AEROMAGNETIC SURVEY OVER THE SOUTH SHETLAND ISLANDS, BRANSFIELD STRAIT AND PART OF THE ANTARCTIC PENINSULA

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ABSTRACT

About 3,500 km of regional magnetic lines have been flown over the South Shetland Islands, the Bransfield Strait and part of the Antarctic Peninsula. Qualitative interpretation of the magnetic maps shows that the general structure of the area is characterized by large magnetic anomalies (northwest of the South Shetland Islands and southeast of the Bransfield Strait) associated with and produced by intrusive rocks of Cretaceous to Middle Tertiary age. This intrusive suite is apparently related to subduction, which ceased during the Lower Miocene giving way to an extensive tectonic phase characterized by a north-east trending system of normal faults. The interpretation of the aeromagmatic map shows these faults to be subparallel to the northwestern border of the Antarctic Peninsula and to the edge of the South Shetland Trench. Associated with these faults, in the central Bransfield Strait, there is a well defined magnetic anomaly pattern. This is interpreted as produced by basic injections into the continental crust, defining an incipient rift along the Bransfield Strait. An overlapping spreading center was recognized near Deception Island. A quantitative model was drawn using 2 1/2 dimensional automatic interpretation along a profile perpendicular to the spreading center anomaly.

RESUMEN

Como parte de un programa aeromagnético regional se sobrevolaron alrededor de 3.500 km de perfiles aeromagnéticos, cubriendo las islas Shetland del Sur, el estrecho de Bransfield y parte de la península Antártica. La interpretación cualitativa del mapa aeromagnético obtenido indica que la región está caracterizada por grandes anomalías magnéticas positivas, al noroeste de las islas Shetland del Sur y al sureste del estrecho de Bransfield, asociadas con y producidas por rocas intrusivas de edad cretácico-terciaria, generadas durante procesos de subducción que, al cesar en el Mioceno Inferior, dieron paso a una etapa de tectónica extensiva, durante la cual se formó el actual Estrecho de Bransfield. De la interpretación del mapa aeromagnético se deduce la presencia, en el Bransfield, de un sistema de fallas normales, subparalelas al borde noroccidental de Península Antártica. Junto a ello, en la "garganta" del Bransfield, existe un sistema de anomalías magnéticas muy bien definidas, que se han interpretado como el producto de inyecciones básicas en la corteza continental, las cuales definen el incipiente "ridge" o centro de expansión oceánica en el estrecho de Bransfield. Usando un procedimiento de interpretación automática en 2 1/2 dimensiones, se calculó un modelo cuantitativo a lo largo de un perfil perpendicular a la anomalía del centro de apertura.

INTRODUCTION

This paper describes the results of a total field aeromagnetic survey, conducted over the South Shetland Islands, the Bransfield Strait and part of the Antarctic Peninsula (Fig.1). This survey is the initial part of a program conducted to make a regional aeromagnetic map of the Antarctic Peninsula. The field work was carried out with the logistic support of the Chilean Air Force during the Antarctic summer of 1983.

Geological mapping has dominated the explo-

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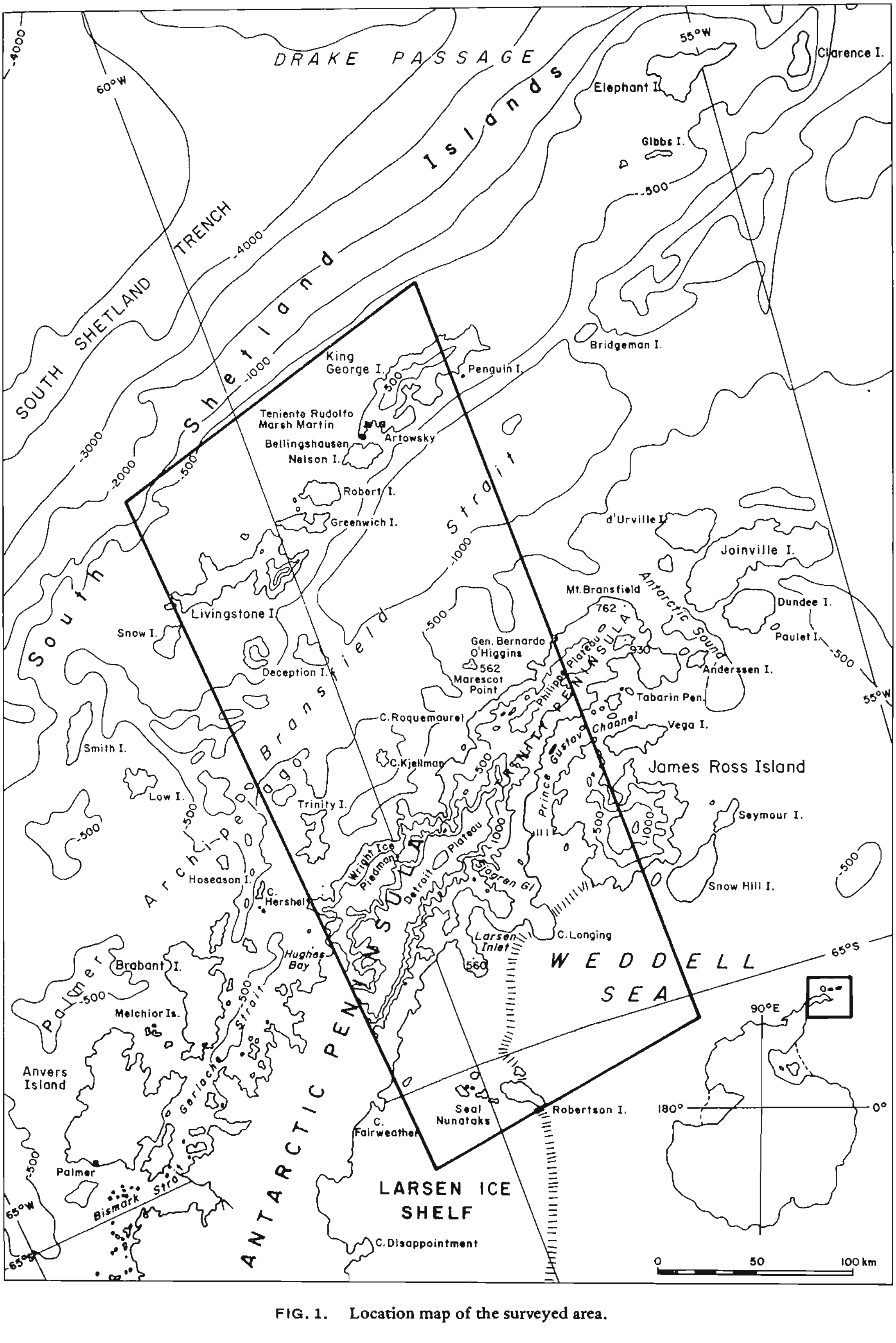

FIG. 1. Location map of the surveyed area.

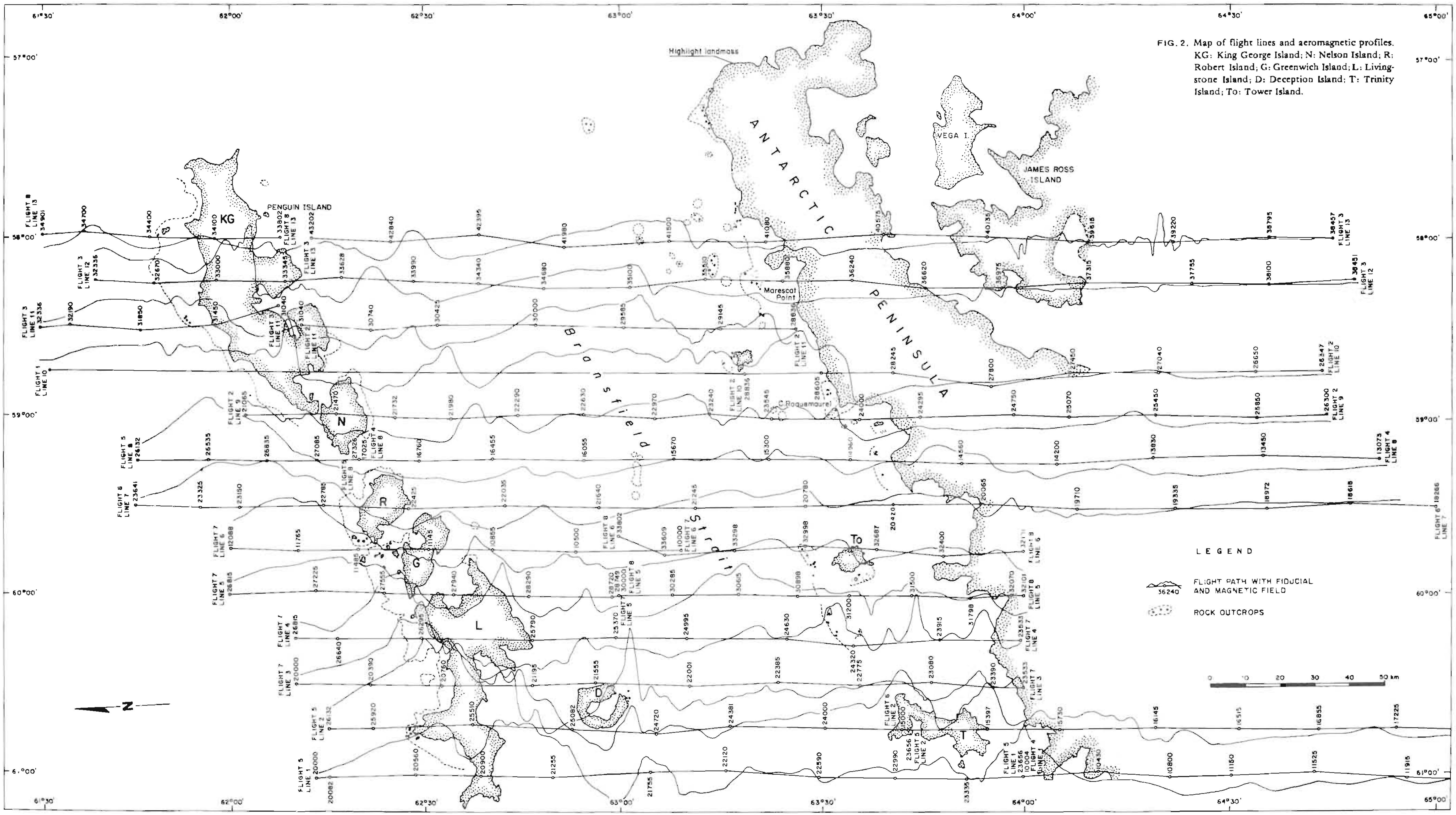

FIG. 2. Map of flight lines and aeromagnetic profiles. KG: King George Island; N: Nelson Island; R: Robert Island; G: Greenwich Island; L: Livingstone Island; D: Deception Island; T: Trinity Island; To: Tower Island.

ration of the Antarctic Peninsula and South Shetland Islands since 1943. Regional aeromagnetic and gravity studies have been in effect since 1959 by the British Antarctic Survey (Ashley, 1962, Ashcroft, 1972, Renner *et al.*, 1977).

THE SURVEY

The equipment, that belongs to the Comisión Chilena de Energía Nuclear (C.Ch.E.N.), included a Geometrics model G-803 proton-precession magnetometer, a Kennedy model 9,700 magnetic tape-recorder, controled by a Geometrics model G-714 data-acquisition system, and an Exploranium model Mars-6 analog recorder. The Aeromagnetic system was installed on board of a Twin Otter aircraft based at Teniente R. Marsh Station, King George Island (Fig. 1). The flights were performed, from January 15 through February 20, 1983 and the sensor was towed 30 meters behind the aircraft. The diurnal variation of the earth's total magnetic field was continously recorded at Teniente R. Marsh using a base station proton-magnetometer, model G-826. The records from the Artowsky Polish Geomagnetic Base (Fig. 1) were used as a second diurnal monitoring data base.

The installation of long-range fuel tanks was necessary to encrease total operating range for the aircraft to 1,500 km. Thirteen fligth-lines, totaling about 3,500 km were flown in a north-south direction across the Bransfield Strait (Fig. 2). The flighline spacing was 10 minutes longitude (aproximately 8.8 km). A constant barometric altitude of 1,500 m was mantained over the South Shetland Islands, the Bransfield Strait, and that part of the Antarctic Peninsula with low elevation. Higher elevations were flown at a 700 m minimun clearance. Flight altitude was measured with a Sperry Model AA-200, radar altimeter. The area south of 64°S, between 59°30' and 60°30' longitude could not be flown because of bad weather conditions.

Visual techniques with the aid of an Omega Navigation System were employed for navigation. An Automax, model GS-2FRP, 35 mm photographic camera was used for a permanent record of the flight path, especially onshore and over the coast lines. The camera uses 35 mm film, and was operated in a discrete frame mode. The recorded positions were plotted onto 1:500,00 scale maps and digitized in geographic coordinates. Visual techniques were also used to determine the onshore flight-path. It is estimated that the positions of the lines are accurate to within 1.0 km, except over the highest part of the Antarctic Peninsula, where the errors could be as large as 2.0 km.

During aeromagnetic data processing, the magnetic tapes were tested for gross errors such as parity, blocks length, time continuity and unrealistic gradients in the measured geomagnetic field. The values of the magnetic field were then linked to the digital flight-path through a common fiducial frame. Diurnal variation was removed automatically from the magnetic field values using the data from the diurnal base station in Teniente R. Marsh. Regional correction was applied by the removal of the International Geomagnetic Reference Field (IGRF) from all profiles. The IGRF values for the interval 1980-1985 (Fabiano *et al.*, 1982) were used, considering the date 1983.1. After removing the IGRF, grid values were calculated for a 2,000 m grid. The contour interval for the aeromagnetic map is 100 gammas.

GENERAL GEOLOGICAL AND TECTONIC BACKGROUND

During the last ten years, an increase in geological-geophysical information has allowed the evaluation of magmatic activity and its relationship to the tectonics of the northwestern Antarctic Peninsula and South Shetland Islands Sea floor research, and radiometric datings have played a major role in the establishment of the chronology of tectono-volcanic events. Among the fundamental contributions the following should be mentioned: González-Ferrán and Katsui, 1970; Adie, 1972; Barker and Griffiths, 1972; Dalziel and Elliot, 1973; Craddock and Hollister, 1976; Herron and Tucholke, 1976; Rex, 1976; Baker *et al.*, 1977; Barker and Burrell, 1977; Grikurov, 1978; Weaver *et al.*, 1979; Renner, 1980; Birkenmajer *et al.*, 1981; Hawkes, 1981; Pankhurst, 1982; Weaver *et al.*, 1982; and González-Ferrán, 1972, 1982, 1983, 1985.

Regional geological evidence suggests that the South Shetland Islands and the islands in the southeastern part of the Weddell Sea, were once part of the Antarctic Peninsula, at least until the Pliocene. Unconformably overlying a pre-Jurassic basement (Trinity Peninsula Series, Adie, 1972), there is a sequence of volcanic, volcaniclastic as well as marine and continental sedimentary rocks of Jurassic-Cretaceous and Tertiary ages. These are intruded by calc-alkaline plutons of the Andean Intrusive Suite (Adie, 1972; Dalziel and Elliot, 1973; Pankhurst *et al.*, 1979).

This intense calc-alkaline, Cretaceous to Tertiary volcanism, is well preserved at Byers Peninsula, Livingston Island (Pankhurst *et al.*, 1979), Copper Mine Peninsula, Robert Island, at King George Island and other places. These volcanics, as well as numerous associated plugs were erupted during subduction-related, island-arc type magmatism along the edge of the South Shetland Islands and northwestern Antarctic Peninsula. Herron and Tucholke (1976) and Barker and Burrel (1977) have recognized the segmentation of the Pacific Plate in the Antarctic Peninsula Arc (Fig.3). Herron and Tucholke have also noted that active subduction along these segments have decreased progressively northeastwards in such a way that the South Shetland trench remains as an active subduction site only until the Lower Tertiary. The arc volcanism appears to end during the Eocene-Oligocene, as indicated by the pyroclastics found in Fildes Peninsula and other localities of King George Island. Associated with this last volcanic phase there is a number of andesitic and doleritic plugs as the Neptuno Cathedral on Robert Island, Three Brothers Hill at Potter Peninsula on King George Island (46 Ma), and other centers at Point Hennequin (30 Ma). The intrusive dioritic-granodioritic phase associated with this calc-alkaline volcanism is evidenced by the outcrops of Two Hummock Islands as well as Trinity, Tower and other islets toward the northeast. Rex (1972) obtained ages of 36 Ma for Two Hummock and 55-64 Ma for Tower Is-

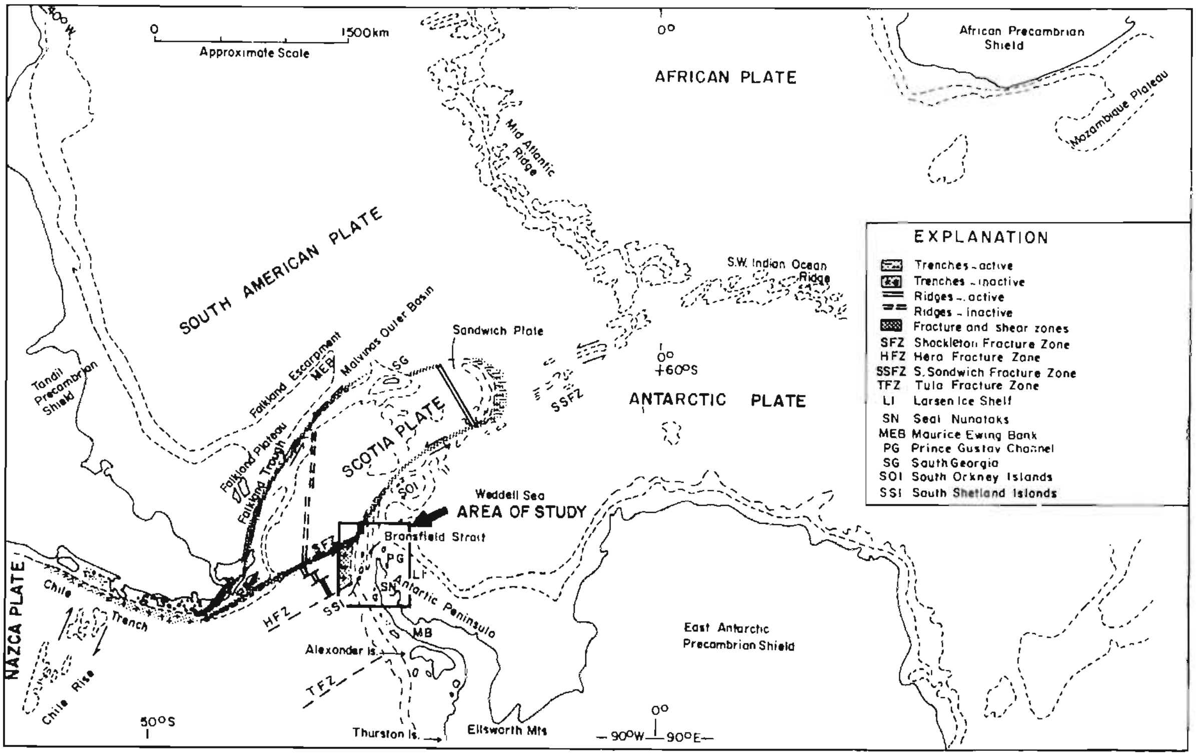

FIG. 3. Relation of the surveyed area with the principal localities and tectonic features of the Scotia Arc, South America and Antarctic Peninsula.

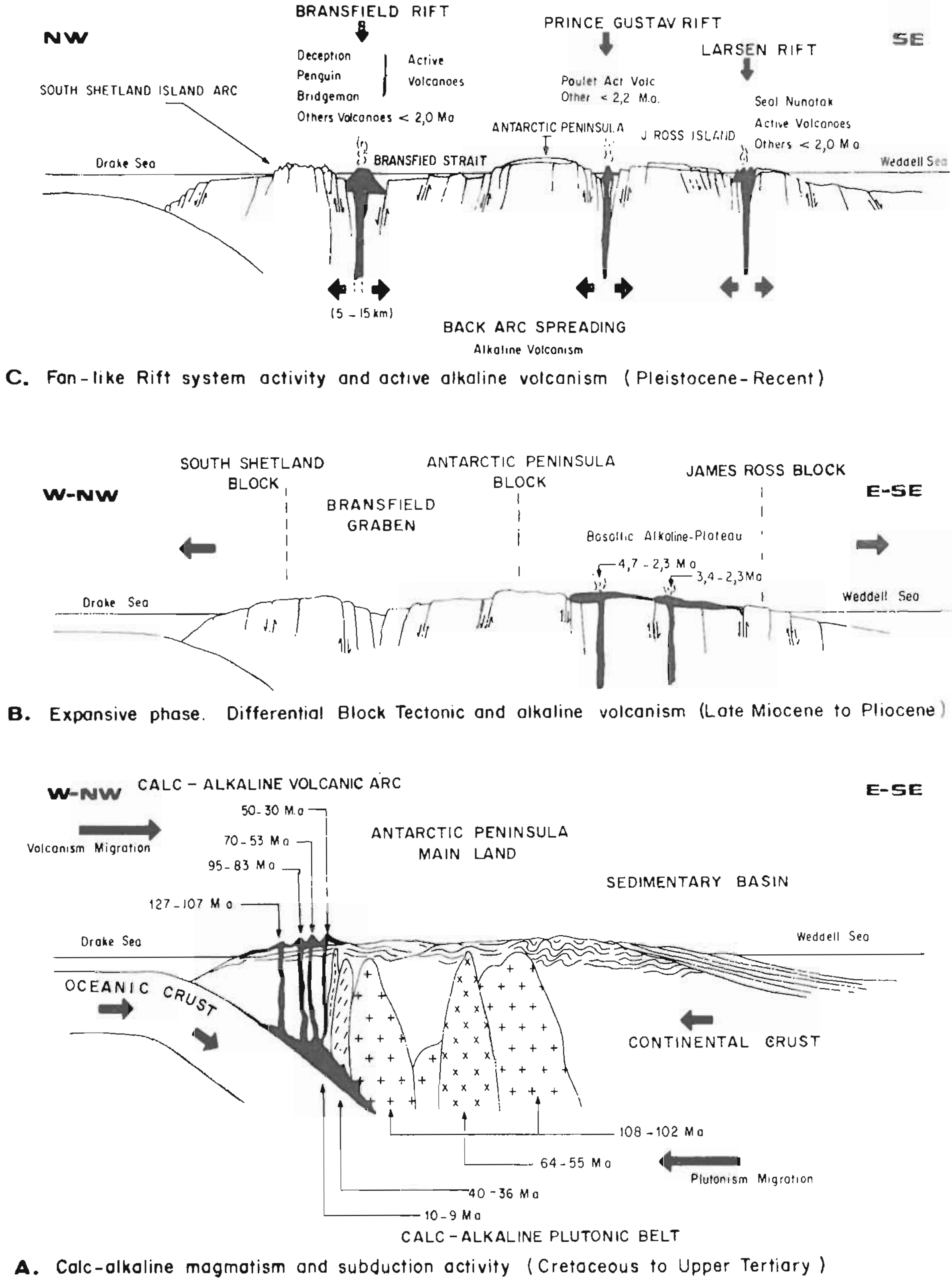

FIG. 4. Tectono-volcanic evolution of the Antarctic Peninsula from Cretaceous to Recent. After González-Ferrán (1985).

land.

Following the cessation of subduction, a tensional tectonic episode began; this was originally characterized by the development of longitudinal fractures, vertical movements and gravity faulting that, finally, gave birth to the Bransfield Strait Graben (Fig. 4). Additionally, a series of "en échelon" blocks which controlled the morphological units of the South Shetlands and the Antarctic Peninsula were formed. It has been estimated that these movements, which started at the end of the Miocene, reached their major intensity during the Pliocene. Almost at the same time alkaline-type volcanism, developing an extensive plateau, started in the back-arc area. Activity was centered along longitudinal fractures, 300 to 600 km southeast of the trench axis (James Ross Island, Tabarin Peninsula), and the volcanic products included both pyroclastics and basalts. Strongly palagonitized hyaloclastics indicate a subglacial volcanic activity (González-Ferrán and Baker, 1973).

Apparently, the extensional processes ended with the formation of a rift on the northwest Bransfield Strait. The active volcanism identifying this rift is represented by Deception, Penguin and Bridgeman Islands and a number of submarine volcanic centers. The petrological and geochemical characteristics of these volcanics have been widely investigated by González-Ferrán and Katsui, 1970; Baker *et al.*, 1975; Weaver *et al.*, 1979; Tarney *et al.*, 1981; Weaver *et al.*, 1982. They display several unusual features, some of which are indicative of island-arc lavas, and others of ocean-floor basalts. According to Tarney (1977) the magmas in Deception and Bridgeman appear to have been generated through relatively shallow melting of the mantle, indicating a transitional stage between calc-alkaline and mid-ocean ridge magmatism. This would be consistent with a model of mantle diapirism splitting the volcanic arc during the initial stages of a back-arc spreading episode. Penguin Island represents the most alkaline phase generated during the rifting proccess, still active at present.

GEOPHYSICAL INTERPRETATION

Both, qualitative and quantitative interpretations are presented as preliminary findings from this regional aeromagnetic survey. In the qualitative interpretation, magnetic features on the computer-drawn profiles (Fig. 2) and contour map (Fig. 5) are studied with regard to shapes, sizes, regional trends, and magnetic intensity. Faults and lithological boundaries are interpreted from gradients or changes in character, in the magnetic contours and profiles, or from abrupt terminations and/or displacement of magnetic trends (Vacquier *et al.*, 1951). Quantitative interpretation is based on a two dimensional model with finite extension in the direction of the strike (2 1/2 dimensions).

QUALITATIVE INTERPRETATION

There are three major anomalies and a number of magnetic lineaments that will be discussed independently:

BRANSFIELD SHELF ANOMALY

A major anomaly was obseved in the northwestern part of the Antarctic Peninsula, on Bransfield Strait (Fig. 5). The size of the area of positive anomalies, as well as its association with exposures of the Andean Instrusive Suite between, suggest that there is a major intrusive body continuos over a wide area (Fig. 6). Exposures are generally of quartz-diorite, quartz-gabbro or granodiorite, and laboratory measurements of their magnetic properties (Allen, 1966) confirm that such an anomaly can be produced by induction of the main field, and by remanent magnetization, that was found is in the direction of the earth present magnetic field. At the southeast end of the anomaly, the magnetic field drops sharply from maximun values of around 500 gammas to negative values, lower than 200 gammas. Modelling this anomaly results in a sharp contact between a high susceptibility unit to the northeast and a non magnetic unit to the southeast. This significant change can be accounted for by assuming a lithologic variation from the more magnetic rocks of the Andean Intrusive Suite to the less magnetics rocks (greywackes and shales) of the Trinity Peninsula Series. The magnetization of the Trinity Peninsula Series sediments is negligible, as shown by Allen (1966)

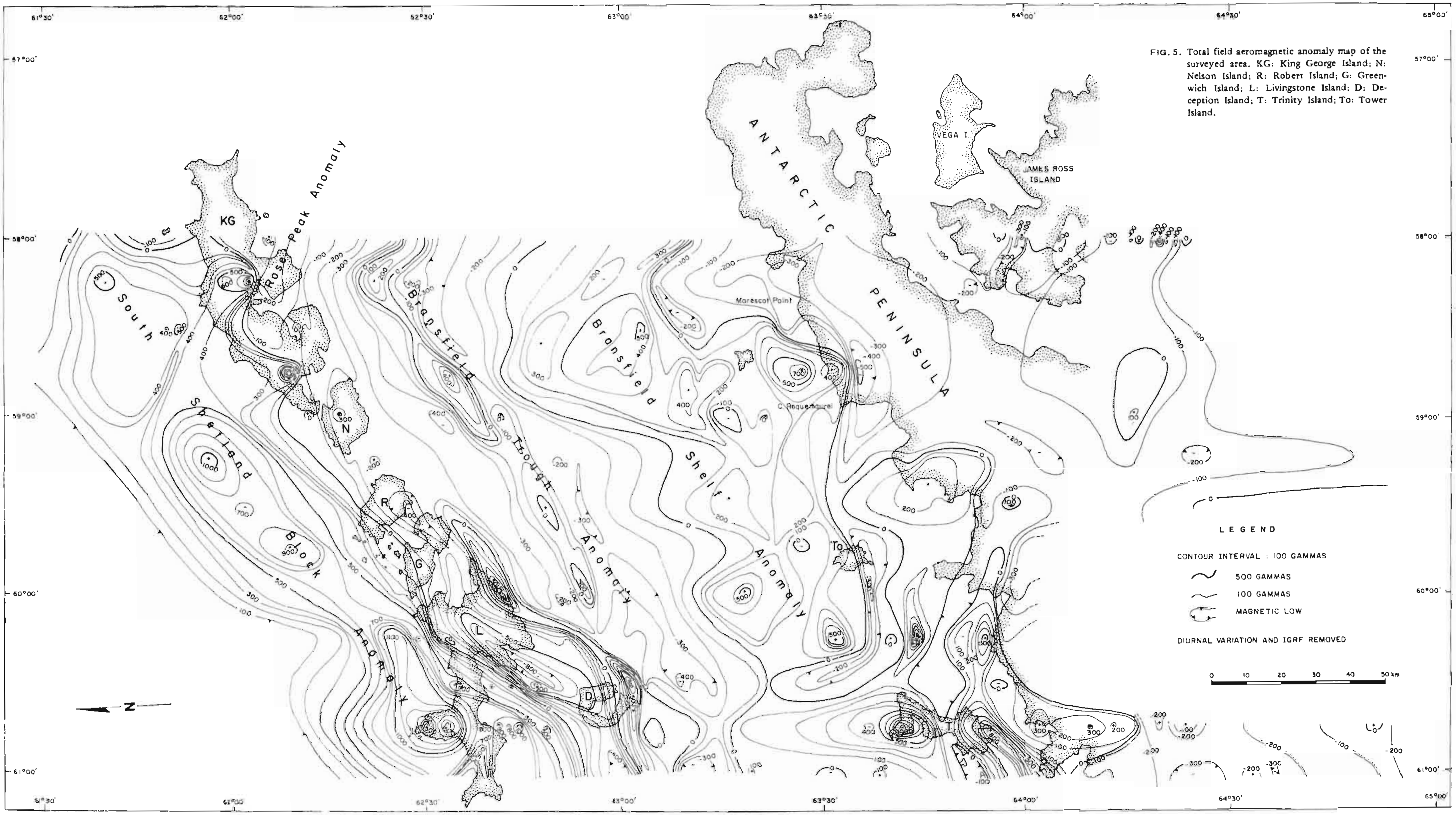

FIG. 5. Total field aeromagnetic anomaly map of the surveyed area. KG: King George Island; N: Nelson Island; R: Robert Island; G: Greenwich Island; L: Livingstone Island; D: Deception Island; T: Trinity Island; To: Tower Island.

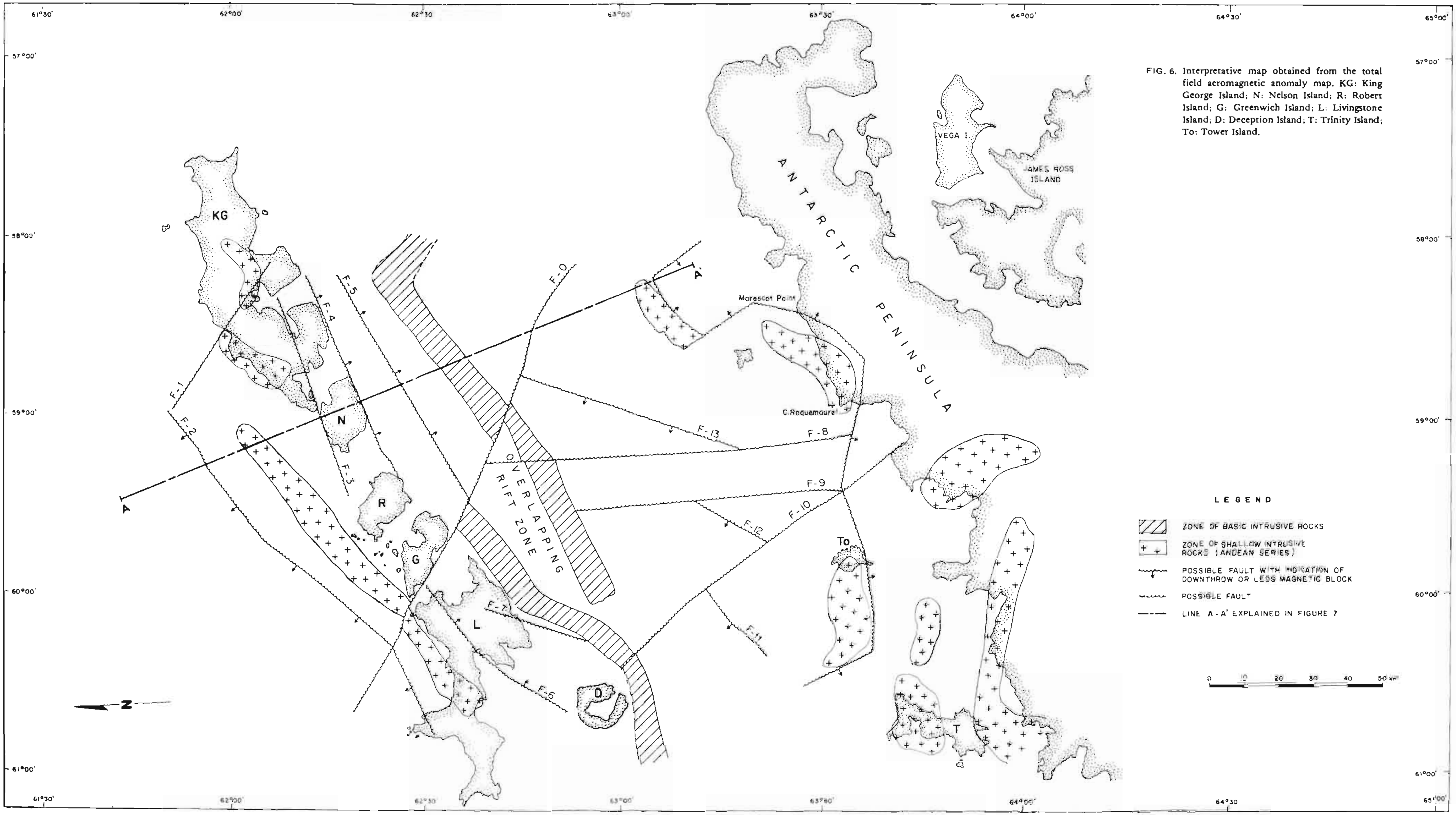

FIG. 6. Interpretative map obtained from the total field aeromagnetic anomaly map. KG: King George Island; N: Nelson Island; R: Robert Island; G: Greenwich Island; L: Livingstone Island; D: Deception Island; T: Trinity Island; To: Tower Island.

which gives a mean value of $(37 \pm 17)10^{-6}$ CGS units/cm^3 for the volume susceptibility of 20 speciments, where no remanent magnetization was found.

Positive values of this magnetic anomaly gradually decrease northwest, which is interpreted as a gradual deepening of the Andean Intrusive Suite bodies. The interpretative map (Fig. 6) shows the position of the zones where the intrusive rocks are near to the surface, or outcropping.

SOUTH SHETLAND BLOCK ANOMALY

North of the survey area, in the South Shetlands, there is a positive anomaly reaching over 1,000 gammas, approximately parallel to the Bransfield Strait trend (N60°E). To the southeast, this anomaly ends abruptly in a magnetic low and to the northwest the positive values gradually decrease. According to Hawkes (1961) and Pankhurst (1982), the Andean Intrusive Suite in King George Island is represented by quartz-gabbros, quartz-diorites and granodiorites forming the axis of the island, trending approximately west-southwest to east-northeast. Samples from Rose Peak, northern King George Island (Fig. 5), collected by Hawkes (1961) are hornblende-biotite, granodiorites with magnetite as accesory mineral. This outcrop is associated with a magnetic high included in the regional positive anomaly. This fact allows us to propose that the broad anomaly obseved in the northern part of King George Island is produced by intrusive rocks of the Andean Intrusive Suite. The steep gradient to the southeast, over the South Shetland Islands, is interpreted in terms of normal faulting affecting the intrusive rocks with downthrow of several kilometers to the southeast (Fig. 6).

BRANSFIELD TROUGH ANOMALY

Between the two regional positive magnetic anomalies there is a very well defined wide magnetic low, elongated in the direction of the Bransfield Trough (N60°E) (Fig. 5). This regional magnetic low is interpreted as due to the presence of a thick pile of rocks with low magnetic susceptibility (sediments). Emerging from this magnetic low there are lineated magnetic anomalies trending in the same direction. These anomalies are located over the deeper part of the Bransfield Trough and are interpreted to be due to high susceptibility rocks such as basalts, covered by more than 1,000 meters of water and non magnetic rocks (Fig. 7). This anomalous area may correspond to a zone of injection of basic dykes into the continental crust, defining an incipient ridge along the Bransfield Strait. The model (Fig. 7) suggests that, in this early stage of the ridge, there is not a typical oceanic crust layer, but a magnetically anomalous body representing a mixture of successive injections of basic material with thick intercalation of sediments, and perhaps, stratoid volcanics.

The Bransfield ridge is segmented and overlapped (Fig. 6). This type of overlapping spreading center was recognized by Mac Donald (1984) and Lonsdale (1984) in a detailed SEABEAM investigation of the East Pacific Rise (8°N to 18°N).

STRUCTURE

Magnetic lineaments indicate that there are at least two systems of faults in the area, one striking approximately northeast and the other northwest. Most faults are shown on the map of Fig. 6. The side displaying less magnetic susceptibility corresponds, often but not always, to the downthrown side.

Considering magnetic features, FO was drawn as a possible major fault with relative right lateral shift (Fig. 6). This fault displaces the northeast magnetic trends and faults and possibly corresponds to the trace of a transform fault parallel to the Hero and Shackleton fracture zones, described by Herron and Tucholke (1976).

Lineaments F-8 through F-10 and F-11 through F-13 may correspond to a north-south system of faults affecting the northeast normal faults. Some of these lineaments are coincident with surface faults as shown in Fig. 8.

QUANTITATIVE INTERPRETATION

A quantitative interpretation along profile A-A' (Fig. 6) was made with the purpose of determin-

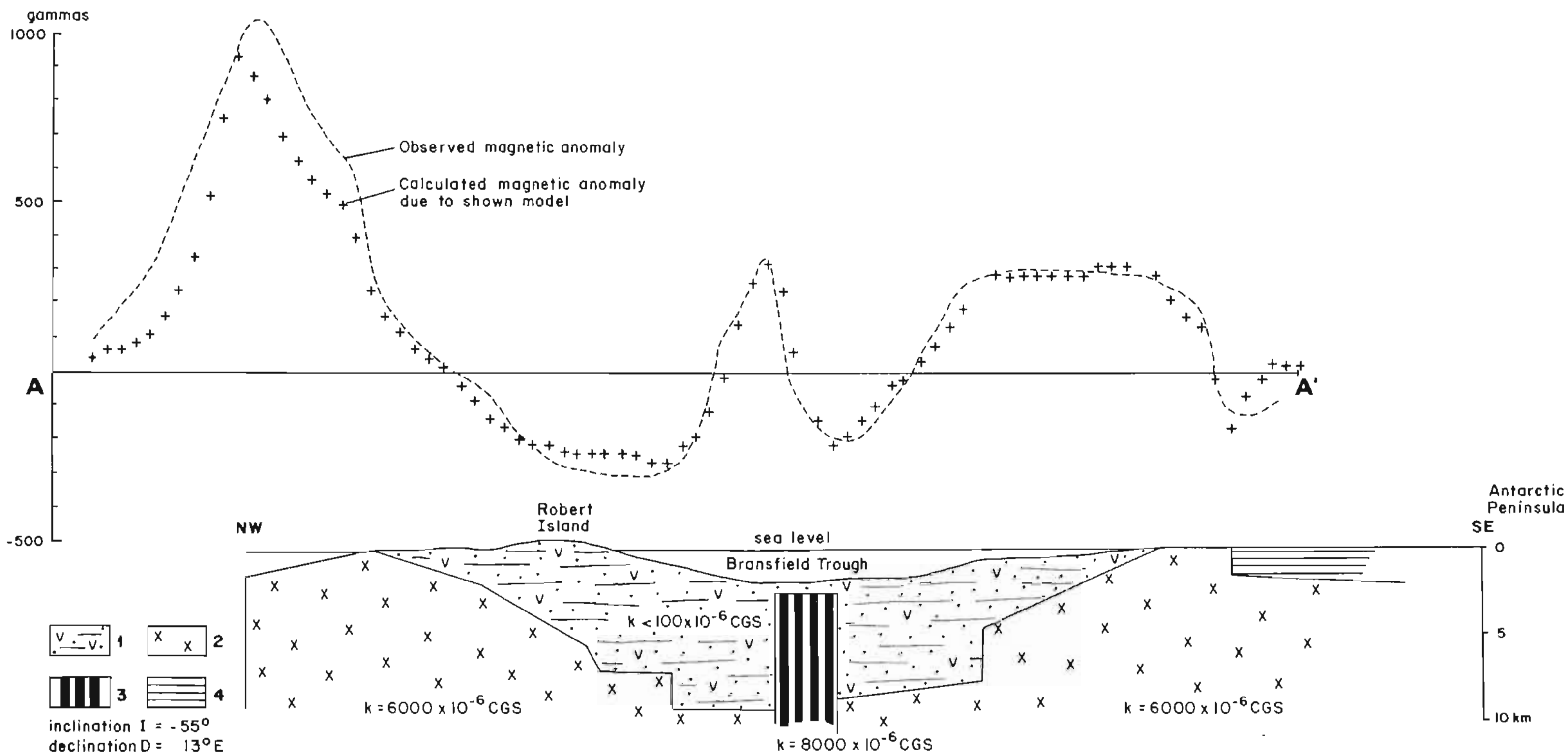

FIG. 7. Interpretative model along line A-A' with 2-1/2 dimensional interpretation. 1. Sediments and volcanic rocks; 2. Andean Intrusive Suite; 3. Zone of basic intrusive rocks; 4. Sediments (Trinity Peninsula Series).

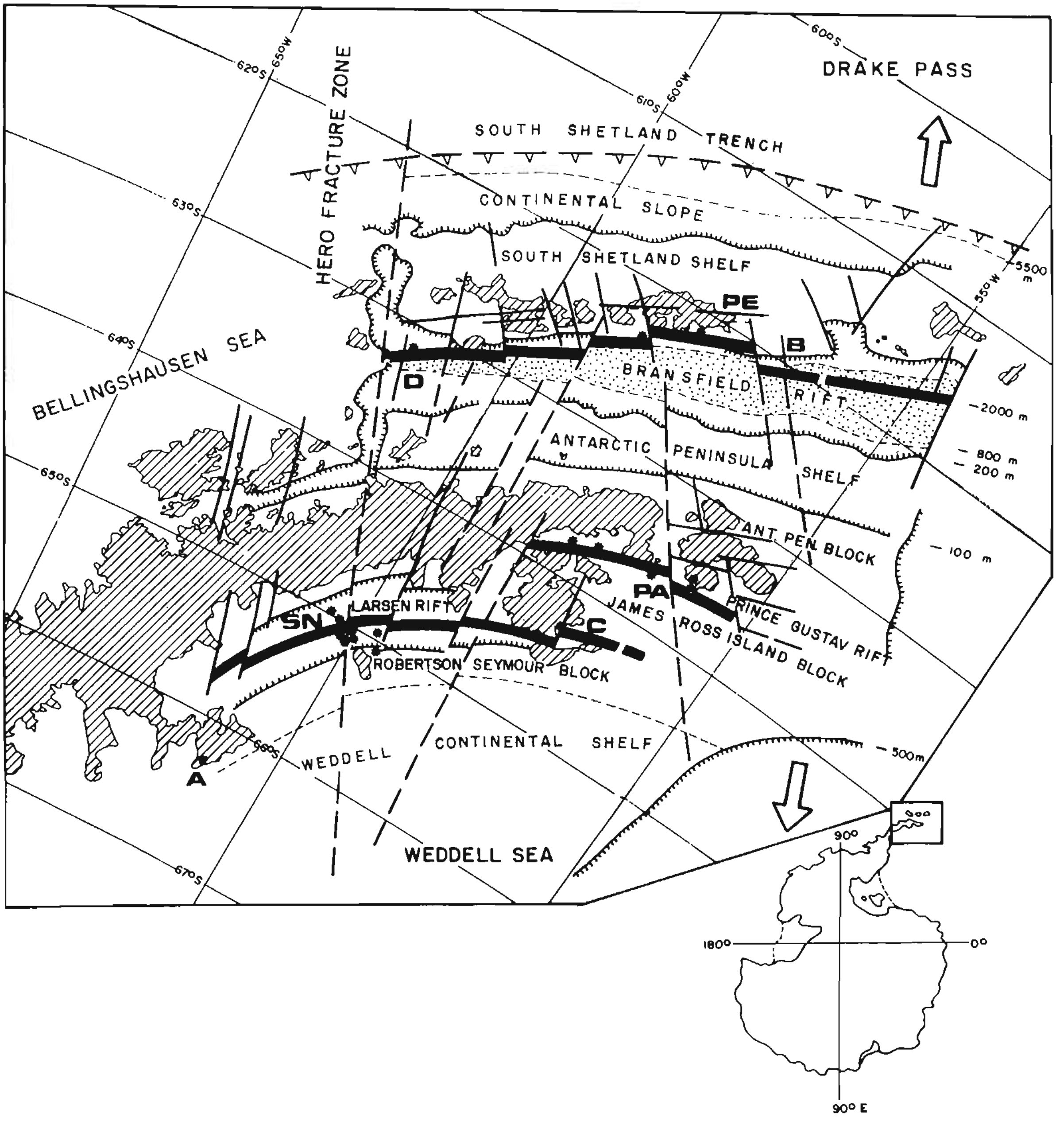

FIG. 8. Schematic map, showing the relations between active rifts-active volcanoes and the main structural blocks and faults at the northern Antarctic Peninsula region. Active volcanic centers: D = Deception; PE = Penguin; B = Bridgeman; PA = Paulet; C = Coley; SN = Seal Nunataks; A = Argo. After González-Ferrán (1985).

ing depth of magnetic source, shape, and magnetic susceptibility of the rock bodies, creating the observed anomalies. This modeling was done using automatic interpretation that considers two dimensional models with finite extension in the direction of the strike. The computer program for the model-fittings solution was based on Shuey and Pascuale (1973). In this method a theorctical anomaly is calculated for a specified two dimensional polygonal body in a direction perpendicular to the strike (Bhattacharyya, 1964, 1966; Bott, 1960, 1963; Heirtzler *et al.*, 1962; Bhattacharyya and Navolio, 1975).

A good fit was obtained between the observed and computed magnetic anomalies (Fig. 7). An average susceptibility of 6,000 10^{-6} CGS units/cm^3 is estimated for the Andean Intrusive Suite. Relative vertical fault displacements of about 7,000 meters can be inferred from the model. The model also shows a thick layer of sediments infilling the Bransfield Trough and a fault contact between the rocks of the Trynity Peninsula Series, and the Andean Intrusive Suite,outcropping in the Antarctic Peninsula. The central positive anomaly of Bransfield Strait was modeled by a high susceptibility body representing the rift zone. A width of 5 km is estimated for the basic extrusive igneous material of the rift.

CONCLUSIONS

From the analysis of the aeromagnetic map (Fig. 5) and the magnetic profiles (Fig. 2) as well as geological information of the Antarctic Peninsula and South Shetlands, the following conclusions are drawn:

1. Positive magnetic anomalies on both sides of the Bransfield Trough which trend parallel to the northwestern border of the Antarctic Peninsula and to the South Shetland Islands Trench are associated with igneous rocks of the Cretaceous to Middle Tertiary Andean Intrusive Suite.
2. Along the Bransfield Strait there is a "magnetic low" apparently produced by a thick layer of non magnetic sediments.
3. Most of the surveyed Antarctic Peninsula represents a magnetic low which is related to non magnetic rocks of the Trinity Peninsula Series.
4. The total magnetic contour map shows well defined positive magnetic anomalies aligned along the Bransfield Trough. These anomalies are interpreted as produced by basic injections into the continental crust, defining an incipient rift along the Bransfield Strait.
5. The quantitative interpretation indicates that the magnetic susceptibility of the basic material at the ridge zone is not as high as the susceptibility of oceanic crust. This may be interpreted as though their chemical composition could be of a transitional type between arc-related and true ocean-floor material.
6. Magnetic lineaments show a system of normal faults trending northeast and related to tensional processes. A major lineament trending northwest may correspond to the trace of a transform fault which parallels the Hero and Schackleton fracture zones.

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