INTERPRETATION OF AEROMAGNETIC SURVEY

ASCENSION ISLAND
SOUTH ATLANTIC OCEAN

Prepared for

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1.0 EXECUTIVE SUMMARY

This report describes a detailed aeromagnetic survey of Ascension Island which was completed in February and March of 1983 as part of the Phase II evaluation of the geothermal potential of Ascension Island. The aeromagnetic map represents a basic data set useful for the interpretation of subsurface geology. An in situ magnetic susceptibility survey was also completed to assist in understanding the magnetic properties of Ascension rocks and aid in the interpretation of the aeromagnetic data.

The aeromagnetic survey has been interpreted using a three-dimensional numerical modeling program which computes the net magnetic field of a large number of vertically sided prisms. Multiple source bodies of complex geometry were modeled and modified until a general agreement was achieved between the observed data and the computed models.

The interpretation indicates northeast- and east-trending elongate bodies of much higher apparent susceptibility than adjacent rocks. The relation to mapped geologic features such as volcanic vents, dikes and faults suggests that these magnetic sources are zones of increased dike density, and other mafic intrusives emplaced along structures which fed the many volcanic centers. A large magnetic source on the northeastern portion of the island may be the intrusive equivalent of trachyte lavas present at the surface.

Faulting is inferred along the margins of some magnetic sources, and at the termination of several sources near the center of the island. An irregular area of approximately 7 sq km within the center of the island, mainly north and west of Green Mountain, is a low-magnetization area of considerable structural complexity. The low-magnetization area corresponds

well with zones of low electrical resistivity mapped in earlier studies. This would appear to be the most likely area for the presence of a geothermal system at moderate (1 to 3 km) depth.

Additional electrical resistivity profiles and deep thermal gradient holes should be completed to refine the subsurface model before drilling a costly production well test.

2.0 INTRODUCTION

The geothermal energy potential of Ascension Island is being evaluated to determine the feasibility of a low-cost, renewable energy alternative for United States facilities at Ascension Auxiliary Airfield (Ascension AAF).

Geologic mapping and interpretation for this resource evaluation was completed in a Phase I study by Nielson and Sibbett (1982). They concluded that the young age of Ascension Island volcanic activity, the presence of geologic structures to provide permeability, and the probability of fluids to transport thermal energy demonstrated a very high potential for the discovery of a geothermal resource. Nielson and Sibbett (1982) recommended that the U.S. Air Force proceed with a Phase II program of more detailed exploration activities. The aeromagnetic and magnetic susceptibility surveys reported here are a part of the geophysical exploration effort.

3.0 GEOLOGY

Ascension Island is located about 100 km west of the Mid-Atlantic Ridge median valley and 50 km south of the Ascension fracture zone (van Andel et al., 1973), as shown in Figure 1. As described by Nielson and Sibbett (1982), the island is composed almost entirely of volcanic rocks, and is the top of a

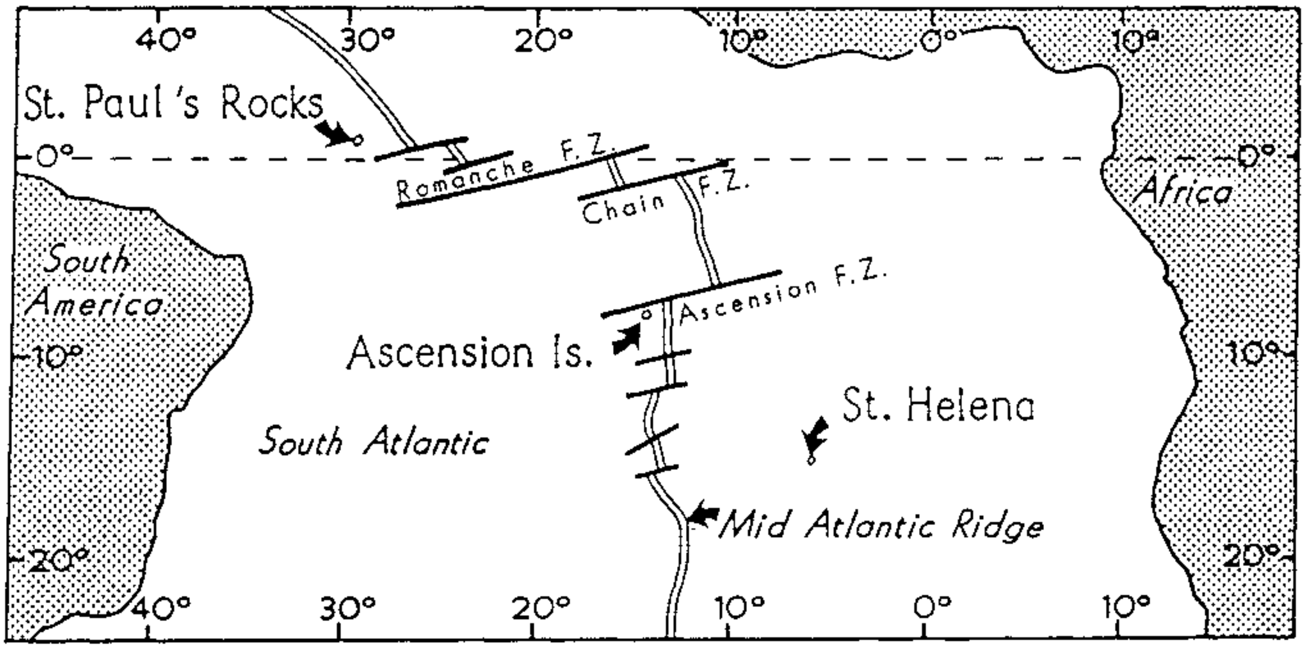


Fig. 1. Location of Ascension Island, the Mid-Atlantic Ridge and ocean fracture zones.

volcanic mountain which rises 4 km above the sea floor and is perhaps 50 km in diameter at its base.

Nielson and Sibbett (1982) present a detailed geologic map of Ascension Island, describe the units and structures in detail, and discuss the geologic history of the island. The geophysical surveys were conducted to extend the geologic data to depth and to search for physical properties indicating a geothermal system at depth. A brief review of the geology is useful as a prelude to discussing the aeromagnetic and magnetic susceptibility surveys.

Basalt flows dominate the surface of Ascension Island, with the youngest flows emanating from the Sisters Peak and South Gannett Hill areas. Nielson and Sibbett (1982) suggest these flows are probably several hundred years old based on the lack of weathering and erosion. These flows cap older flows which occur throughout the island. Trachyte lava flows, pyroclastic deposits, domes and intrusions dominate the central and eastern portions of the island. Age dating suggests that the Bears Back dome was emplaced approximately 610,000 years ago. The Middleton Ridge rhyolite flow, exposed at the base of the Green Mountain stratigraphic sequence, was dated at approximately 0.94 m.y. Prominent cinder cones and cinder aprons occur throughout the island.

4.0 GEOPHYSICS

4.1 Geophysical Surveys

No significant geophysical data base has been published for Ascension Island prior to the present geothermal studies, although Dash and Milson (1973) do comment on the gravity field of the island. Nielson and Sibbett (1982) recommended aeromagnetic and resistivity surveys and thermal gradient drilling as the Phase II geothermal exploration program. An electrical resistivity survey was completed in June 1983 and is reported separately (Ross et al., 1984). Three self-potential traverses completed in March 1983 are also described in that report.

Reconnaissance electrical resistivity measurements, using the bipole-dipole array, were completed which covered the central 35 sq km of the island. A broad zone of low apparent resistivity was mapped which trends north-northeast from Devil's Riding School through Thistle Hill. Areas west of Spoon Crater and northeast of Thistle Hill showed the lowest apparent resistivities within this broad (2 km by 5 km) zone.

Three dipole-dipole profiles were completed which refined the location, depth and intrinsic resistivity of the low resistivity zones. The profiles show high resistivities above sea level, with some resistive masses extending to considerable depth. Low resistivity zones at depth are thought to result from a saline water table which is located at sea level (Ross et al., 1984). Geothermal brines probably contribute to low-resistivity zones further inland, i.e. from Devil's Riding School to McTurk's Culvert, and south of Thistle Hill. These low-resistivity zones remain incompletely defined. The low-resistivity areas indicated by the survey work were recommended for thermal gradient test drilling in a subsequent exploration effort.

Three self-potential traverses were completed in March 1983 in an attempt to map electric potentials generated by moving geothermal fluids. Several small positive anomalies were recorded which correspond to mapped geologic structures and favorable low resistivity zones. The amplitudes of the anomalies are small compared to self-potential anomalies observed in geothermal areas in Hawaii and in the western United States, but the location of the anomalies adds some encouragement for the presence of thermal fluids moving along geologic structures.

4.2 Description of the Aeromagnetic Survey

The remote location of Ascension Island is such that a conventional aeromagnetic survey using a permanently instrumented, fixed wing aircraft would be very costly even if an aircraft with sufficient range could be contracted. The presence of a British helicopter unit, the 845th Squadron Detachment, Royal Navy, on Ascension Island provided the opportunity to conduct a survey using a "button on" or portable aeromagnetic survey system. The British base commander agreed with the U.S. AAF base commander to provide helicopter support for the survey when flight operations schedules permitted. The Earth Science Laboratory/UURI obtained the use of a privately owned button on magnetic survey system in exchange for technical services rendered to the company. Personnel and equipment were mobilized to Ascension Island in February 1983.

The principal components of the data acquisition system are shown schematically in Figure 2. The heart of the system is a GeoMetrics Model G-803 Airborne Proton Magnetometer which houses the electronics for sensor interfacing, signal amplification, phase lock and frequency multiplication, digital to analog conversion and other systems control functions. The sensor is a toroidally wound coil immersed in a selected hydrocarbon fluid (kerosene) rich in protons. The sensor is mounted in an aerodynamically designed housing approximately 0.7 meter long which is commonly referred to as the "bird". The magnetometer console was mounted in a Wessex helicopter and connected to the sensor by a 100-foot long electrical cable with an exterior nylon sleeve strength member. Protons within the kerosene are polarized when a few amperes

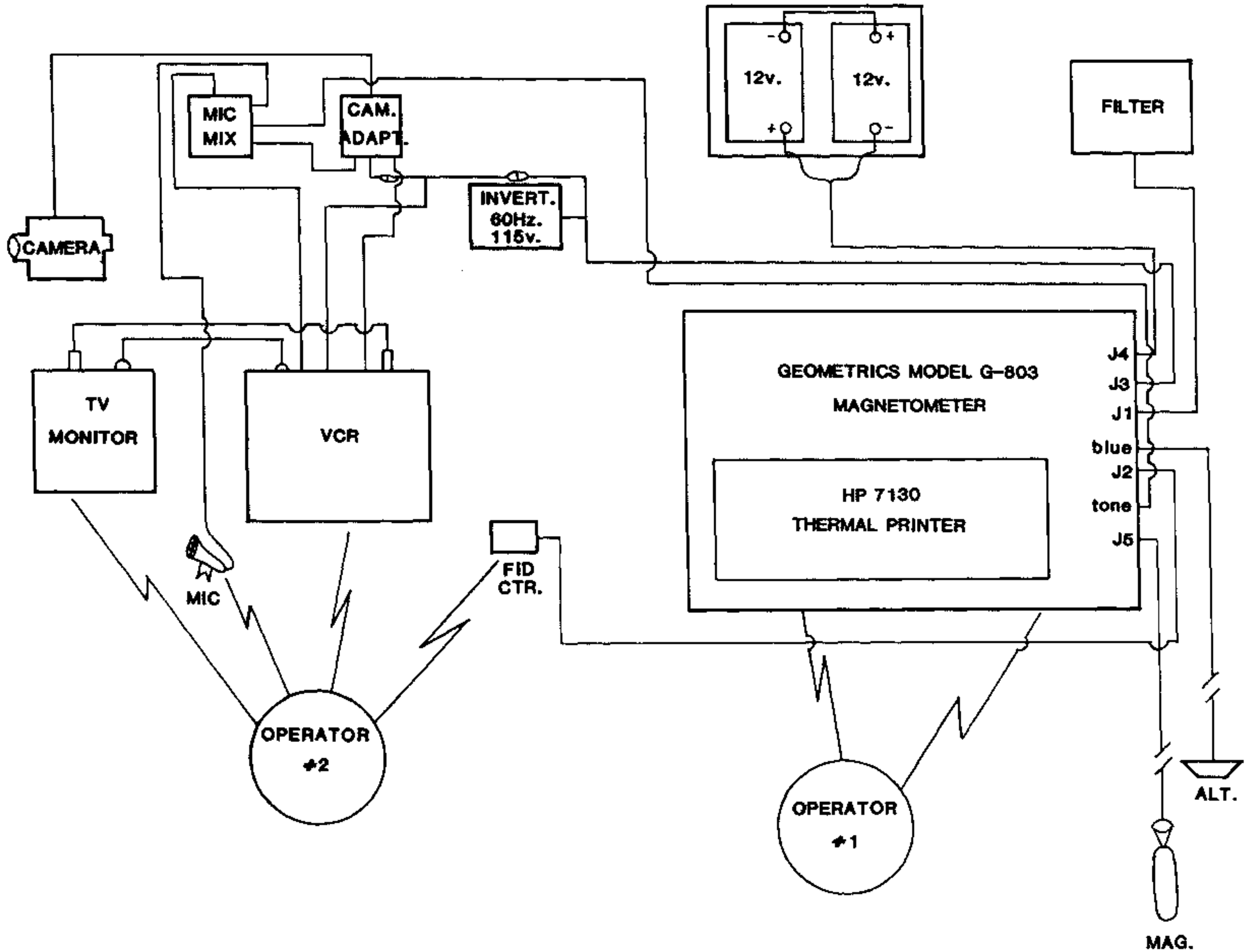


Figure 2. Schematic illustration of aeromagnetic survey instrumentation.

of current are passed through the coil surrounding the hydrocarbon fluid sample and align with the applied magnetic field. When this magnetic field is removed, the protons precess about the direction of the ambient (earth's) magnetic field at a rate proportional to the total magnetic intensity. The frequency of the precession signal is counted by the magnetometer (GeoMetrics, 1973).

A Mark-10X Bonzer radar altimeter was mounted on the helicopter skid to record the height of the aircraft above the ground surface. Magnetometer and altimeter outputs are recorded on a Hewlett Packard 7130 thermal printer which simultaneously records two channels of information in addition to the magnetometer-driven counting (fiducial) marker. The flight path corresponding to the magnetic observations is simultaneously observed by a downward-looking camera system and recorded on a Sony vido recorder (model AV-3600). The video system performance was monitored in flight (Figure 2) by an instrument operator who also verbalized the fiducial numbers and operated the counter and VCR. The magnetometer was operated at a sensitivity of 1.0 gamma corresponding to a sampling rate of 0.5 seconds, or a distance of 20 to 30 meters on the ground depending on true ground speed. In survey application, the thermal printer was used to record the total magnetic intensity at two sensitivities, 10 gammas per inch and 100 gammas per inch, rather than one magnetic data channel and one channel of radar indicated terrain clearance. Two 12-volt automotive batteries provided power for the instrumentation for approximately four hours of operation time.

The flight crew included five people: the pilot, navigator, helicopter crewman and cargo observer, magnetometer operator, and videosystem operator. The survey was completed in four flights beginning February 28 and concluding on March 4. Constant cloud cover over Green Mountain during the survey period resulted in a data gap of 2 by 3 km centered on the Green Mountain area.

Aeromagnetic surveys are generally flown with the primary flight direction perpendicular to geologic structure so that the higher data sampling frequency corresponds to the direction of greater change in geologic features. Geologic mapping by Nielson and Sibbett (1982) indicated both northwest and east-northeast structural trends on Ascension Island. The primary flight-line directions were oriented S65°E directly into (or out of) the strong (20 knot) southeast trade winds to minimize drift off the intended flight path. Twenty-nine flight lines were completed at an average separation of 380 m (1240 ft). Eight tie lines were flown in a north-northeast direction, roughly perpendicular to the primary flight direction, at varying intervals across the entire island. The helicopter was flown on a smoothly draped flight path with a mean terrain clearance of 230 m (750 ft) as monitored by the aircraft radar altimeter. The magnetometer sensor hung approximately 25 m vertically below the aircraft, at the end of the 30 m cable. The total magnetic intensity data thus pertain to a mean terrain clearance of approximately 205 m (670 ft).

4.3 Magnetic Survey Compilation

Several time-consuming steps were required in completing the compilation and adjustment of the aeromagnetic data. The flight path recovery was completed by playback of video tapes, identifying the surface features on the video monitor with respect to aerial photography and the 1:25,000 topographic map of the island, and assigning a fiducial number by interpolation of the audio fiducial count. Total magnetic intensity strip chart recordings were manually digitized at all maximum and minimum points and at intervals of 1 to

5 fiducial points between these points, depending on the magnetic gradient and noise levels. In addition, all intersections between flight lines and tie lines were digitized. Thus, magnetic field values were digitized at intervals of less than 400 m (ground distance) and most typically at less than 200 m, along all flight lines, except for a 2 km length of three lines between the English Bay Road and Pryamid Point. Here extremely high noise levels from the nearby BBC transmitter complex (and other transmitters?) were picked up by cables and ground loops of the aeromagnetic system and added to the magnetic field variations, and only occasional smoothed magnetic values could be accepted as reliable data. Accordingly, the final magnetic contours for this area (Plate I) are dashed to reflect uncertainty in the magnetic field values.

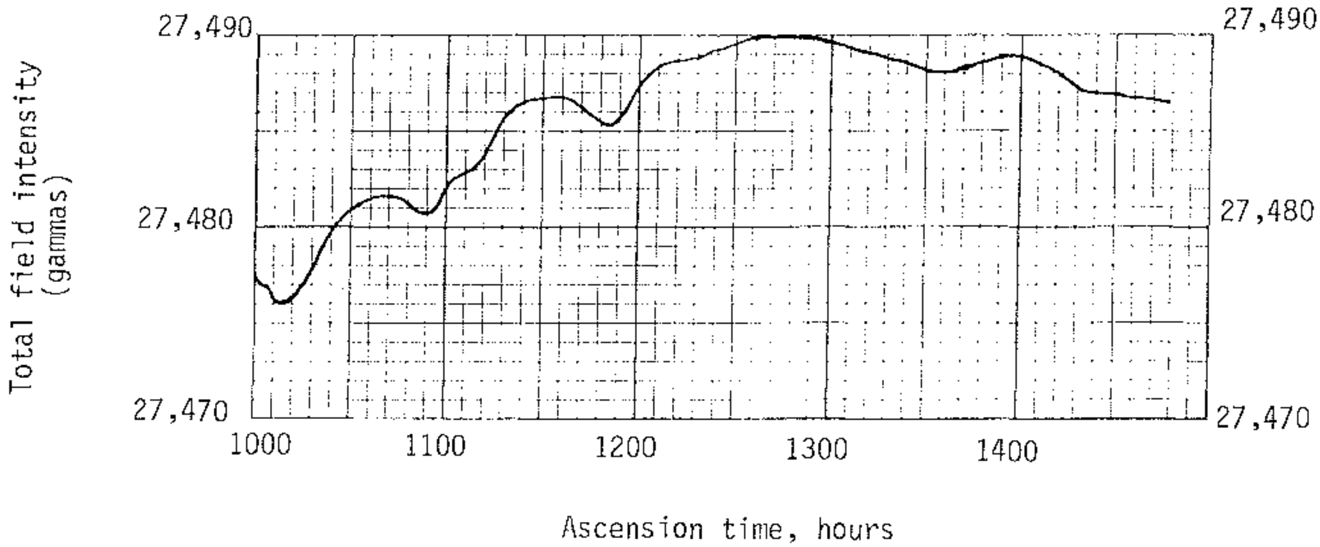
The final map of magnetic field intensity should denote magnetic field variations as a function of lateral position only, and time-varying or survey dependent variations should be removed to obtain the level of survey accuracy that is desired. Diurinal variations (described in the next section) during a given 2-hour flight were found to be less than 10 gammas and were not specifically corrected. Magnetic field variations as measured between different flights were adjusted by minimizing the residuals at flight line/tie-line intersections using the method of least squares (Yarger et al., 1978). All data values were therefore adjusted to the second survey flight which occurred between 0930 and 1200 hours, March 2, 1983. Contouring of the data points was assisted by reference to an independent compilation of maxima-minima positions and magnetic gradient notations compiled directly from the analog records. The overall accuracy of the data compilation, reflecting errors in position, diruinal variation, altitude variation and leveling, is judged to be ± 20 gammas. This is considered sufficient for the exploration effort underway and justifies a 20-gamma contour interval for the compiled map. A constant value of 27,000 gammas was subtracted from all observed data values for the presentation of data on Plate I. The total magnetic intensity field strength, for a fairly uniform area near the center of the island (approximately one km south of Two Boats Village), is approximately 27,800 gammas at 200 m above the ground surface.

4.4 Diurnal Variation

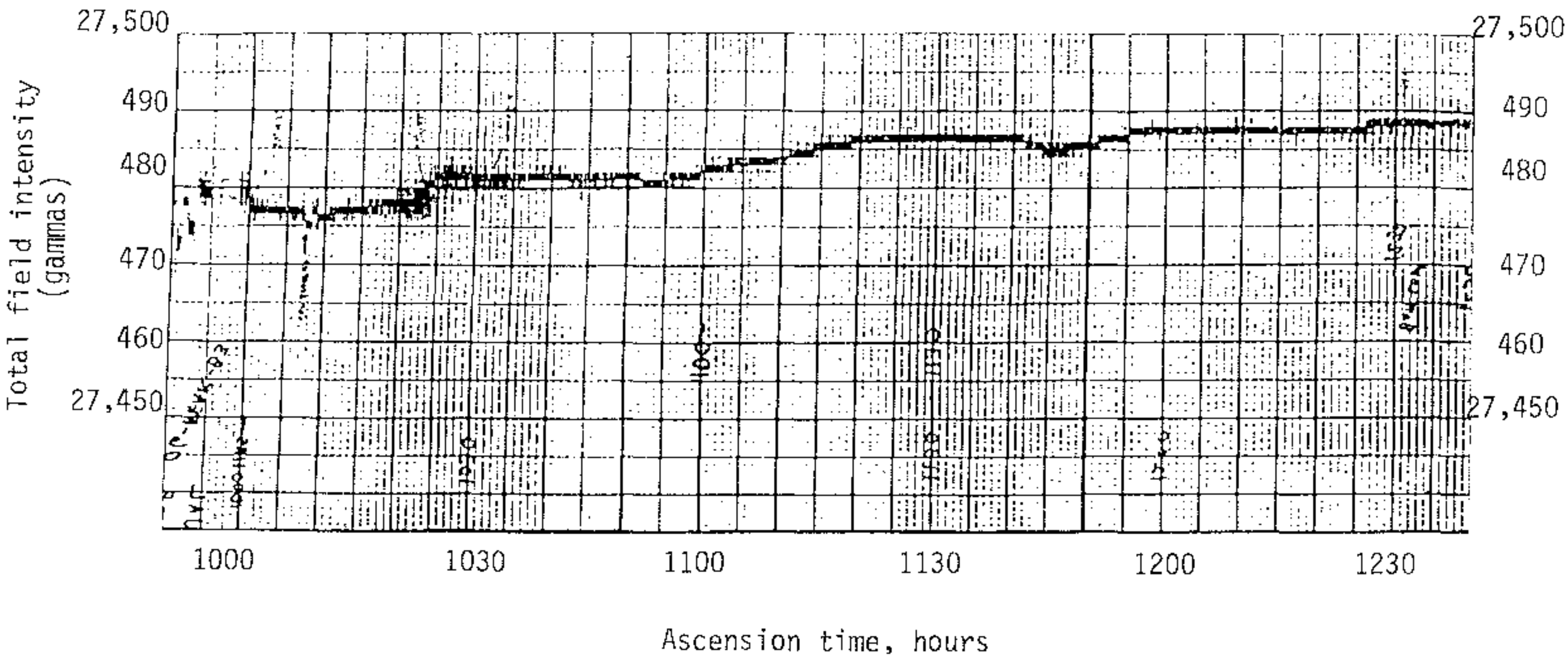
Ascension Island is located at approximately 8° south latitude, perhaps 10° south of the equatorial electrojet region where abnormally large variations in magnetic field strength occur within the diurnal cycle (Nelson et al., 1962). The diurnal variation was monitored prior to and after the airborne survey to evaluate the magnitude of change corresponding to data acquisition times. Figure 3a illustrates the diurnal field variation observed from 1000 hours to 1430 hours on March 6, 1983. The total field varied from a low of 27,476 at 1010 hours to a maximum of 27,490 gammas at 1250 hours then decreased to 27,486 at 1430 hours when the recording was terminated. The observation site was located at a magnetically quiet area near the southeast end of the Two Boats soccer field. A portion of the detailed record, Fig. 3b, indicates a smoothly varying magnetic field with 98 percent of the variation within a one-gamma envelope, and no excursions exceeding 3 gammas. The range of variation within a two-hour period comparable to the longest airborne survey period, is less than 10 gammas. The diurnal field variation was not recorded during actual survey flights, but is inferred to be similar.

5.0 MAGNETIC SURVEY INTERPRETATION

The interpretation of the aeromagnetic survey data for resource exploration has two main components: the delineation of magnetization



a) Diurnal summary.



b) Strip chart record.

Figure 3. Diurnal variation record, total magnetic intensity. Ascension Island, March 6, 1983.

contrasts and physical property parameters, and the interpretation of these parameters in geologic terms. Physical property measurements on outcropping rocks can often improve the geologic interpretation portion of the interpretation.

5.1 Magnetic Susceptibility Survey

Magnetic susceptibility is a basic physical property of rocks and other materials. The induced component of magnetization of an anomalous feature in response to an inducing or impressed magnetic field (i.e. the earth's magnetic field) is proportional in intensity to the strength of the inducing field. The constant of proportionality is termed the magnetic susceptibility. The magnetic susceptibility of natural rocks is generally a function of the amount of the mineral magnetite ($Fe_2O_3 \cdot FeO$) which is present. Empirical studies indicate that one volume percent of pure magnetite will result in a magnetic susceptibility of approximately 3000×10^{-6} cgs, although this is highly variable. Other iron minerals can give rise to magnetic susceptibility, but these are much less important and probably of no significance on Ascension Island.

Magnetic susceptibility measurements were made with a Bison Instruments magnetic susceptibility system, Model 3103, equipped with a Bison 3120 in-situ coil (Bison Instruments, 1969). The flat, 6-inch diameter sample coil was held against a smooth, planar rock surface to obtain the uncorrected susceptibility value. The observed value was multiplied by a correction factor to account for the average surface roughness which prevented a perfect contact between the rock surface and the sample coil. This correction varied between 1.00 for no offset from the surface, to 1.21 for an average offset of 0.3 inches. A single susceptibility measurement represents a volume of approximately 60 in^3 or 1000 cm^3.

Plate II shows the location of 29 sample sites where susceptibility determinations were completed on Ascension Island. Many locations represented two or three sample stations 30 to 100 m apart, or traverses of up to 300 m length. Three to 13 different measurements were made at each sample area, for a total of 289 readings. Table I summarizes the rock type and location, number of samples (n), sample mean ($\bar{x}$) and standard deviation (s) for each station.

The 42 sample groups of Table I have been composited into 13 rock type groupings for easier comprehension, in Table II. Basalt flows, which dominate the surface of the island, show the highest and most variable susceptibility with individual readings varying from 235×10^{-6} to 2927×10^{-6} cgs. The range of station averages for basalt flows lies between 494 and 2521×10^{-6} cgs. In general, the more vesicular the sample (i.e. higher porosity), the lower the susceptibility, though no attempt was made to quantify this relationship. A most typical susceptibility for basalt would be approximately $1,500 \times 10^{-6}$ cgs. Very high susceptibility flows ($> 2,000 \times 10^{-6}$ cgs) occur north of Sisters Peak, along the coast, and at Dark Slope Crater. One basalt dike (sta. 22) also showed a very high ($2,521 \times 10^{-6}$ cgs) average susceptibility. Since all average susceptibilities are less than $3,000 \times 10^{-6}$ cgs it would appear that the basalts contain less than one volume percent of pure magnetite. If substantial amounts of titanium are present in the magnetite lattice, several volume percent of magnetite could be present in the basalts, since titanium decreases magnetic susceptibility. Chemical analyses reported by Nielson and Sibbett (1982) do indicate substantial amounts of titanium oxides are present, probably as titanomagnetite.

TABLE I. Magnetic Susceptibility, Ascension Island Rock Units

Station	Rock Type and Location	n	$\bar{x}$	s
1	Two Boats basalt flow (near vent)	6	1952	508
2	Two Boats basalt flow (away from vent)	5	1499	248
3	Two Boats basalt flow - vesicular	4	1597	91
4	Basalt flow #1 (So. Sisters-vesicular)	5	1633	222
5	Basalt flow #1 (So. Sisters, in E-W structure)	4	1796	503
6	Basalt flow #1 (So. Sisters; vesicular)	4	609	91
7	Basalt flow - (Donkey Flat; vesicular)	5	1015	129
8	Basalt flow (Donkey Flat; vent area; vesicular)	7	570	80
9a	Basalt cinders (West Travelers Hill-b.c.-black)	4	254	73
9b	Basalt cinders (West Travelers Hill-mixed red & black)	4	145	67
9c	Basalt cinders (West Travelers Hill-mixed red & black)	3	83	30
10a	Basalt flow #1 (North Sisters; on coast; vesicular)	3	1566	111
10b	Basalt flow #1 (North Sisters; on coast; vesicular)	6	2402	248
11a	Basalt flow #1 (English Bay Rd.-rough flows, boulders)	4	1911	179
11b	Basalt flow #1 (English Bay Rd.-rough flows, boulders)	3	1445	333
12a	Trachyte (Daly's Crags)	12	128	39
12b	Black cinders (Daly's Crags)	7	68	26
13	Trachyte (Cross Hill; uniform, lt. gray)	12	326	292
14	Older basalt flow (N.E. Bay Club; porphyritic)	12	1322	553
15	Trachyte (At Blow Hole; devitrified)	10	296	233
16	Pillow basalt (At Blow Hole)	4	494	86
17a	Trachyte (Blow Hole road)	8	124	131
17b	Basalt (Blow Hole road)	3	555	93
18	Basalt flow (Bears Back; vesicular)	7	324	88
19a	Trachyte (Drip Dome)	12	304	98
19b	Trachyte ash (Drip Dome, pumice)	6	229	52
19c	Basalt cinders (Drip Dome)	7	252	81
20a	Trachyte pumice (Mtn. Road)	8	143	29
20b	Basalt cinders (Mtn. Road)	6	191	55
21	Basalt flow bf#2 (Spoon Crater; vesicular)	9	700	198
22	Basalt intrusive (massive)	9	2521	328
23	Basalt intrusive (lower dike-massive)	8	761	250
24a	Basalt (upper dike; massive)	10	748	273
24b	Basalt (upper dike; massive to porous)	9	1139	154
24c	Pumiceous sediments, pumice (fine grain)	3	395	68
25a	Dacite (Ragged Hill)	9	114	49
25b	Dacite (Ragged Hill)	9	197	101
26	Basalt flow (massive)	13	1210	331
27	Basalt flow (massive)	11	1559	426
28	Basalt (massive; Dark Slope Crater)	9	1993	187
29a	Basalt (up on Dark Slope Crater)	3	2443	200
29b	Basalt (up on Dark Slope Crater)	6	2417	375

Explanation: Station locations shown on Plate III; n = number of observations; $\bar{x}$ = mean susceptibility, μcgs units; s = standard deviation, μcgs units.

TABLE II. Magnetic Susceptibility Summary, Ascension Island

Rock Type, Locality and Stations ( )		No. Sta.	$\bar{x}$	s	Range
Basalt Flows					
Two Boats Basalt Flow	(1,2,3)	3	1683	238	1500-1952
South Sister's Peak - vesicular basalt flow #1	(4,5,6)	3	1346	643	609-1796
North Sister's Peak - vesicular basalt flow #1	(10,11)	4	1831	429	1445-2402
Donkey Flat - basalt flows	(7,8)	2	792	--	570-1015
Older basalt flow - southeast, NASA Road	(26,27)	2	1384	--	1210-1559
Older basalt flow - NE Bay Club	(14)	1	1322	--	1322
Basalt; pillow basalt - Blow Hole Road	(16,17b)	2	524	--	494-555
Older basalt flows - Dark Slope Crater	(28,29a,29b)	3	2284	253	1993-2443
Basalt intrusives (dikes, massive)	(22,23,24a,24b)	4	1292	839	748-2521
Other Rock Types					
Trachyte	(12a,13,15,17a,19a,20)	7	221	89	124-326
Dacite-Ragged Hill	(25a,25b)	2	156	--	114-197
Basalt Cinders	(9a,9b,9c;12b;19c;20b)	6	166	81	68-254
Pumiceous sediments, pumice	(24c)	1	395	--	395

Table I shows that the other principal rock types present on Ascension, trachyte, dacite, basalt cinders and pumice or pumiceous derived sediments, all exhibit magnetic susceptibilities lower by a factor of 5 to 10 than the basalts. Other rock types may be present at depth that have higher (or lower) magnetic susceptibilities. A geothermal reservoir area within the basalts could be expected to exhibit lower susceptibilities than adjacent basalts as a result of alteration processes.

The susceptibility measurements reported here have many similarities to the susceptibility of basalt flows and dikes of the Reydarfjordur, Iceland area. Bleil et al. (1982) reported on the magnetic susceptibility and remanent magnetization properties of a 3 km vertical section of Icelandic crust in conjunction with the drilling of the Iceland Research Drilling Project (IRDP) hole. They observed magnetic susceptibilities of 1000-5000 x 10^{-6}cgs, generally increasing with depth in the upper 1.5 km of crust accessible through surface exposure. Schonharting and Hall (1982) completed a very detailed susceptibility log of the 1919-m IRDP drill hole, and noted that the susceptibility of flows increased to depths of approximately 1 km, then decreased systematically to the bottom of the hole. The susceptibility of dikes varied much less both within a given dike, and with the depth of dike occurrence in general. They noted that iron-titanium composition, grain size and abundance controlled the initial susceptibility of the basaltic rocks. Weathering and oxidation, dike density, and hydrothermal alteration were important factors governing the net susceptibility of IRDP section.

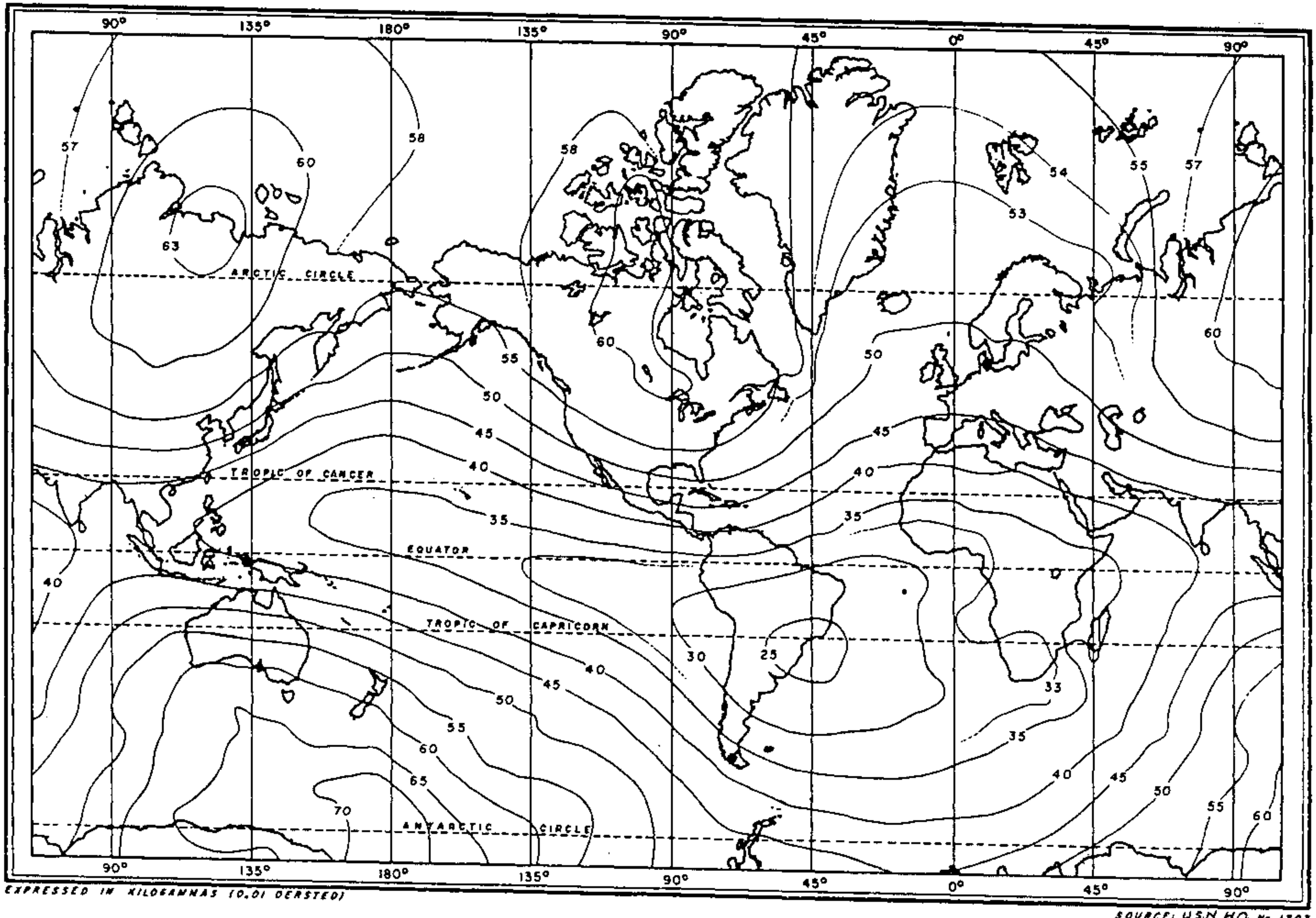
5.2 Qualitative Interpretation

The earth's magnetic field vector at Ascension Island is somewhat different than for any major land area on earth. The total field intensity, observed to be approximately 27,800 gammas (nanoteslas) is near the minimum of the earth's field which occurs east of Brazil (Figure 4). Ascension Island lies south of the magnetic equator. The magnetic field has an inclination of 27° (similar to parts of Africa, South America, and Indonesia) and a declination of approximately 21° west of geographic north. Thus, the magnetic field anomaly is substantially different for a magnetic body on Ascension than for the same source body located in northern magnetic latitudes, for which the majority of literature has been published.

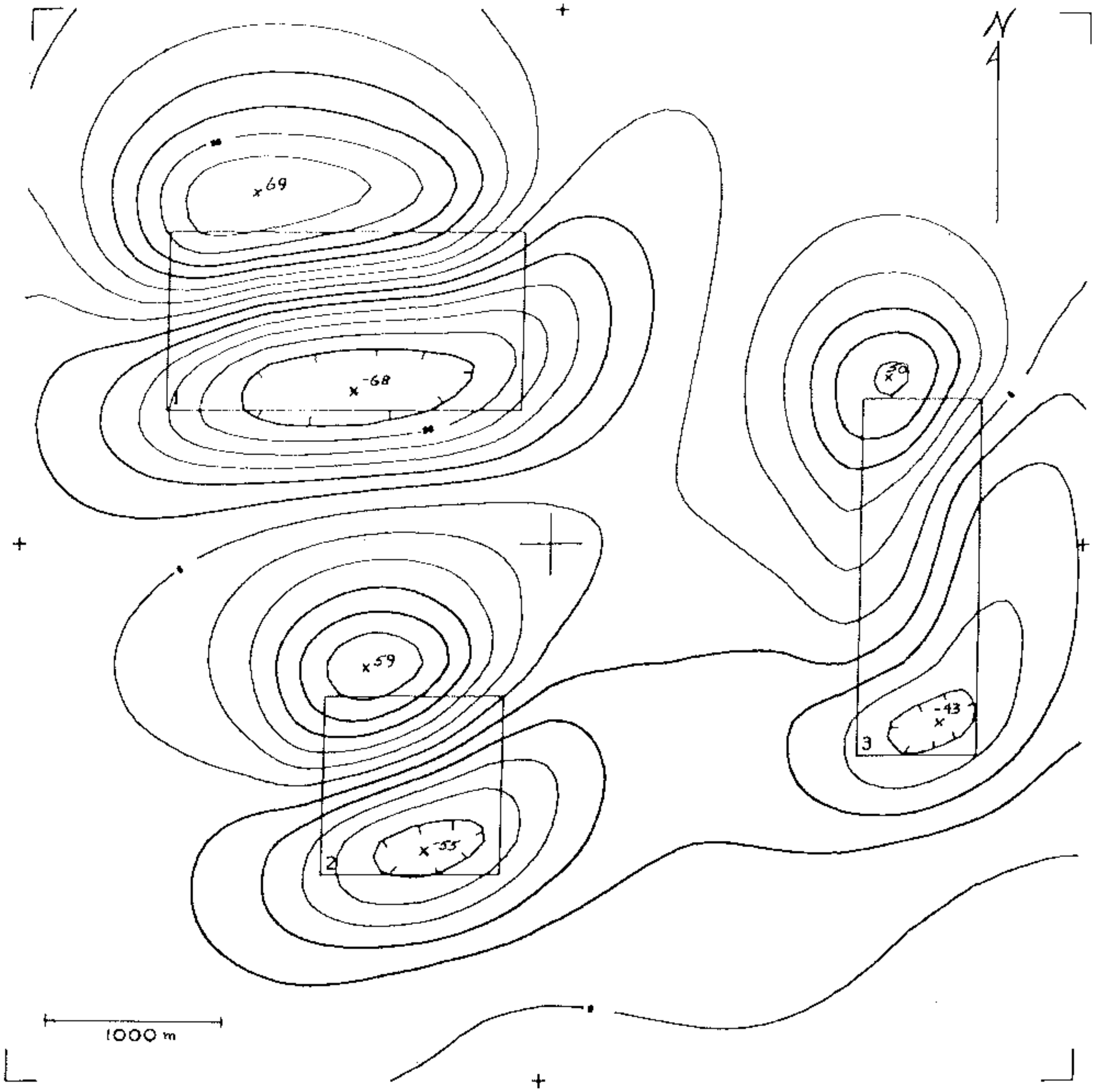
Figure 5 illustrates the computed magnetic anomalies for three simple prism models using the magnetic field characteristics of Ascension. These models have an upper surface 1000 feet (305 m) below the data plane, lower surface 3000 feet (915 m) below this plane, and an assumed susceptibility of 2000×10^{-6} cgs, close to the measured average for Ascension basalt flows and intrusives. The amplitudes of these computed anomalies are much smaller than the amplitudes of the observed anomalies. This indicates that the net magnetization of several sources is three to five times as large as would be expected from a susceptibility of 2000×10^{-6} cgs.

The anomaly minima occurs within the southern margin of the source and a positive maximum occurs north of the northern edge of the body and somewhat west of center. A first approximation of magnetic source position and shape was determined from the aeromagnetic map by reference to models such as those in Fig. 5, and an initial depth estimate was determined from the steep linear gradient across the center of the body.

The island itself generates a strong anomaly on the earth's magnetic field, as it is the upper portion of a magnetic rock mass rising several kilometers above the sea floor. Figure 6 illustrates to a first approximation



The Total Intensity of the Earth's Magnetic Field
FIGURE 4



PROJECT NAME
TEST MODELS
ASCENSION ISLAND

MODEL NAME
SAMPLE

NUMBER OF PRISMS: 3.

MAGNETIC MODEL (GAMMAS)

GRID PARAMETERS
GRID POINTS X 18. ; Y 18
GRID SPACING : 1000. FEET
GRID DIMENSIONS X 18000. ; Y 18000. FEET
GRID OFFSET X: 0. Y. 0. FEET
SCALE 1:2 030.
DATA MAXIMUM: 69.
DATA MINIMUM: 68.
CONTOUR INTERVAL 50

Body Parameters:	Depth to Top:	1000 ft (305m)
	Depth to Bottom:	3000 ft (915m)
	Susceptibility Contrast:	2000×10^{-6} cgs

Figure 5. Magnetic anomalies for simple prism models for Ascension magnetic field vector.

the anomaly pattern due to the island itself, assuming a uniform susceptibility of 6000 x 10^{-6} cgs susceptibility (to approximate induced plus remanent magnetization) and a moderate (15°-20°) slope to the sea floor away from the island. The positive gradient observed north of the island (Plate I) and a weak high-to-low trend across the island are due in part to the overall island mass, rather than an indication of geologic structure or details within the land mass. Closed magnetic lows occur along the southern coastline in the observed data (Plate I) as in the simple model of Figure 6.

A qualitative interpretation of the observed survey data was completed using reference to precomputed simple models (Fig. 5), rule of thumb depth estimates, and a cross correlation between magnetic intensity, topography, and geologic maps. Several high amplitude anomalies with steep linear gradients of short horizontal extent are present on the map. These occur near Sisters Peak, Lady Hill, Red Hill, South West Bay, Green Mountain and several other areas. The short linear gradients suggest instrument ground clearances perhaps as low as 150 m (480 ft.) in several places. The reduced ground clearance over a magnetic ground surface helps explain the unusually high amplitude of several anomalies noted above.

Elongate, northeast-trending magnetic sources are indicated near Sisters Peak, Bears Back and Green Mountain. West- to northwest-trending magnetic bodies are present on the western portion of the island. The central and northeastern parts of the island appear, in general, to be less magnetic than the rest of the island. These are the areas of outcropping trachyte flows, domes, and intrusions whereas the more magnetic areas are generally basalt flows and cinder deposits.

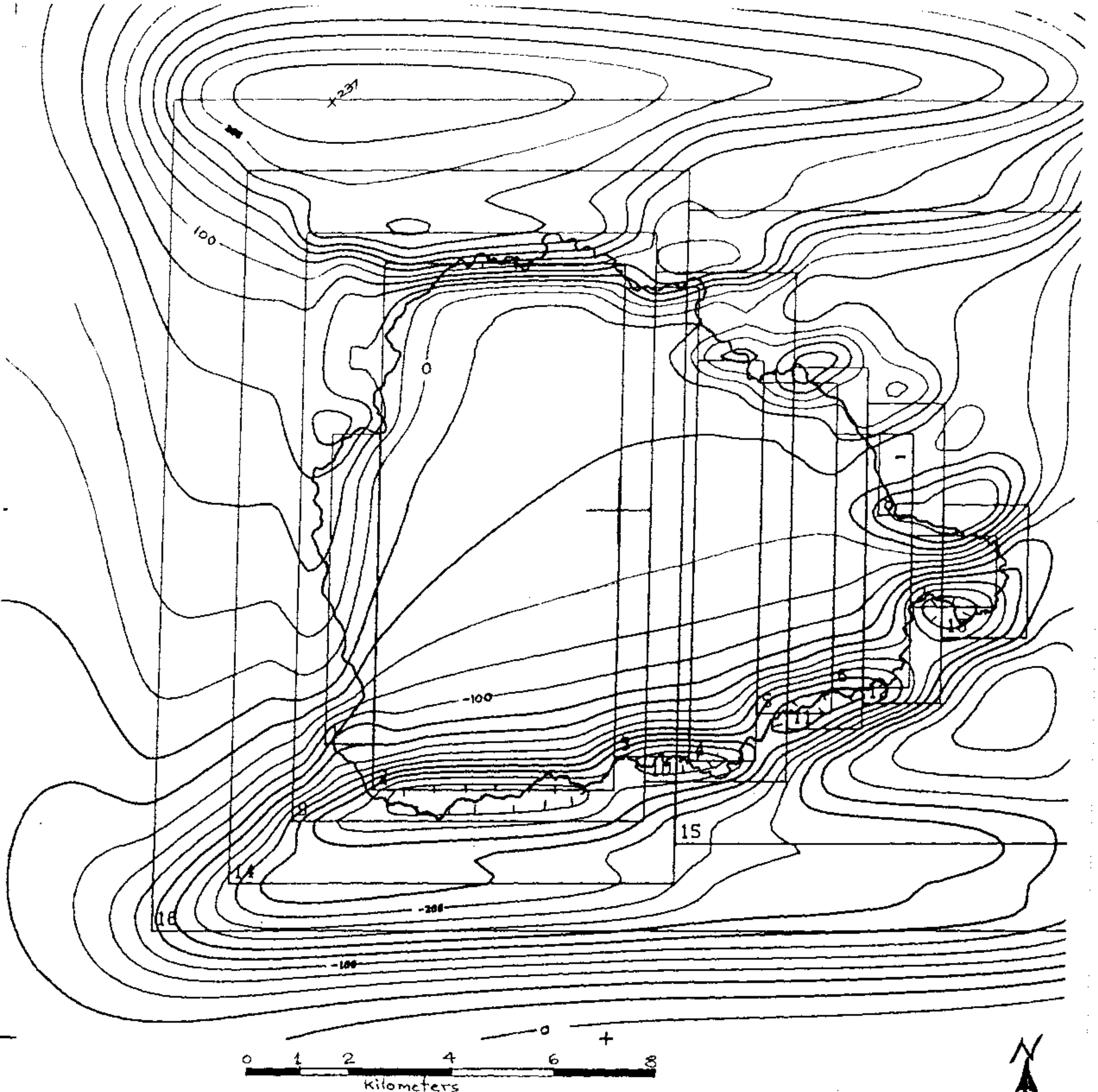


Figure 6. Magnetic expression due to a uniformly magnetized island as modeled by vertical sided prisms.

MODEL NAME

ISLAND

NUMBER OF PRISMS: 16.

MAGNETIC MODEL (GAMMAS)

GRID PARAMETERS

GRID POINTS X 41. : Y 35.

GRID SPACING : 2000. FEET

GRID DIMENSIONS X 80000. : Y 68000. FEET

GRID OFFSET X: 0. Y: 0. FEET

SCALE 1.1000'0.

DATA MAXIMUM: 237.

DATA MINIMUM: -285.

CONTOUR INTERVAL: 100.

5.3 Quantitative Model Interpretation

Numerical modeling was employed to refine the location, size and magnetization of various magnetic bodies identified in the qualitative interpretation. Program GM3D was used to calculate the net magnetic field anomaly due to many (40) right rectangular prisms. Several prisms may be used to comprise a single complex magnetic source, and the complex anomaly resulting from multiple sources can be approximated by several groups of prisms. Two complex models were computed and modified, one for the east half of the island (E/2 ASCN) and one for the west half (W/2 ASCN). A third model was computed to verify the increased magnetization of the North Coast area. The models and computed magnetic contour patterns are presented as Plate IIIa, IIIb, and IIIc.

The models achieved a good match to the mid- to long-wavelength observed anomalies, and in many cases to the 'sharp' or short-wavelength anomalies which result from varying terrain clearance and near surface features. The emphasis was placed on approximating the deeper (mid- to long-wavelength) information which could relate to buried geological structures and intrusive bodies not evident at the surface. Four iterations for the west half, and five for the east half, resulted in good agreement with the anomaly maxima and minima positions and contour trends present in the observed data (Plate I). The anomaly amplitudes and gradients have been matched to a lesser degree, reflecting uncertainties in instrument terrain clearance, depth to the top of the magnetization source, and probable nonvertical dips which are not easily modeled with program GM3D.

The depth to the top and bottom of the prism models and assigned magnetic susceptibility are tabulated in Appendix I. Most magnetic sources appear to occur within a few hundred meters of the surface, as inferred from the steepest linear gradients. The inteference of many different sources precludes an accurate interpretation of the depth extent of the sources, and these have generally been arbitrarily assigned to 600 to 800 meters.

The magnetic susceptibilities required to approximate the observed amplitudes typically vary from 3000 to 6000 x 10^{-6} cgs. This is a factor of 1.5 to 3 times as large as the higher average susceptibilities determined in the in situ susceptibility study. There are several probable explanations for this difference. Most of the basaltic rocks probably contain viscous remanent or thermoremanent magnetization roughly directed along the present field direction which may be 0.3 to 10 times the induced magnetization. In addition, the magnetic sources may actually be 10-20 percent shallower than modeled or the bodies could have a greater depth extent than modeled. The susceptibility and/or remanent magnetization may be expected to increase with depth as observed by Bleil et al. (1982) and Schonharting and Hall (1982) in the IRDP study.

Plate II summarizes the integrated magnetic interpretation using geologic (Nielson and Sibbett, 1982) and topographic maps and indicating dips and geometric changes from the numerical models which minimize disagreement with the observed data. In the simplest sense, Plate II separates the magnetic and relatively non-magnetic portions of the island's geology, primarily with respect to depths of 0 to 1000 m. Most of the magnetic areas are elongate with relatively straight or gently curving margins, suggesting structural borders which may separate less mafic intrusions and flow sequences from basaltic feeder zones, such as dike swarms, and basaltic lava sequences. The correspondence between source borders (and terminations) and geologic structures mapped by Nielson and Sibbett (1982) is reasonable, especially north of Green Mountain, south of Sisters Peak, and near Devil's Riding School. A brief description of the principal magnetic sources follows.

Sisters Peak Source. The Sisters Peak magnetic source is an elongate body which occurs at or near the surface at Sisters Peak and extends 3.5 km to the coast in a N60°E direction. The equivalent (apparent) susceptibility contrast (most likely susceptibility plus remanent magnetization) is approximately 3000-5000 x 10^{-6} cgs. The body is 1 km wide near the volcanic cone and narrows to about 0.2 km near the coast. Cinder cones and older basalt flows correlate well with the source position, but the numerical modeling suggests a depth extent of 500 m or more. The magnetic source is probably a composite source of basaltic cinders and flows, and northeast-trending basaltic dikes or plugs related to the eruptive features. The dikes intruded northeast-trending fractures. The source may be terminated west of Sisters Peak by a northwest-trending fault not identified at the surface but mapped to the southeast near Green Mountain.

South Bears Back. This elongate magnetic source also trends N60°E from south of Bears Back to North East Point. The elongation is normal to structures mapped by Nielson and Sibbett (1982) but related structures may terminate the source southwest of Bears Back. The source does not correlate well with the surface geology and arises from shallow (25-100 m) depths. The numerical model suggests a depth extent of 500 m or more, and apparent susceptibility contrasts of 2000-4000 x 10^{-6} cgs. A dike swarm or intrusive is the probable source, located along structures which served as magma conduits for Upper Valley Crater and Lower Valley Crater.

Mountain Red Hill - White Hill Source. This is a large composite magnetic source which includes more than 10 sq km of the eastern portion of the island (Plate II). The northern edge of the source is relatively well defined and corresponds in part to a series of northeast trending faults mapped by Nielson and Sibbett (1982). Very sharp anomalies with short horizontal gradients, indicating reduced terrain clearance (topographic effects), contribute to anomaly amplitudes in several places, such as near South East Crater, Green Mountain, and Cricket Valley. Trachyte flows, domes, and intrusions occur throughout much of the source area and an underlying intrusive (syenite?) may comprise the magnetic source at depth. This magnetic source has a higher apparent susceptibility contrast ($K \simeq 4000\text{-}8000 \times 10^{-6}$ cgs) than other bodies discussed previously. Cinders, flows and probably basaltic intrusives which fed Mountain Red Hill and The Peak comprise the source on the west. The numerical model for the east half of the island (E/2 ASCN; Plate IIIb) suggests an abrupt north-trending termination of the source at its western limit along Grazing Valley.

West of Crystal Bay. Numerical model results (Plate IIIb) insist on the presence of a 2 km long east trending source body north and west of Crystal Bay. The anomaly may include components from the interference pattern of sources to the north and west, and the southern edge of the island itself. Plate IIIb does achieve a good fit to the observed data by incorporating this distinct source, however. The geologic nature of the source is unknown, but the trend is similar to sources on the western portion of the island.

Georgetown - Lady Hill. This 6 km long magnetic source (Plate V) has a predominant east-west elongation and includes the Travelers Hill, Lady Hill, and Cross Hill vent areas, and in part corresponds with the outcrop pattern of the bf_2 flows of Nielson and Sibbett (1982). The numerical model, Plate IIIa, suggests considerable depth extent (600-800 m) and a high apparent susceptibility contrast (6000 x 10^{-6} cgs) for the source. These parameters, coupled with the geologic setting, suggest basaltic feeder dikes and/or a great thickness of magnetic flows filling a structural depression, as the probable magnetic source.

Dark Slope Crater. This 4.5 km long, east trending magnetic source includes the Command Hill and Dark Slope Crater cinder cones and basalt flows. Disagreement between observed and computed magnetic anomalies indicates that the source dips, or thins (or both) to the south. The eastern side of the source may terminate against a fault (Plate II).

South Gannet Hill. Another east trending magnetic source includes Cross, South Gannet, and Booby hills. The source cuts across several different flows. The observed data can be approximated by bodies 300 m thick and apparent susceptibilities of 3000-5000 x 10^{-6} cgs. Basaltic dikes and flows are thought to be the source.

North Coast Area. A south-to-north magnetic gradient of 1000 gammas in a distance of 1.5 km occurs along the north coast near English Bay. Numerical modeling (Fig. 6, Plate IIIc) suggests that 200 to 300 gammas of this anomalous gradient may be due to island mass-ocean contrast, but that a large increase in net magnetization is required to explain the full magnitude of the gradient. The 300 gamma closed low occurs just north of the southern border of the magnetic body. Young basalt flows derived from the Sisters Peak area form the surface rocks which cover the magnetic source. The geometry and depth extent of the source suggests that the source is a large intrusive body.

Areas of Low Magnetization. Two specific areas have been identified where anomaly character and amplitude suggest apparent magnetizations below the less magnetic zones within the interior of the island. These areas would have magnetic susceptibilities near zero, or alternatively remanent magnetization directly opposite to the present field direction. The Clarence Bay-Long Beach area includes sediment infill, beach sands and trachyte intrusives in the near surface, and with increased terrain clearance north of Cross Hill could explain the first area of low apparent magnetization. The second area of low apparent magnetization lies along the southern edge of Wideawake Flats, primarily over water adjacent to the coastline. Sea floor topography (a low) or southward projection of the central low magnetization zone seems the most likely explanation.

An irregular area of approximately 7 sq km within the center of the island, primarily north and west of Green Mountain, is a low-magnetization area where peripheral magnetic bodies have terminated and structures can be inferred from the magnetic data. Mapping by Nielson and Sibbett (1982) shows the surface to be relatively devoid of basaltic lava flows. Various trachyte flows and intrusions, basaltic ash and trachyte pyroclastics are present, and these are cut by northeast-, northwest- and north-trending structures.

All of the apparent magnetic susceptibility contrasts modeled are 2 to 4 times as large as the highest average susceptibilities actually measured in situ. In addition, there is little correlation between the location of high-susceptibility sample sites and the interpreted position of magnetic source bodies. This lack of spatial correlation is not surprising in view of the intent to characterize rock types with easy access rather than a uniform susceptibility coverage of the island. Magnetization studies of the Iceland volcanic crust (IRDP; Bleil et al., 1982) indicate substantial thermoremanent magnetization and an unknown amount of viscous remanent magnetization, as well as higher susceptibilities at depth. Similar rock magnetization variations are probably present at Ascension.

The geometric and geologic relationships presented on Plate II suggest that the older, elevated core of the island is situated at the intersection of major geologic structures. The younger cinder cones and basaltic vents are peripheral to this core area. The density of structural intersections may be favorable for high permeability zones in fractures at depth.

6.0 SUMMARY AND RECOMMENDATIONS

A detailed aeromagnetic survey of Ascension Island was flown in February and March 1983 as one part of a program to evaluate geothermal resource potential. Interpretation of these data, supported by numerical modeling, presents a picture of east- and northeast-trending magnetic sources peripheral to the central core of the island. The magnetic sources are interpreted as zones of increased dike density and intrusives which now occupy the feeder zones for recent cinder cones and basalt flows. A large magnetic source which includes much of the eastern portion of the island could be the intrusive equivalent (syenite?) of the trachytic domes, intrusives, and flows seen at the surface.

The central 7 sq km of the island is relatively non-magnetic and is cut by northeast-, northwest- and north-trending structures. The combination of complex structural intersections and low magnetization suggests the possibility of rock alteration resulting in magnetite destruction, or more acidic intrusive rocks at moderate depths (200-1000 m) in this central portion of the island.

A comparison between electrical resistivity survey results (Ross et al., 1984) and the magnetic interpretation of Plate II is also revealing. With few exceptions, low resistivity areas indicated by both reconnaissance and dipole-dipole resistivity data correspond to areas of low apparent susceptibility. Several interpreted structures and magnetic source borders are indicated as resistivity changes on the interpreted models for resistivity lines 1, 2 and 3. The strong agreement gives substantial confidence in the geometric interpretations for both geophysical methods, although the geologic explanations may still be subject to some ambiguity.

Several self-potential anomalies reported by Ross et al. (1984) also correspond to structures and body borders independently interpreted from the magnetic data. The total area covered by self-potential traverses may be too limited to make this correlation truly significant. The detailed magnetic survey provides a useful continuous data set which adds significance to the more limited and discrete electrical resistivity and self-potential data.

Uncertainties and ambiguities in magnetic interpretation may preclude a more refined interpretation of these data. Additional electrical resistivity and self-potential surveys and perhaps two or three deep thermal gradient tests are recommended before drilling a deep geothermal production well. A continuing effort in the integration of the available geologic and geophysical information is also recommended.

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8.0 REFERENCES

Bison Instruments, 1969, Instruction manual, Bison Instruments magnetic susceptibility system, Model 3101: Minneapolis, 10 p.

Bleil, U., Hall, J. M., Johnson, H. P., Levi, S., and Schonharting, G., 1982, The natural magnetization of a 3-km section of Icelandic crust: Jour. Geophys. Res., v. 87, B8, p. 6569-6589.

Dash, B. P., and Milson, J., 1973, Gravity field of Ascension Island, South Atlantic: Earth Planetary Sci. Letters, v. 21, no. 1, p. 79-84.

GeoMetrics, 1973, Operating and maintenance manual for Model G-803 airborne proton magnetometer, Sunnyvale, CA.

Nelson, J. H., Hurwitz, L., and Knapp, D. G., 1962, Magnetism of the earth: Coast and Geodetic Survey Publ. 40-1, 79 p.

Nielson, D. L., and Sibbett, B. S., 1982, Technical Report: Geothermal potential of Ascension Island, South Atlantic - Phase I - Preliminary Examination: Earth Science Laboratory/UURI rept. to U.S. Air Force and U.S. DOE/ID, 79 p.

Ross, H. P., Green, D. J., Sibbett, B. S., and Nielson, D. L., 1984, Technical Report: Electrical resistivity surveys, Ascension Island, South Atlantic Ocean: Earth Science Laboratory/UURI rept. to U.S. Air Force and U.S. DOE/ID, 33 p.

Schonharting, G., and Hall, J. M., 1982, Detailed susceptibility log of Iceland Research Drilling Project drill core, Reydarfjordur, eastern Iceland: Jour. Geophys. Res., v. 87, B8, p. 6601-6604.

van Andel, T. H., Rea, D. K., von Herzen, R. P., and Hoskins, H., 1973, Ascension fracture zone, Ascension Island and the mid-Atlantic Ridge: Geol. Soc. America Bull., v. 84, p. 1527-1546.

Yarger, H. L., Robertson, R. R., and Wentland, R. L., 1978, Diurnal drift removal from aeromagnetic data using least squares: Geophysics, v. 43, no. 6, p. 1148-1156.

9.0 APPENDIX

NUMERICAL MODEL INPUT PARAMETERS

Units: (may be feet or meters)

Magnetic Field Parameters
Earth's Field: 27,800 gammas
Inclination: -27. degrees
Declination: 339. degrees

Prism No.	X1	X2	Y1	Y2	D1	D2	SC
	West	East	South	North	Depth to Top	Depth to Bottom	Susceptibility

Prism coordinates
with respect to model 0,0.

(Note: Units may be in feet or meters as indicated above)

Models Included

Sample Bodies

Uniformly Magnetized Island

W/2 Island

E/2 Island

North Coast Area

Project name: TEST MODELS

Model: SAMPLES

Units in Feet

MAGNETIC PARAMETERS
Earth's field: 27800. gammas.
Inclination = -27. degrees Declination = 339. degrees.

PRISM	X1	X2	Y1	Y2	D1	D2	DC	SC
1	-6550.	-550.	2250.	5250.	1000.	3000.	0.00	2000.
2	-3750.	0750.	-5550.	-2550.	1000.	3000.	0.00	2000.
3	5250.	7250.	-3550.	2450.	1000.	3000.	0.00	2000.

Project Name: ASCENSION

Model: ISLAND

Units in Meters

MAGNETIC PARAMETERS
Earth's field: 27800. gammas.
Inclination = -27. degrees   Declination = 339. degrees.

PRISM	X1	X2	Y1	Y2	D1	D2	DC	SC
1	-18635.	-15485.	-15092.	4921.	1275.	1775.	0.00	6000.
2	-15485.	100.	-18044.	15945.	1275.	1775.	0.00	6000.
3	100.	4921.	-15879.	14403.	1275.	1775.	0.00	6000.
4	4921.	9252.	-16148.	9711.	1275.	1775.	0.00	6000.
5	9252.	14107.	-13058.	8300.	1275.	1775.	0.00	6000.
6	14107.	19094.	-11417.	4987.	1275.	1775.	0.00	6000.
7	19094.	24606.	-6200.	-1575.	1275.	1775.	0.00	6000.
8	16896.	19094.	-295.	4987.	1275.	1775.	0.00	-6000.
9	-20635.	2100.	-20044.	17945.	1775.	2775.	0.00	6000.
10	2100.	11252.	-17479.	15403.	1775.	2775.	0.00	6000.
11	11252.	16107.	-14058.	9300.	1775.	2775.	0.00	6000.
12	16107.	21094.	-12417.	6987.	1775.	2775.	0.00	6000.
13	21094.	26606.	-8200.	425.	1775.	2775.	0.00	6000.
14	-24635.	4100.	-24044.	21945.	2775.	3775.	0.00	6000.
15	4100.	30606.	-21479.	19403.	2775.	3775.	0.00	6000.
16	-29500.	34500.	-27100.	26500.	3775.	6775.	0.00	6000.

Project Name: ASCENSION

Model: W/2 ASCN ITER #4 (final)

Units in Meters

MAGNETIC PARAMETERS
Earth's field: 27800. gammas.
Inclination = -27. degrees Declination = 339. degrees.

PRISM	X1	X2	Y1	Y2	D1	D2	DC	SC
1	-3440.	-2790.	930.	2740.	400.	1000.	0.00	6000.
2	-2790.	-2220.	260.	2540.	300.	1000.	0.00	6000.
3	-2220.	-1570.	-40.	2410.	200.	1000.	0.00	6000.
4	-1570.	-1260.	-270.	1260.	200.	1000.	0.00	6000.
5	-1260.	-320.	-90.	1180.	300.	1000.	0.00	6000.
6	-320.	190.	60.	1040.	300.	1000.	0.00	6000.
7	190.	1520.	200.	820.	250.	1000.	0.00	6000.
8	1520.	1900.	340.	1010.	250.	1000.	0.00	5000.
9	1900.	2450.	615.	1360.	250.	1000.	0.00	5000.
10	1040.	1560.	2730.	3020.	200.	1000.	0.00	6000.
11	1560.	2030.	2120.	2930.	200.	1000.	0.00	5400.
12	2030.	2480.	2470.	3100.	200.	1000.	0.00	4000.
13	2480.	2980.	2800.	3280.	200.	1000.	0.00	3000.
14	-1790.	-960.	-1490.	-780.	200.	1000.	0.00	6000.
15	-960.	-510.	-1550.	-360.	200.	1000.	0.00	6000.
16	-510.	30.	-1670.	-90.	200.	1000.	0.00	6000.
17	30.	470.	-1600.	-460.	200.	1000.	0.00	6000.
18	470.	1080.	-1550.	-900.	200.	1000.	0.00	6000.
19	1080.	1620.	-1320.	-580.	250.	1000.	0.00	4000.
20	-3210.	-1590.	-2700.	-2530.	200.	700.	0.00	6000.
21	-2680.	-2390.	-3100.	-2700.	200.	700.	0.00	6000.
22	-950.	-80.	-3110.	-2540.	300.	600.	0.00	5000.
23	-80.	640.	-3420.	-2420.	300.	600.	0.00	5000.
24	640.	1340.	-3720.	-2660.	300.	600.	0.00	5000.
25	-1590.	-950.	-3480.	-2600.	300.	600.	0.00	3000.

Project Name: ASCENSION

Model: E/2 ASCN ITER #5 (final)

Units in Meters

MAGNETIC PARAMETERS
Earth's field: 27800. gammas.
Inclination = -27. degrees Declination = 339. degrees.

PRISM	X1	X2	Y1	Y2	D1	D2	DC	SC
1	-1670.	-1000.	1120.	1840.	220.	1000.	0.00	3000.
2	-1000.	-640.	1200.	2280.	220.	1000.	0.00	2750.
3	-640.	-190.	1340.	2380.	220.	1000.	0.00	2500.
4	-190.	320.	1960.	2560.	220.	1000.	0.00	3500.
5	320.	840.	2400.	3070.	300.	1000.	0.00	2000.
6	840.	1520.	2880.	3520.	250.	1000.	0.00	3000.
7	-2620.	-1960.	-3050.	-1820.	300.	5000.	0.00	5000.
8	-1960.	-1280.	-4190.	-1580.	300.	1000.	0.00	4000.
9	-1280.	-430.	-3480.	-1140.	250.	1000.	0.00	4000.
10	-430.	130.	-2220.	-390.	200.	1000.	0.00	8000.
11	130.	620.	-1700.	720.	300.	1000.	0.00	8000.
12	620.	5580.	-1810.	1590.	300.	1000.	0.00	6000.
13	380.	1400.	-2980.	-2430.	300.	1000.	0.00	3000.
14	1400.	2120.	-2960.	-2320.	200.	1000.	0.00	8000.
15	-4000.	-3620.	1990.	2440.	200.	1000.	0.00	5000.
16	-3620.	-3040.	1390.	2180.	200.	1000.	0.00	5400.
17	-3040.	-2580.	1790.	2480.	200.	1000.	0.00	2800.
18	-2580.	-2100.	2110.	2595.	200.	1000.	0.00	3000.
19	-2100.	-1650.	2610.	2970.	250.	1000.	0.00	4000.
20	-1650.	-1280.	2870.	3190.	200.	1000.	0.00	4000.
21	-1280.	-820.	3190.	3400.	200.	1000.	0.00	4000.
22	-4320.	-3540.	-520.	100.	250.	1000.	0.00	3000.
23	-3540.	-3170.	-320.	280.	250.	1000.	0.00	6000.
24	-3170.	-2620.	-90.	740.	250.	1000.	0.00	4700.
25	-3980.	-3440.	-2005.	-1270.	200.	1000.	0.00	4000.
26	-1130.	-620.	-2860.	-2200.	180.	500.	0.00	6000.
27	920.	3140.	-1540.	-340.	200.	300.	0.00	6000.

Project Name: ASCENSION

Model: NORTH COAST ITER #3 (final)

Units in Meters

MAGNETIC PARAMETERS
Earth's field: 27800. gammas.
Inclination = -27. degrees Declination = 339. degrees.

PRISM	X1	X2	Y1	Y2	D1	D2	DC	SC
1	-4540.	-3500.	-8500.	1840.	205.	705.	0.00	3000.
2	-3500.	260.	-9500.	2580.	205.	705.	0.00	3000.
3	260.	1500.	-8500.	2240.	205.	705.	0.00	3000.
4	1500.	4000.	-7000.	520.	205.	705.	0.00	3000.
5	-5540.	5000.	-10500.	3580.	705.	1205.	0.00	3000.
6	-1440.	-930.	-860.	-570.	200.	1000.	0.00	6000.
7	-930.	-460.	-1480.	-670.	200.	1000.	0.00	5400.
8	-460.	-30.	-1120.	-440.	200.	1000.	0.00	4000.
9	-30.	520.	-820.	-320.	200.	1000.	0.00	3000.
10	520.	930.	-320.	70.	250.	1000.	0.00	4000.
11	930.	1320.	-40.	280.	200.	1000.	0.00	4000.
12	1320.	1750.	280.	490.	200.	1000.	0.00	4000.
13	-6540.	6000.	-11500.	4580.	1205.	2205.	0.00	3000.
14	-2750.	-640.	320.	3160.	300.	1200.	0.00	8000.
15	-640.	1640.	660.	2860.	300.	1200.	0.00	6000.