of Figure 1 with negligible error. To achieve a least squares estimate of Figure 1 reduced to the pole, fields of the point dipoles were recomputed at 400 km elevation assuming an inducing field of 60,000 nT and radial inclination at all sources and observation points (Figure 2).

Comparison of Figures 1 and 2 shows a progressive shift of anomalies toward the poles in Figure 2 relative to Figure 1, with decreasing magnetic inclination and an inversion of the anomaly polarities near the magnetic equator.

Accordingly, assuming magnetizations directed along the current earth's magnetic field, the anomalies of Figure 2 may be used in analysis and modeling, as well as for spatial comparison with other geophysical and tectonic data. A number of interesting correlations are observed. The most prominent anomaly in Africa is the Bangui anomaly of west-central Africa. The magnetic anomaly maxima which correlates with regional heat flow and gravity anomaly minima was interpreted by Regan and Marsh (1982) as originating from a major ancient intracrustal lithologic feature. No profound magnetic anomaly appears to characterize the Tertiary East African rift zone. The Alpine orogenic belt from the Atlas Mountains in northwestern Africa through the Alps of south-central Europe to the orogenic elements of Eurasia is associated with a trend of magnetic minima and heat flow maxima that is especially pronounced in the European Alps. This Alpine trend of magnetic minima appears to ring the northern margin of a positive anomaly centered over the toe of the Italian peninsula. Pronounced magnetic positive anomalies also are located over the northern Arabian Plate, Scandinavia, and Iceland and its associated oceanic plateaus. In contrast, central Europe is dominated by the Alpine (?) magnetic minimum. The most intense maximum of the satellite magnetic data of Europe is found over the Kursk region of the central Russian highland and its well-known high-amplitude positive aeromagnetic anomalies. Finally, a prominent magnetic trend of minima projects westward from the Rifean Timan uplift near the north-central Ural Mountains to the Gulf of Finalnd. The large western minimum is associated with a well-defined heat flow minimum and zone of enhanced crustal thickness.

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Presented at the 52 Annual International Meeting and Exposition of the Society of Exploration Geophysicists, Dallas, TX, 1982.

REGIONAL ANOMALIES OF THE MISSISSIPPI RIVER AULACOGEN

R.R.B. von Frese - Ohio State University

Knowlege of Mississippi embayment crustal structure is particularly important because it is one of the more generally recognized and better known aulacogens and is related to a zone of intense seismicity in a highly urbanized portion of the midcontinent. The embayment is characterized by regionally positive gravity and negative magnetic anomalies that are observable in surface, aerosurvey, and satellite data. Regional, spherical earth modeling using Gauss-Legendre quadrature integration indicates that the long-wavelength gravity and magnetic anomalies of the embayment may be related to a rift zone along the axis of the embayment that defines a nonmagnetic block of high density material within the lower crust. The decreased magnetization of this component may be related to reversed magnetic remanence, or an intralithologic variation, or an upwarp of the Curie isotherm.

The Mississippi embayment is a structural trough of Mesozoic and Cenozoic sedimentary rocks that projects into the North American craton from the Gulf Coast province. The axis of this feature lies along the Mississippi River, tapering northward into the tectonically active New Madrid seismic zone (Figure 1c). A popular tectonic model for the origin of the embayment is that it represents a late Precambrian aulacogen which was reactivated most recently in the late Cretaceous by forces related to the formation of the present Atlantic Ocean basin.

Surface, 1 degree-averaged free-air gravity anomaly data low-pass filtered for wavelengths greater than about 8 degrees characterize the embayment by a regional anomaly of nearly 10 mgal in amplitude (Figure 1a). These data were upward continued on a spherical earth to 450 km

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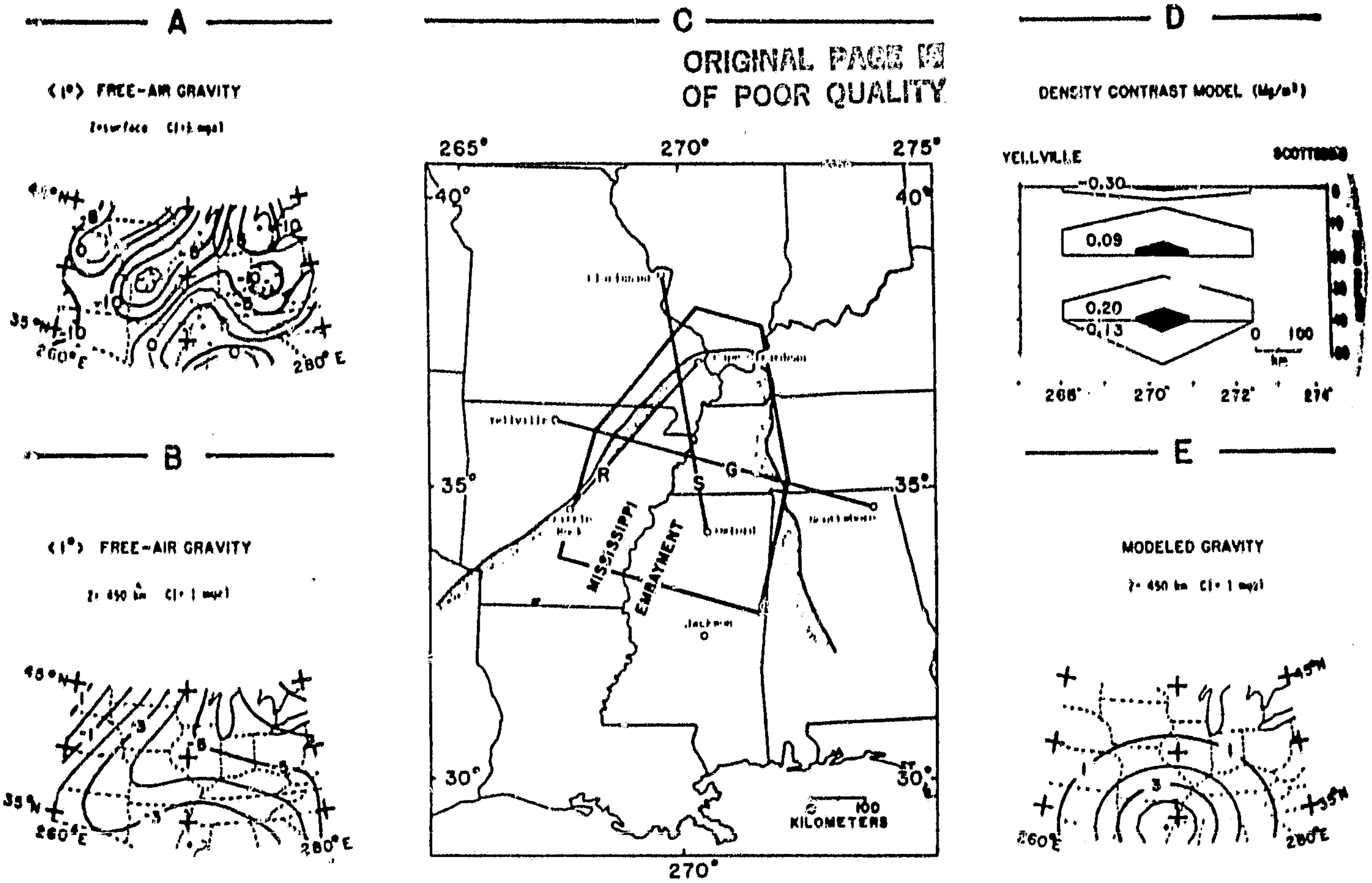

FIG. 1. Regional gravity anomalies and gravity modeling of Mississippi embayment crustal structure.

elevation by equivalent point source inversion (Figure 1b) to enhance the long-wavelength anomaly characteristics, as well as to facilitate comparison with satellite magnetic data and, hence, demonstrate the utility of satellite elevation potential field data for regional modeling applications.

A geologic density contrast model for the crustal structure of the embayment was generalized from published regional Bouguer gravity anomaly, seismic refraction, and surface wave dispersion studies. The configuration of this three-dimensional model is given in Figure 1c and the cross-section along profile G is shown in Figure 1d, where shading represents the projections of the northern ends of the model into the profile. The gravity effect of this spherical model was computed by integrating the effects of Gauss-Legendre quadrature distributed point masses within the model. The modeled positive gravity anomaly (Figure 1e) compares favorably with the upward continued gravity data (Figure 1b) suggesting the generalized model is representative of the crustal structure of the embayment.

The regional magnetic minimum of the embayment was first observed in POGO satellite magnetometer data (Figure 2a), and subsequently confirmed by the NOO aeromagnetic survey of the conterminous U.S.A. To facilitate modeling, the data of Figure 2a were differentially reduced to the pole (Figure 2b) by equivalent point source inversion using a normalized polarizing field of 60,000 nT and high-pass filtered wavelengths smaller than about 10 degrees (Figure 2d).

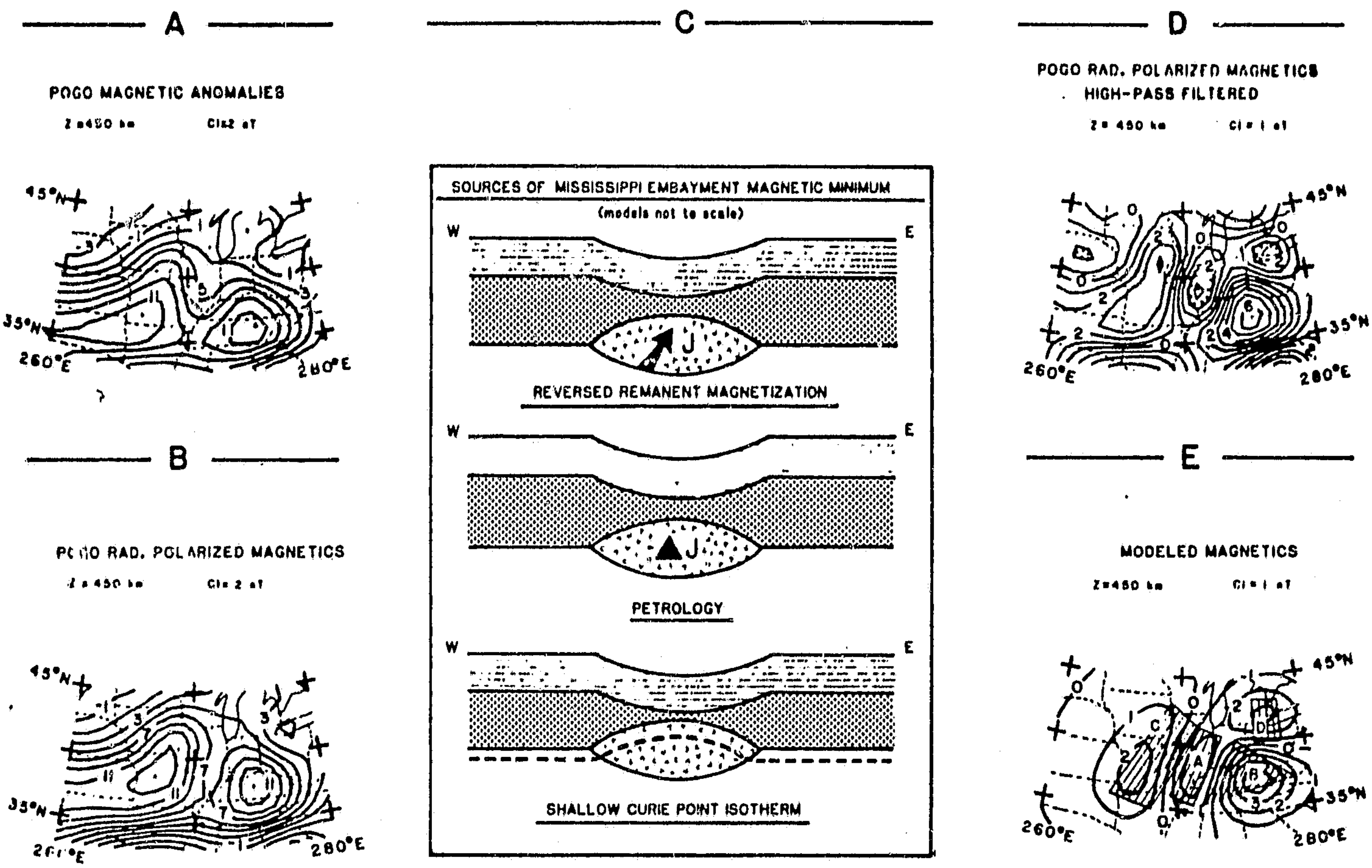

FIG. 2. Regional magnetic anomalies and magnetic modeling of Mississippi embayment crustal structure.

The filtered data (Figure 2d) roughly reveal a -3 nT anomaly for the embayment that can be modeled using results derived from gravity modeling considerations. Analysis of the inverse gravity and magnetic anomaly correlation using Poisson's theorem, and other published arguments favoring deep crustal magnetization variations as the origin of long-wavelength magnetic anomalies, focus on the body located at the base of the crust with density contrast 0.20 Mg/m^2 (Figure 1d) as a primary candidate for the source of the embayment's magnetic minimum. The correlation analysis indicates a magnetization contrast of -2.2 A/m for this body that compares favorably with typcial estimates of deep crustal magnetization. Previous studies have suggested that this body is a manifestation of a mantle upward beneath the embayment consisting of a mixture of crust and intruded upper mantle material that subsequently cooled to form a high density block.

Accordingly, a 3-D, spherical earth model was developed for the radially polarized magnetic data (Figure 2d) using Gauss-Legendre quadrature integration of simplified spherical prismatic bodies (Figure 2e). The modeled anomalies A, B, C, and D are represented by the deep crustal prisms shaded in Figure 2e which all range between depths of 25 to 40 km. The magnetic anomaly minima are approximately modeled by prisms A and D which have magnetizations of -3.9 and -2.7 A/m, respectively, whereas the positive anomalies are modeled by prisms B and C with respective magnetizations 2.7 and 1.2 A/m. These magnetic maxima also correspond inversely to regional free-air gravity minima that may be related to regions of enhanced crustal thickness.

Several origins may be postulated for satisfying the regional magnetic minimum (Figure 2c), which in general can only be discriminated on the basis of auxiliary geologic and geophysical information. These include:

(1) reversed magnetization of intrusives into the lower crust which were emplaced during the rifting process, (2) petrologic variations between the normal lower crustal rocks which are generally highly magnetic and mantle intrusives, and (3) high temperatures in the embayment that raise the Curie point isotherm from a normal position near the base of the crust to within the crust, thereby effectively removing magnetization of the lower crust beneath the position of the isotherm.

Presented at the 52nd Annual International Meeting and Exposition of the Society of Exploration Geophysicists, Dallas, TX, 1982.

REGIONAL GEOPHYSICAL ANALYSIS OF MISSISSIPPI EMBAYMENT CRUSTAL STRUCTURE

R.R.B. von Frese - Ohio State University

Information concerning the crustal structure of the Mississippi Embayment is important for deciphering the mineralization and seismicity of a highly urbanized portion of the midcontinent. Spherical earth inversion analysis of free-air gravity, U.S. Naval Oceanographic Office aeromagnetic, and satellite magnetometer data show the embayment to be characterized by regionally positive gravity and negative magnetic anomalies. Incorporating constraints developed from seismic refraction and surface-wave dispersion studies of the region with Gauss-Legendre quadrature potential field modeling suggests that the regional gravity and magnetic anomalies may be related to a rift zone along the axis of the embayment which defines a non-magnetic block of high density material within the lower crust. The decreased magnetization of this component may be due to reversed magnetic remanence, or an intra-lithologic variation, or an upwarp of the Curie isotherm.

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DO SATELLITE MAGNETIC ANOMALY DATA ACCURATELY PORTRAY THE CRUSTAL COMPONENT?

R.R.B. von Frese - Ohio State University; and W.J. Hinze - Purdue University

Scalar aeromagnetic data obtained during the U.S. Naval Oceanographic Office (NOO)-Vector Magnetic Survey of the conterminous United States have been upward continued by equivalent point source inversion and compared with POGO satellite magnetic anomaly and preliminary scalar MAGSAT data. Initial comparisons indicate that the upward continued NOO data is dominated by long wavelength (≅ 1000-3000 km) anomalies which are not present in the satellite anomaly data. Thus, the comparison of the data sets is poor. Several possible sources for these differences are present in the data analysis chain. However, upon removal of these long wavelengths from the upward continued NOO data, a close comparison observed between the anomalies verifies that satellite magnetic anomaly data do portray the crustal component within a range of wavelengths from roughly 1000 km down to the resolution limit of the observations.

Presented at the Geomagnetic Conference, Denver, Colorado, 1982.

LONG-WAVELENGTH MAGNETIC AND GRAVITY ANOMALY CORRELATIONS OF AFRICA AND EUROPE

R.R.B. von Frese - Ohio State University; R. Olivier - University of Lausanne; and W.J. Hinze - Purdue University

Regional geopotential anomalies and their correlations provide important constraints for investigating the megatectonic framework of Africa and Europe. Accordingly, preliminary satellite (MAGSAT) scalar magnetic anomaly data are compiled for comparison with long-wavelength-pass filtered free-air gravity anomalies and regional heat-flow and tectonic data. To facilitate the correlation analysis at satellite elevations over a spherical-earth, equivalent point source inversion is used to differentially reduce the magnetic satellite anomalies to the radial pole at 350 km elevation, and to upward continue the first radial derivative of the free-air gravity anomalies. Correlation patterns between these regional geopotential anomaly fields are quantitatively established by moving-window linear regression based on Poisson's theorem. Prominent correlations include direct correspondences for the Baltic Shield, where both anomalies are negative, and the central Mediterranean and Zaire Basin where both anomalies are positive. Inverse relationships are generally common over the Precambrian Shield in northwest Africa, the Basins and Shields in southern Africa, and the Alpine Orogenic Belt. Inverse correlations also presist over the North Sea Rifts, the Benue Rift, and more generally over the East African Rifts. The results of this quantitative correlation analysis support the general inverse relationships of gravity and magnetic anomalies observed for North American continental terrane which may be broadly related to magnetic crustal thickness variations.

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VERIFICATION OF THE CRUSTAL COMPONENT IN SATELLITE MAGNETIC DATA

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Abstract. To investigate the utility of satellites for mapping crustal magnetic anomalies, POGO (Polar Orbiting Geophysical Observatory) and prelim...ary MAGSAT magnetometer data are compared with scalar aeromagnetic data obtained by the U.S. Naval Oceanographic Office (NOO)-Vector Magnetic Survey of the conterminous U.S.A. POGO and available MAGSAT data demonstrate remarkable consistency over the study region. The NOO aeromagnetic data are low-pass filtered for wavelengths larger than about 4° and spherically upward continued to 450 km elevation by equivalent point source inversion for direct comparison with POGO satellite magnetometer observations. The upward continued NOO data show that most of the energy is in the long wavelength (≈ 1000-3000 km) anomalies. Removal of these wavelengths by suitable filtering reveals a residual anomaly field that corresponds well with the satellite anomalies, thus demonstrating that the satellite data are useful for mapping crustal magnetic anomalies. A number of correlations between the NOO, POGO and preliminary MAGSAT data are evident at satellite elevations, including a prominent transcontinental magnetic high which extends from the Anadarko Basin of the eastern Texas panhandle to the Cincinnati Arch. The transcontinental magnetic high is breached by negative anomalies located over the Rio Grande Rift and Mississippi River Aulacogen.

Introduction

Satellite magnetometer observations permit the characterization of magnetic signatures for lithospheric regions measured in hundreds or even thousands of kilometers which are not readily obtained from conventional aeromagnetic surveys. These regions, identified and characterized on a global basis, provide useful information for deciphering earth history including paleo and contemporary geodynamics, delineation of segments of the lithosphere into resource provinces, and for numerical modeling of lithospheric processes.

Although highly precise satellite magnetic vector and scalar measurements are becoming increasingly available for lithospheric analysis, few studies have attempted to verify the satellite data directly by comparison with aeromagnetic anomalies. In general, this reflects problems related to measuring and compiling regional-scale aeromagnetic anomaly data sets, as well as difficulties in processing lithospheric potential field anomalies in the spherical domain. A notable exception is the investigation by Langel et al. [1980] in which aeromagnetic and POGO satellite magnetic anomalies over western Canada were compared at satellite elevations. The good spatial and amplitude agreement observed between the data sets provides strong evidence for the utilization of the POGO satellite magnetic anomalies in lithospheric studies.

To further investigate the use of satellites for mapping crustal magnetic anomalies, the present study compares POGO and MAGSAT magnetometer data with scalar aeromagnetic data obtained by the U.S. Naval Oceanographic Office - Vector Magnetic Survey of the conterminous U.S.A.

Data Sets and Processing

The NOO scalar aeromagnetic data, which are available from the National Geophysical and Solar-Terrestrial Data Center at 0.1 km intervals along 1° meridians, were screened for periods of intense diurnal magnetic activity and reduced to anomaly form using the IGS-75 geomagnetic field model updated to the nearest tenth of the survey year (1976.8). The resultant aeromagnetic anomaly profiles were low-pass filtered utilizing a 50% cutoff at 200 km wavelength and contoured [Sexton et al., 1982].

To facilitate inversion processing for comparison with satellite magnetometer observations, the contoured NOO data were gridded at 1° intervals, the mean value (-176 nT) removed, and then high-cut filtered for wavelengths less than about 4°. These data (Figure 1) were spherically upward continued to 450 km elevation (Figure 2) by equivalent point source inversion [von Frese et al., 1981] using the updated IGS-75 geomagnetic field model for direct comparison with POGO satellite magnetic anomalies.

POGO satellite magnetometer observations, obtained during 1968, were processed according to procedures described by Mayhew [1979] to yield the magnetic anomaly map for the study area (Figure 3) at an elevation of 450 km. Briefly, data processing consisted of removal of the POGO 13th degree geomagnetic field from the original orbital profiled data. Next, data profiles were selected in the elevation range (240-700 km) and a least

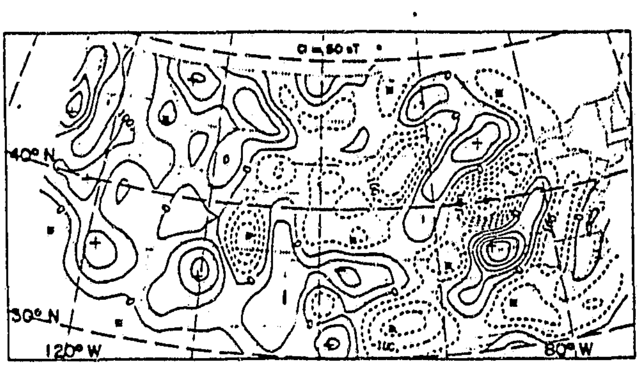

Fig. 1. Low-pass (λ ≥ 4°) filtered NOO aeromagnetic anomaly data for the conterminous U.S. A mean value equal to -176 nT was removed from the data prior to filtering. Contour interval is 50 nT.

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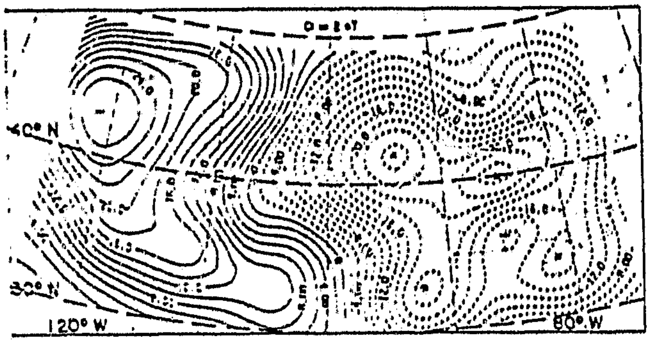

Fig. 2. NOO aeromagnetic anomaly map of the conterminous U.S. (Fig. 1) upward continued to 450 km elevation by equivalent point source inversion. Contour interval is 2 nT.

squares quadratic function was fitted to the profiles and removed to account for Dst variation arising from ring current flow in the magnetosphere during storm time. An inversion then was performed on a spherical surface grid of prismatic dipolar moments which were oriented in the local direction of the IGRF-1965 updated to 1968. The field of these dipolar moments was recomputed at 450 km elevation in the local direction of the IGRF-1965 updated to 1968 to obtain the total magnetic intensity anomaly map for the U.S. (Figure 3).

Preliminary MAGSAT data for the study area, obtained from NASA's Goddard Space Flight Center, are presented in Figure 4. This map was prepared by averaging quiet-time MAGSAT orbital profile data over 2° x 2° areas for orbits with elevations of 400 km or less. The anomaly reduction was achieved using the preliminary geomagnetic reference field model MG680982 derived from early orbits of the MAGSAT satellite. In Figure 4, the mean number of observations per 2° x 2° area is 12 and the average elevation of the observations is 347 km.

Correlation Analysis and Results

Consideration of POGO data (Figure 3) and MAGSAT data (Figure 4) show that the satellite magnetic anomaly fields are remarkably consistent, in spite of the preliminary nature of the processing used to develop the MAGSAT magnetic anomaly map. However, correlations between the upward continued NOO magnetic anomaly (Figure

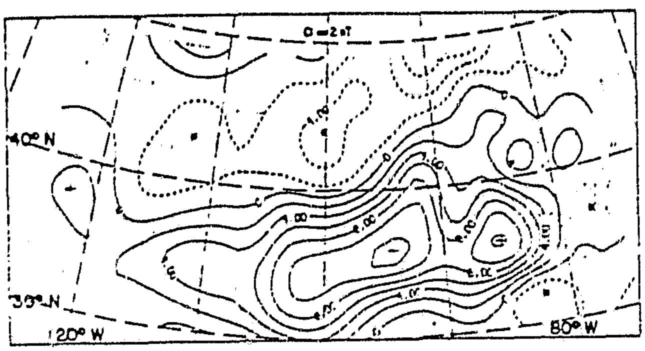

Fig. 3. POGO satellite magnetic anomaly map for the conterminous U.S. at 450 km elevation. Contour interval is 2 nT.

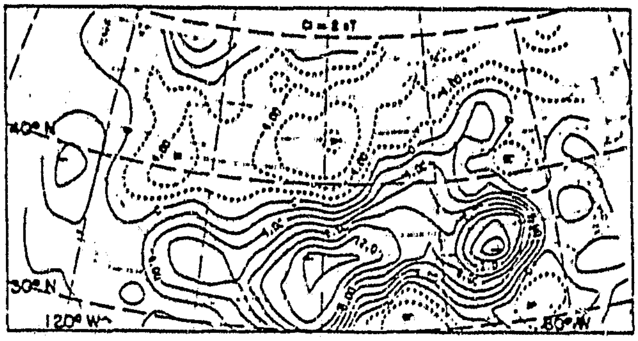

Fig. 4. 2°-averaged MAGSAT magnetic anomaly map for the conterminous U.S. at an average elevation of about 350 km. Contour interval is 2 nT.

2) and satellite magnetic anomaly data are not immediately obvious.

Comparison of Figures 2 and 3 reveals a long wavelength anomaly component in the NOO data that is clearly not evident in the satellite magnetic anomaly data. This feature is characterized in Figure 2 by a long wavelength anomaly with a maximum of about 21 nT over the western third of the U.S. which decreases to a broad minimum of about -21 nT over the eastern half of the U.S. Although this long wavelength feature may be a vestige of the updated IGS-75 reference field used to derive the NOO aeromagnetic anomalies, a crustal origin for this feature cannot at present be excluded. Should the latter alternative hold, then the POGO satellite data would appear to be limited to wavelengths shorter than about 1000 km due, possibly, to errors in the updated IGRF-65 reference field and/or elimination of long wavelength crustal anomaly components by removal of quadratic functions from the orbital profile data prior to the inversion processing.

In any event, this result suggests that the longer wavelength components of Figures 2 and

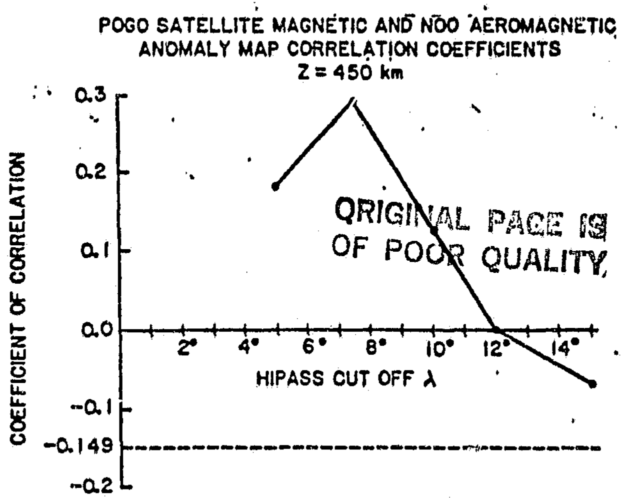

Fig. 5. Distribution of coefficients of linear correlation computed between POGO satellite magnetic and NOO aeromagnetic anomalies high-pass filtered for a number of cutoff wavelengths, λ, at 450 km elevation. The dashed line marks the value of the correlation coefficient between the unfiltered data sets (Figs. 2 and 3).

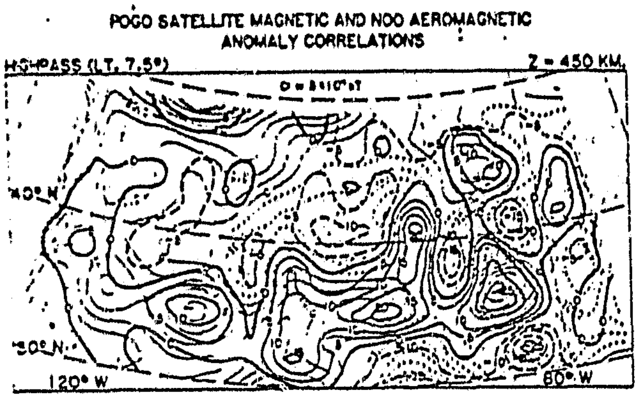

Fig. 6. POGO satellite magnetic (heavy contours) and NOO aeromagnetic (thin contours) anomaly correlations for the conterminous U.S. at 450 km elevation. Both data sets are normalized to a zero mean and high-pass ($\lambda \leq 7.5°$) filtered. Contour values for both data sets are given in multiples of 10^{-1} nT where the contour interval is 0.5 nT.

3 should be removed to facilitate the correlation analysis. Accordingly, these data sets were high-pass filtered for a number of cutoff wavelengths and the correlation coefficient was computed between the filtered maps to assess the anomaly wavelengths most consistently represented in the POGO satellite magnetic anomaly (Figure 3) and upward continued NOO aeromagnetic anomaly (Figure 2) data. The results are shown in Figure 5 where a well defined maximum correlation is observed between the data sets high-pass filtered for anomaly wavelengths smaller than about 800-1000 km (≈ 7.5°). The resultant upward continued NOO and POGO satellite data sets, high-pass filtered for wavelengths smaller than about 7.5°, are plotted together in Figure 6 to facilitate the correlation analysis.

Consideration of Figure 6 shows excellent correspondence between anomalies in the high-passed POGO and upward continued NOO data. Prominent correlations include, for example, a nearly peak-for-peak correspondence related to the transcontinental magnetic high that extends from Kentucky westward to Arizona and then turns northward along California to Oregon. A well defined trend of negative magnetic anomalies are observed in both data sets along the northern margin of the transcontinental magnetic high.

Negative anomalies over the Rio Grande Rift breach the transcontinental magnetic high in both data sets. An additional breach of this anomaly is observed over the northern extension of the Mississippi River Aulacogen, although here the correspondence between the two data sets is perhaps less clear than observed for the Rio Grande Rift. This is because the NOO data in the vicinity of the Mississippi Embayment are strongly influenced by the large magnetic low over Indiana which is poorly defined due to limited NOO magnetic anomaly data in this region [Sexton et al., 1982]. Prominent anomaly maxima over the Michigan Basin centered in Michigan and the Colorado Plateau in Arizona are quite comparable in both data sets as are intense negative anomalies over southern Georgia and the Central Rocky Mountains in Colorado.

Taken together, the results of this analysis indicate that the filtered NOO and POGO data sets correlate remarkably well with respect to the spatial location, sign and general amplitude of their relative anomalies at 450 km elevation. Dissimilarities, in general, are associated with anomalies located near the boundaries of the data sets where edge effects related to the data processing are difficult to avoid.

Conclusions

Upward continued NOO aeromagnetic and POGO satellite magnetic anomaly data for the conterminous U.S. show good correlations for wavelengths shorter than about 7.5° at 450 km elevation. For longer wavelengths the correspondence between the two data sets deteriorates and becomes slightly inverse, due probably to anomaly reduction errors related to inconsistent updated geomagnetic reference field models and/or the removal of quadratic functions from the satellite data that also contain significant long wavelength crustal anomaly components. However, the good overall correspondence between the data sets for anomaly wavelengths smaller than about 800-1000 km (≈ 7.5°) provides strong evidence for the utility of satellites to map crustal magnetic anomalies. Accordingly, MAGSAT data offer considerable promise for studying cruscal magnetic anomalies, because of the close morphological similarity observed between POGO and available MAGSAT magnetic anomalies.

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U.S. AEROMAGNETIC AND SATELLITE MAGNETIC ANOMALY COMPARISONS

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To investigate the utility of satellites for mapping crustal magnetic anomalies, POGO and preliminary MAGSAT magnetometer data are compared with scalar aeromagnetic data obtained by the U.S. Naval Oceanographic Office - Vector Magnetic Survey of the conterminous U.S. The NOO aeromagnetic data, which are available at 0.1 km intervals along 1° meridians, were screened for periods of intense diurnal magnetic activity and reduced to anomaly form using the updated IGS-75 geomagnetic field model. The resultant aeromagnetic anomaly profiles were high-cut filtered utilizing a cutoff at 200 km wavelength, and contoured and gridded at 1° intervals. For comparison with satellite magnetometer observations, these data were low-pass filtered for wavelengths larger than about 4° and spherically upward continued to satellite elevations by equivalent source inversion. The upward continued NOO data show that most of the energy is in the long-wavelength (≅ 1000-3000 km) anomalies. Removal of these wavelengths by suitable filtering reveals a residual anomaly field that compares well with the morphology of the satellite measured anomalies, thus, demonstrating that the satellite data are useful for mapping crustal magnetic anomalies. A number of correlations between the NOO, POGO and preliminary MAGSAT data are evident at satellite elevations, including a prominent transcontinental magnetic high which extends from the Anadarko Basin to the Cincinnati Arch. The transcontinental magnetic high is breached by negative anomalies located over the Rio Grande Rift and Mississippi River Aulacogen. Differentially reduced-to-pole NOO and

POGO magnetic anomaly data show that the transcontinental magnetic high corresponds to a well-defined regional trend of negative free-air gravity and enhanced crustal thickness anomalies.

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RELATION OF MAGSAT ANOMALIES TO THE MAIN TECTONIC PROVINCES OF SOUTH AMERICA

by

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Comparison of satellite scalar magnetic anomaly data (MAGSAT) to the main tectonic provinces and boundaries of South America reveals a number of geologic correlations. South America is divisible into a broad platform of Precambrian shields and cratons separated by Phanerozoic basins, grabens and aulacogens to the east, the Phanerozoic Patagonian Platform to the south, and the Mesozoic to Cenozoic Andean Fold Belt and Caribbean Mountain System to the west and north. The continental shields are mainly more magnetic than continental basins and orogenic belts. This is particularly true of the Guyana Shield, the Central Brazilian Shield, and parts of the Atlantic Shield, all of which are coincident with magnetic highs. In contrast, the prominent Amazon Basin (aulacogen) is associated with large magnetic lows. Other basins coincide either with magnetic lows or magnetic gradients. Cratons, mainly covered by younger sedimentary rocks, are generally associated with magnetic gradients. Most of the anomalies associated with the Patagonian Platform are positive and have higher amplitudes eastward away from the Andean Fold Belt. The northern Andes are coincident with positive magnetic anomalies, whereas the central and southern Andes are associated mainly with negative anomalies. The trend of the Andean anomalies generally does not follow the trend of the fold belt, but instead has a general east-west trend which is probably related to noise derived from data processing. The anomalies of western South America along the margin of the South American Plate appear to be distinct from those of the adjacent ocean basin. In contrast, eastern South America is characterized by magnetic anomalies which commonly extend into the Atlantic Ocean.

DETAILED DISCUSSION

More detailed assessment of the relation of the magnetic anomalies (Fig. 1) to the main tectonic provinces of South America (Fig. 2) can be made by consideration of the individual provinces and subprovinces. Three extensive provinces can be recognized based on origin, age, and structural development:

South American Platform (Region A, Fig. 2)

Shields and Cratons

This is the oldest province and includes most of eastern South America. The basement of this old platform consolidated between the end of the Precambrian and the Cambrian and contains the only known Archean rocks of the continent. Although partly covered by Phanerozoic rocks, the basement of the South American Platform is well exposed in three major shields and forms the basement of three major cratons:

1. Guyana Shield (Ala, Fig. 2) This entire region is underlain by Precambrian rocks. A magnetic high overlies this region, and the general east-northeast trend of the anomalies coincides with Precambrian structural trends.

2. Central-Brazilian Shield (Alb, Fig. 2) This old cratonic region consolidated prior to 1,800 m.y., and was partially remobilized in the Trans Amazonian orogenic cycle (1,800-2,200 m.y.). Magnetic anomalies are very high in most areas, especially in the eastern region.

3. Atlantic Shield (A4, Fig. 2) This shield lies along the coastal margin of Brazil and Uruguay. A large magnetic anomaly high occurs in the area of the Caririan-Propria Fold Belt (A4a) and is apparently associated with metamorphic and volcanic intrusive rocks of that old belt. The positive anomaly appears to extend eastward into the ocean basin. The Riberira Fold Belt to the south (A4b) is associated with a magnetic low having an east-west trend along the northern part of the belt and with a magnetic high having a north-south trend in the southern part of the belt.

4. Sao Luiz Craton (A5, Fig. 2) The Sao Luiz Craton is a narrow feature along the northeast Atlantic coast. As the main part of the craton is covered by Paleozoic or younger sedimentary rocks, the older crystalline rocks are very poorly known. The magnetic anomaly pattern shows a broad gradient over this area which decreases from south to north. This gradient continues northeastward into the adjacent Atlantic Ocean Basin.

5. Sao Francisco Craton (A2, Fig. 2) The Sao Francisco Craton acted as the foreland to the Brazilian Fold Belt which developed along its borders. The basement of the craton is made up of Lower Precambrian sialic rocks which are partially covered by Mesozoic sedimentary rocks and Cenozoic volcanics. A large magnetic anomaly low occurs along the southern border of the craton and a positive magnetic anomaly occurs at the northern part of the craton. The magnetic low appears to be part of a larger anomaly that extends eastward into the adjacent ocean basin.

6. Rio de La Plata Craton (A6, Fig. 2) This craton is mostly covered by Phanerozoic sediments. The basement of this ancient area consolidated in the Upper Precambrian and probably represents the southernmost extent of Precambrian rocks in the Atlantic coastal region of South America. The craton lies along a strong magnetic gradient between negative magnetic anomalies in the continental areas of eastern Argentina and positive anomalies in coastal Uruguay and southern Brazil. These positive anomalies are part of a larger series of north-to-northeast-trending magnetic highs that occur along the southeastern continental shelf of South America and extend into the Atlantic Ocean Basin.

Basins

The Guyana, Central Brazilian, and Atlantic Shields are separated from one another by large basins which probably are underlain in part by major synclines or grabens. The sedimentary and associated volcanic rocks which occur in these basins are of Silurian or younger age.

1. Amazon Basin (Alc, Fig. 2) The Amazon Basin is the most prominent and the largest basin in South America. It is widely regarded as being an intercratonic basin, and has been variously interpreted as an autogeosyncline, an extensive and complex graben system, a rift basin, and most recently as an aulacogen. The basin contains a thick sequence of Paleozoic, Mesozoic, and Cenozoic sediments and lesser basaltic volcanic rocks. Prominent magnetic lows occur in most of the basin, especially in the eastern part and to the west in the area of the Upper Amazon.

2. Parnaiba Basin (A3, Fig. 2) The Parnaiba Basin is also an intercratonic basin and contains Paleozoic and Mesozoic sedimentary and volcanic rocks. It is separated from the small coastal basins on the north by the Ferrer Arch and from the old craton by younger Precambrian metamorphic and sedimentary rocks. The magnetic signature in this basin is not definitive and appears to occur along an irregular gradient that increases from north to south.

3. Parana Basin (A6b, Fig. 2) Cretaceous basalt (Parana Basalt), covering an area of 1,200,000 km^2, and associated sediments of mainly Mesozoic age fill most of the Parana Basin. Much of the basin is underlain by a magnetic low and a magnetic gradient which is high in the southeast and low in the northwest.

4. Chaco Basin (A6a, Fig. 2) Cenozoic sedimentary and minor volcanic rocks cover most of the Chaco Basin. The magnetic anomaly values are negative in the most of the area, but most anomalies are broad and the negative values are small.

Patagonian Platform (Region B, Fig. 2)

The Patagonian Platform occupies the broad southeast continental margin of South America. It is a young platform with a basement that stabilized from the Middle Paleozoic onwards, developing a volcano-sedimentary cover after the Carboniferous; this cover almost completely masks the platform basement.

The magnetic anomaly pattern in this platform is elongate in shape with a north-south trend that essentially parallels the coast line. The anomalies are positive in most areas and become higher from west to east away from the Andean Fold Belt. A northwest-trending arm of the positive anomalies extends into the Andean Fold Belt.

Andean Fold Belt and Caribbean Mountain System (Region C and C1, Fig. 2)

The Andean Fold Belt, which forms the western margin of South America is part of the Circum-Pacific Mountain System of great seismic and volcanic activity. The enormous quantity and size of the intrusive bodies (Andean batholithic rocks) have contributed to the Andes being referred to as a "magmatic mountain range". The Andes are widely regarded as a classic example of a mountain system formed at a convergent plate margin.

A large magnetic anomaly high occurs along the Cordillera of Colombia, and positive anomalies occupy most areas of the northern part of the Andes (north of lat 16°S). In contrast, a large magnetic anomaly low occurs in the central part of the Andes, and negative anomalies occupy most regions of the central and southern Andes. The trend of these anomalies does not, in general, parallel the north-south structural trend of the fold belt, but instead has a general east-west pattern. This pattern which is common over most of the MAGSAT map is probably related to processing noise derived from data reduction procedures to correct for external magnetic field effects. However, the pattern over the Andes is sufficiently distinct from the generally north-trending magnetic anomalies occurring in the adjacent Pacific Ocean to reflect the boundary between the leading edge of the South America Plate and the oceanic Nazca Plate.

The Caribbean Mountain System, which extends along the northern boundary of the South American Platform, is part of an island arc complex of the eastern Caribbean. The basement of this region consists of Paleozoic rocks with metamorphosed igneous complexes. Sedimentary rocks of Lower Cretaceous or possibly Upper Jurassic age overlie these older rocks. Negative magnetic anomalies appear throughout the system, and they are clearly different from the positive anomaly pattern that occurs along the northern Andes and the Guyana Shield.

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Figure 1. Equivalent point source field approximation of 2^{o}-averaged scalar MAGSAT magnetic anomaly data differentially reduced to radial polarization at 350 km elevation. The normalized amplitude for the polarizing induction field is 60,000 nT. Contour interval is 2 nT.

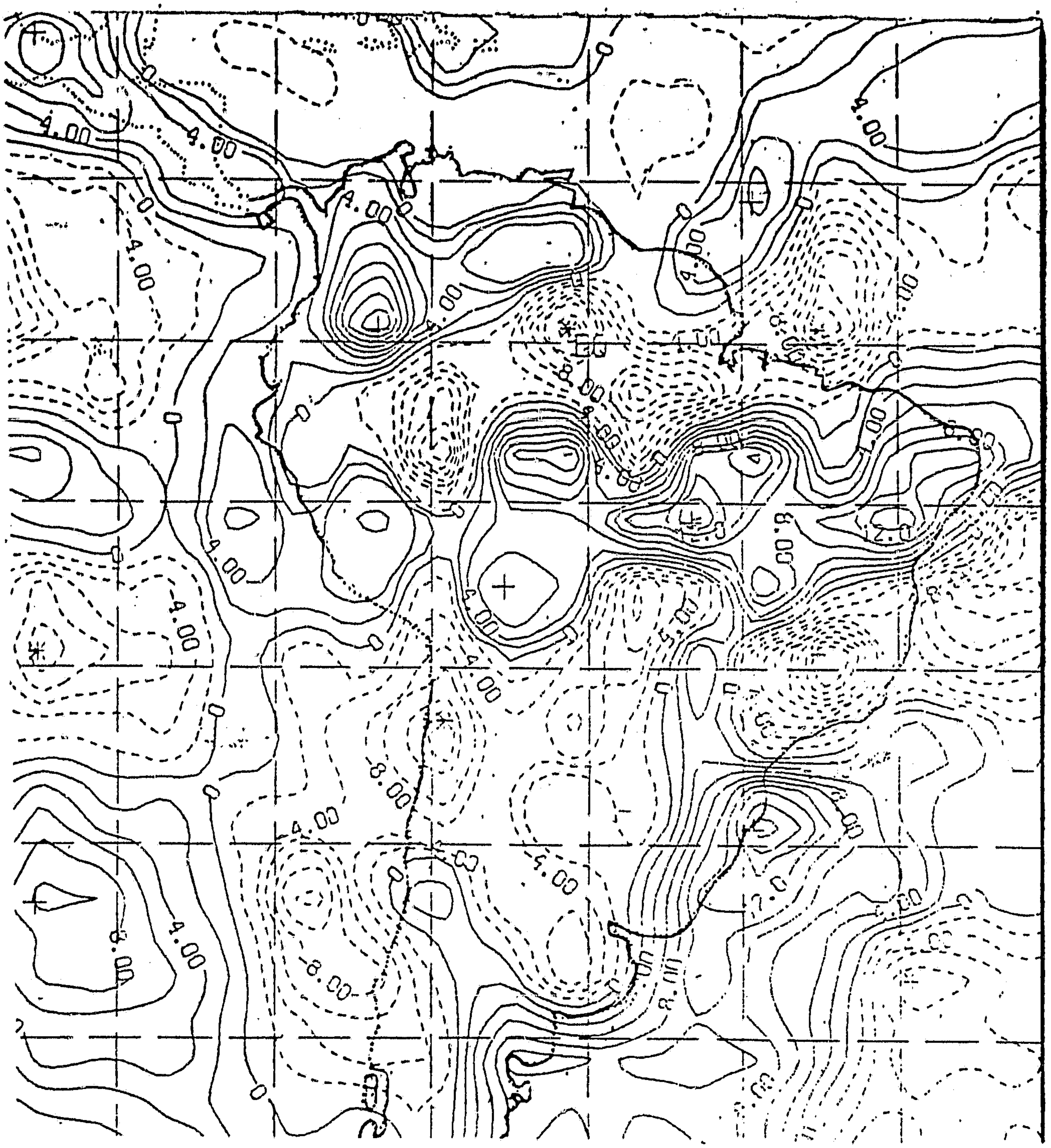

Figure 2. Tectonic Provinces of South America