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FINAL REPORT
GEOTHERMAL RESOURCES PROJECT-STAGE ONE

Part 5
GRAVITY AND MAGNETIC SURVEYS

Prepared for

GOVERNMENT OF NICARAGUA
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PREFACE

This Final Report on STAGE ONE of the Nicaraguan GEOTHERMAL RESOURCES PROJECT is submitted to the Government of Nicaragua by TEXAS INSTRUMENTS INCORPORATED in Spanish and English versions.

The report is the work of several authors and consists of ten parts, or chapters, each of which is bound separately, as follows:

Part 1 - PROJECT SUMMARY, by D. E. Heilner and L. T. Braun

Part 2 - REGIONAL GEOLOGY: Thermal Manifestations of Western Nicaragua, by John B. Thigpen

Part 3 - SURFACE GEOLOGY: San Jacinto-Tisate-Najo Area, by John B. Thigpen

Part 4 - SURFACE GEOLOGY: South Volcan Momotombo Fumaroles, by John B. Thigpen

Part 5 - GRAVITY AND MAGNETIC SURVEYS, by Mario Mazzolini

Part 6 - ELECTRICAL GEOPHYSICAL SURVEYS in Relation to the Location of Geothermal Power Resources in Northwestern Nicaragua, by George Keller and Norman Harthill

Part 7 - GEOCHEMISTRY of the Nicaraguan Geothermal Project Area by R. Bennett

Part 8 - TEMPERATURE GRADIENT WELLS at San Jacinto and South Volcan Momotombo, by R. Bennett

Part 9 - DEEP BOREHOLE TEST at the South Volcan Momotombo Fumarole Area, by John B. Thigpen

Part 10 - CONCLUSIONS AND RECOMMENDATIONS, by Texas Instruments Staff and Consultants

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ABSTRACT

A program of gravity and magnetic surveys was conducted in Western Nicaragua to determine the expression of major geologic features in terms of regional gravity and magnetic patterns, as well as to determine the effects of near-surface variation in rock densities and magnetic materials over selected thermal areas.

A reconnaissance gravity-magnetometer survey was made along a line extending across the Pacific Coastal Plain, the Volcanic Range, and the Nicaraguan Depression. Detail surveys were made in the San Jacinto and South Volcan Momotombo thermal areas.

The west dipping gravity regional indicates seaward tilting of the Pacific Coastal Plain. A gravity maximum near San Jacinto in the Volcanic Range is associated with a large mass of high-density igneous rocks. Greatest thickness of sediments in the Nicaraguan Depression appears to coincide with the axis of a major negative northwesterly trend about 20 kilometers east of San Jacinto. Farther east, gravity gradients indicate gentle folds.

The thermal areas of San Jacinto and South Volcan Momotombo correlate with local gravity and magnetic negative trends.

INTRODUCTION

The gravity-magnetometer program completed in Western Nicaragua includes approximately 122 kilometers of reconnaissance line extending from Poneloya on the Pacific coast, to San Isidro, on the east side of the Nicaraguan Depression; 17 kilometers of detail program in the San Jacinto area; and six kilometers in the South Volcan Mombotombo area.

The purpose of the survey was twofold: (1) Provide a reconnaissance line of profiles across the Pacific Coastal Plain and the Nicaraguan Depression with the primary objective to indicate major geologic features in terms of regional gravity and magnetic anomalies. (2) Observe in detail the effects of near-surface distribution of rock densities and magnetic materials over the thermal areas of San Jacinto and South Volcan Momotombo.

The main geologic features are tentatively recognized as follows:

1- The west dipping gravity regional indicates seaward tilting of the Pacific Coastal Plain showing one broad fold as expressed by the positive trend partially delineated just west of Leon.

2- The San Jacinto gravity "maximum", showing an amplitude of thirty milligals, is associated with a large mass of high-density materials (igneous rocks). The east flank of this anomaly shows two well defined fault-type features of significant displacement. No fault gradients occur on the west flank.

3- Greatest thickening of the sediments may occur near Station 122, coinciding with the axis of the major negative trend found in the Graben.

4- Over the east portion of the Graben, gravity gradients indicate only gentle tilting and folding of the rocks.

5- From relatively flat gravity gradients over the east side of the Depression, the regional plunges for at least 16 kilometers to the northeast, from a value of 426 milligals near Station 214, to a value of 403 milligals near the Inter-American highway, delineating what appears to be the west limb of a major syncline.

6- The thermal areas of San Jacinto and South Volcan Momotombo correlate with local gravity and magnetic negative trends.

The drawbacks of the survey were: (a) strong winds limited barometric leveling to early morning hours, (b) wire fences and power lines forced the magnetometer operator to step-out in open fields.

FIELD OPERATIONS AND STATISTICAL DATA

The instruments, including one gravity meter, magnetometer and altimeter, were received on February 18, and field operations were started on February 21, 1970. The city of Leon was used as headquarters for office and field operations. The gravity party consisted of one Party Chief/operator/computer and one driver/assistant, equipped with one Scout Vehicle.

Between February 21 and June 19, 1970, a total of 244 stations and two density profiles were surveyed and metered. Five magnetometer stations were lost due to local

attraction. Field terrain estimates to a radius of 400 meters were made for 69 stations. A total of 63 locations were chained. Stations were spaced at one-half kilometer intervals, except for the east end of the Reconnaissance Line and the South Volcan Momotombo Prospect, where the intervals averaged 1.59 and 0.3 kilometers, respectively.

Production

The following are the production totals for each project:

	Recon.Line	San Jacinto	S. Volcan Momotombo
Work Period	Feb 21-April 19 May 20-June 4	April 20-May 19 -	June 15-21 -
Crew/Months	2.46	1.00	0.23
Stations Observed	189	34	21
Estimated km. completed	121.80	17.00	6.30
Station Interval (km.)	0.50-1.59	0.50	0.30
Mode of Operation	Vehicle/Fast	Foot/Horseback	Vehicle/Slow

Surveying

Station locations were spotted on controlled airphoto sheets, scale 1:20,000, except for stations 153-164 and 199-223, which were estimated on topographic maps, scale 1:50,000, and stations 224-244 (S.Volcan Momotombo), spotted on uncontrolled airphoto mosaics, scale 1:10,000 . Whenever necessary, distances were measured with

a 100-meter chain to establish ties with control points visible on the airphoto sheets.

Stations surveyed along the west edge of the Interior Highlands, which show the roughest topography of the survey area, were located so as to minimize terrain effects, disregarding the constant interval used in other parts of the Reconnaissance Line.

A comparison between the airphoto rectangular grid and the grid of a topographic map over the S. Volcan Momotombo area, indicates a latitude discrepancy of about 500 meters. The airphoto grid was used as a reference for drawing the maps of the prospect area.

Vertical control for the Reconnaissance and San Jacinto surveys was based on numerous IAGS bench marks, established by the "Direccion General de Cartografia" along the Poneloya-Leon-San Isidro highway. Vertical control for the S. Volcan Momotombo survey was based on the water level of Lake Managua. Because of lack of bench marks in the area, the elevation of the water was assumed to be 100 meters.

An American Paulin System Altimeter was used in leveling. Elevations were established on wooden pegs, and each station was marked with a wooden lath nailed to a tree or pole. The Single Altimeter method was used in field procedures; the instrument was returned to base within one hour. Corrections were made for changes in air column temperature and barometric pressure.

Figure 1 is a plot of the percentage of elevation check errors versus check error level. The curve shows that 73.4% of the errors are one meter or less, which would be equivalent to a Bouguer gravity error of 0.22 milligals. No adjustments were made on

elevation traverses showing check errors of 1.5 meters or less.

Metering

Worden Prospector Gravity Meter No. 828 and Jalander Magnetometer No. 7299 were uaed for the entire survey. The Texas Instruments "absolute" dial constant of 0.10992 milligal per scale division was assumed to be correct. The magnometer has a selection of five sensitivity ranges, but only Range-1 was used in the survey. The constant of 10.1 gammas per scale division was supplied by the manufacturers.

A leap-frogging procedure was used to meter three gravimeter and two magnetometer bases along the line of reconnaissance profiles. Numerous sub-bases were also metered in the San Jacinto Prospect. Only one gravity meter and one magnetometer base were set out in the S. Volcan Momotombo Prospect, both of them being common with Station 238.

Readings were taken on gravity bases and/or sub-bases at no more than two-hour intervals to measure instrument drift and diurnal variations, so that adequate corrections for these effects could be made. A longer time interval was allowed for the magnetometer.

Figure 2 is a plot of percentage of gravity check errors versus check error level. This curve shows that 92.4% of the gravimeter checks were more accurate than 0.07 milligals. Figure 3 is a similar plot of magnetometer checks. The check errors vary between 10 and 80 gammas, indicating a possible noise level of about 160 gammas for some stations, die to extremely high magnetic gradient within very short distances.

All meter readings were recorded in field books and subsequently transferred on regular forms in the office. Three books of original field notes for altimeter, gravimeter, and magnetometer, as well as other materials used in computations described below, are in custody of Texas Instruments and will be submitted to the Government of Nicaragua upon request. These materials include a description of the gravimeter and magnetometer bases, their locations and values; a diagram showing the base values, intervals between bases and dates they were metered; the respective gravity and magnetometer final computation notes; two density profiles; and maps giving latitude corrections for gravity and magnetometer computations.

Terrain Corrections

Terrain correction estimates were made for 69 stations. Three stations had a total correction of less than 0.01 milligal, the highest was 0.20 milligal. The density used for the computations was 2.0 gr/cm^3.

Terrain evaluations were made in the field with the aid of a chart, by dividing the topography into a series of circular zones, partioned into compartments and extending out from the station to a radius of 400 meters. The elevation difference between the station and the average elevation of the compartments were estimated and entered in a book of terrain correction charts. The corresponding gravity attraction for each compartment was read from Hammer's Tables (Nettleton, Page 145), converted to the metric system.

Computing

(a) Gravity

Two density profiles were observed in the area. Profile No. 1, metered 4.5 kilometers southwest of Leon, indicates surface densities of 1.9-2.0. Profile No. 2, surveyed 7.5 kilometers northeast of Telica, indicates densities of 1.9-2.0 to a depth of three meters and 2.8 for deeper strata.

Since the boundaries of the areas with varying surface densities are not known, an elevation factor of 0.2249 milligals per meter was used as a preliminary approach to computing the Bouguer values. This factor incorporates a density of 2.0.

The latitude corrections for the Reconnaissance and San Jacinto Surveys have a negative sign and are based on tables in Geophysical Prospecting for Oil, by L. L. Nettleton, which give the theoretical gravity on the International Ellipsoid. The latitude correction lines and abbreviated values in milligals were marked in red pencil on the location maps. The complete theoretical values can be obtained by adding 978 gals.

Because of its limited program and separation from other areas, the S. Volcan Momotombo survey was not connected with the other projects. The latitude corrections were referenced to an arbitrary latitude line with an assumed negative value of 100.00 milligals. The corrections were calculated as the distance in kilometers from the reference latitude multiplied by a constant of 0.342 milligal, which is the average rate of gravity change per kilometer at latitude 12°25'00".

An assumed value of 700.00 milligals was used for Base A, origin the Reconnaissance

and San Jacinto Surveys. Values for the other bases were determined by converting the measured scale division intervals to milligals with the constant of 0.10992 furnished for the gravity meter.

As assumed value of 500.00 milligals was used for Base 238, the only reference station set-out in the S. Volcan Momotombo Prospect.

(b) Magnetometer

Assumed values of 7000 and 5000 gammas were respectively used for Base A, origin of the Reconnaissance and San Jacinto Surveys, and Base 238, the only reference station set-out in the S. Volcan Momotombo Prospect.

The normal corrections have a negative sign; the normal lines were marked in pencil on the location maps as parallel lines spaced 8,953 meters apart, corresponding to differences in the normal field of 100 gammas. The altitude of the lines and values were determined by interpolation from the Vertical Intensity Magnetic Chart. For the S. Volcan Momotombo Survey, however, an assumed value of 500 gammas was used for the line of reference.

RESULTS

Reconnaissance Survey

1- Two Bouguer Maps, Scale 1:50,000
2- Two Magnetic Maps, Scale 1:50,000
3- Six Sets of Gravity /Magnetic Profiles

San Jacinto Detail Survey

1- One Bouguer Map, Scale 1:20,000
2- One Magnetic Map, Scale 1:20,000
3- Two Gravity Profiles

S. Volcan Momotombo Detail Survey

1- One Bouguer Map, Scale 1:10,000
2- One Magnetic Map, Scale 1:10,000

A contour interval of one milligal was used for gravity data and 100 gammas for the magnetic maps. Caution should be used in comparing gravity anomalies, since the average density used for the reduction of field values may not be valid for all areas of the survey. A double value for a magnetic station shows the spread of observations taken only a few meters apart, indicating surface flows of lava. Evaluation of the Bouguer anomalies is based on the general assumption that the density of rocks increases with depth.

Reconnaissance Survey

The line of gravity profiles across the Coastal Plain and Nicaragua Depression is dominated by a major northwest trending positive anomaly, centering near the village of San Jacinto and showing a maximum amplitude of about 30 milligals. The regional plunges for 20 kilometers to the northeast of its axis, from a maximum value of 461.63 milligals at Station 79 to a minimum interpolated value of 426.20 milligals near Station 122, coinciding with the axis of a major negative trend. On the west flank, the gradient dips at an average rate of 2.5 milligals per kilometer, to a minimum value of 435.27 milligals at Station 5.

The San Jacinto gravity feature is probably related to massive high density material (igneous rocks) at depth. The east flank of the anomaly shows two gravity gradients normally associated with major faulting or similar contacts between strata

of different density. The type of faults that may be interpreted depends on two choices in drawing the regional. If the theory of block faulting is favoured, fault No. 1 is observed with its center of gravity between Stations 92 and 93, and fault No. 2 near Station 109, downthrown sides toward the axis of the positive anomaly. The amount of displacement depends on densities involved. If a density contrast of 0.5 is assumed, the characteristics of the faults are as follows:

Fault No.	1	2
Location	St. 92-93	St. 109
Total anomaly in mgl.	9.5	7.8
Density contrast (assumed)	0.5	0.5
Throw in meters	456	374
Throw attitude (down)	west	southwest

If the anomalous masses in contact are different kinds of lavas, the resulting density contrast may be lower than 0.5 and the computed displacement proportionally greater. On the other hand, if the contact is between igneous rocks and pyroclastics, a somewhat higher density contrast than 0.5 may have to be considered in computing the displacement of the faults.

The north-south trending positive anomaly situated just west of Leon appears to be related to a major fold. It shows an amplitude of at least 15 milligals and a regional gradient gentler than the San Jacinto feature. Profile A-A' indicates possible faulting on the west flank, upthrown to the west. This anomaly is only partially delineated and no quantitative interpretation is possible.

Over the east portion of the Graben, the gravity regional rises gently from a

minimum value of 426.20 milligals at Station 122, to a maximum value of 436.83 milligals at Station 159, a rate of about 0.5 milligal per kilometer. Minor anomalous gradients are superimposed on the regional, indicating gentle tilting and folding of the rocks.

Along gravity profiles E-E' and F-F', the regional gradient dips to the northeast for about seven kilometers at a rate of one milligal per kilometer, from a value of 436.83 milligals at Station 159 to about 426.00 milligals, forming a plateau of flat gravity, seven kilometers long. The regional then plunges for at least eight kilometers to the northeast, to a minimum value of 402.84 milligals at Station 223, delineating what appears to be the west limb of a major negative anomaly. The gravity expression of a fault is observed on the lower portion of the limb, upthrown side to the southwest. Gravity profile F-F' shows a total residual anomaly of four milligals. An assumed density contrast of 0.5 was used to compute a displacement of 192 meters.

The magnetic profiles over the entire reconnaissance line show an essentially flat regional, broken by a series of sharp positive and negative anomalies, probably associated with surface flows of lava. This is in contrast, for instance, with the high amplitude of the San Jacinto gravity anomaly, indicating that there is almost no susceptibility contrast between igneous rocks, lavas and volcanic sediments. The only evidence of good correlation between gravity and magnetometer data is shown on profiles D-D' and E-E', both methods mapping possible near-surface intrusions.

San Jacinto Detail Survey

The addition of new data added three milligals of amplitude to the outline of the San Jacinto gravity feature, which trends northwest-southeast and gives every indication that it extends for some distance in either direction. Two negative trends occur on its flanks at right angle with the positive axis and separated by a saddle centering near Station 167. Their area of influence includes the "hervideros" of San Jacinto - Tisate and correlate with the low resistivity contours of the "hot area", as interpreted by Dr. Norman Harthill. A magnetic negative anomaly showing a closure of 500 gammas, approximates the attitude and coverage of the gravity negative trends mentioned above.

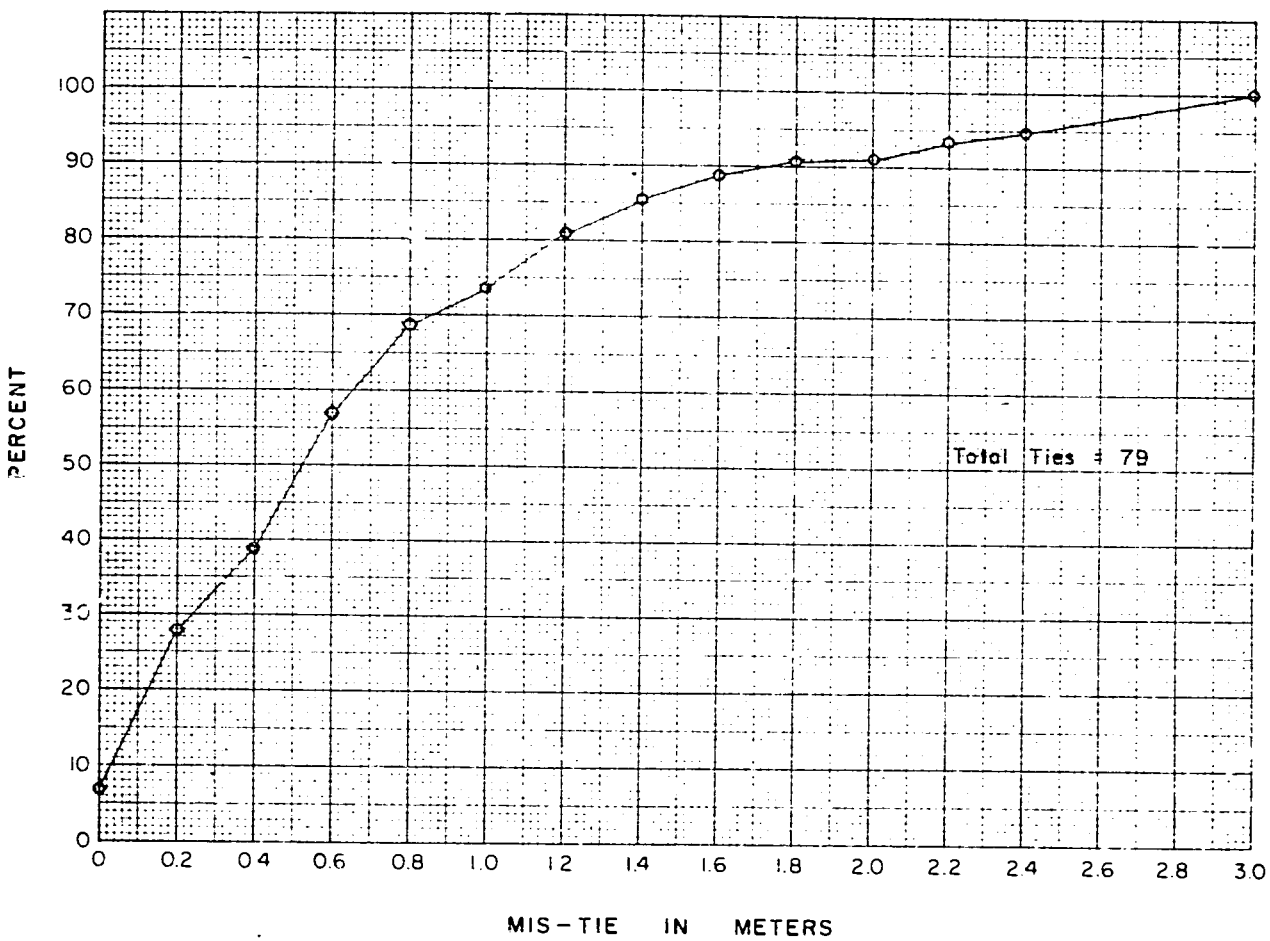
Gravity profiles G-G' and H-H' indicate possible faulting on the southwest flank of the San Jacinto feature, upthrown toward the axis of the positive anomaly.

S. Volcan Momotombo Detail Survey

Only 23 stations were observed along the trail roughly paralleling the shoreline of Lake Managua and extending over some of the thermal areas. The contoured data appear to confirm the correlation characteristics between gravity and magnetic anomalies found in San Jacinto Prospect.

The gravity negative trends superimposed on the flanks of the positive anomaly are related to strata of low density (altered rocks). The magnetic negative anomalies, showing possible closures of several hundred gammas, indicate areas of altered rocks which have lost part of the original magnetic properties.

FIGURE 1 Percentage Of Elevation Check Errors Versus Check Error Level



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Reference Center
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FIGURE 2 Percentage Of Gravity Check Errors Versus Check Error Level

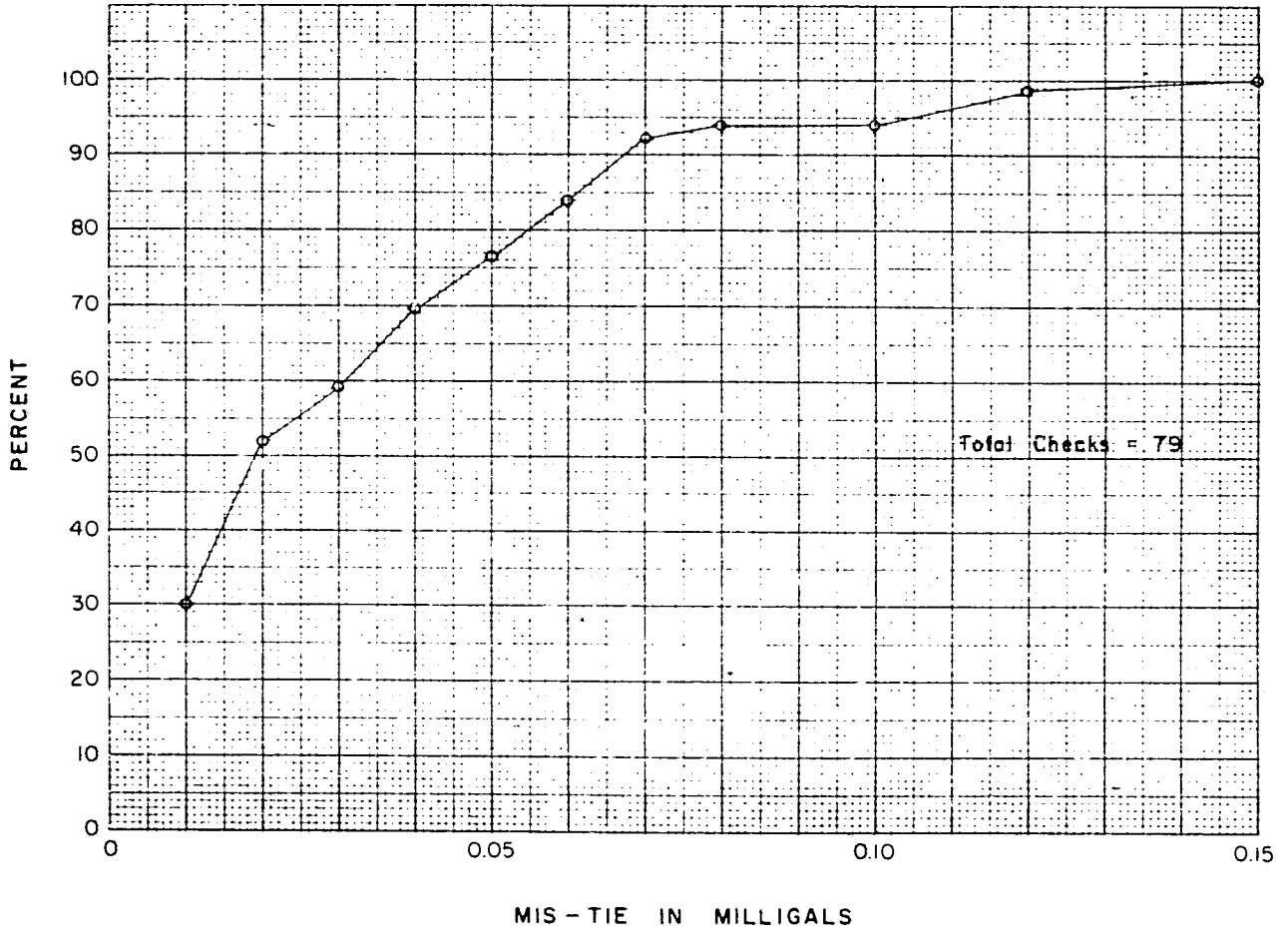
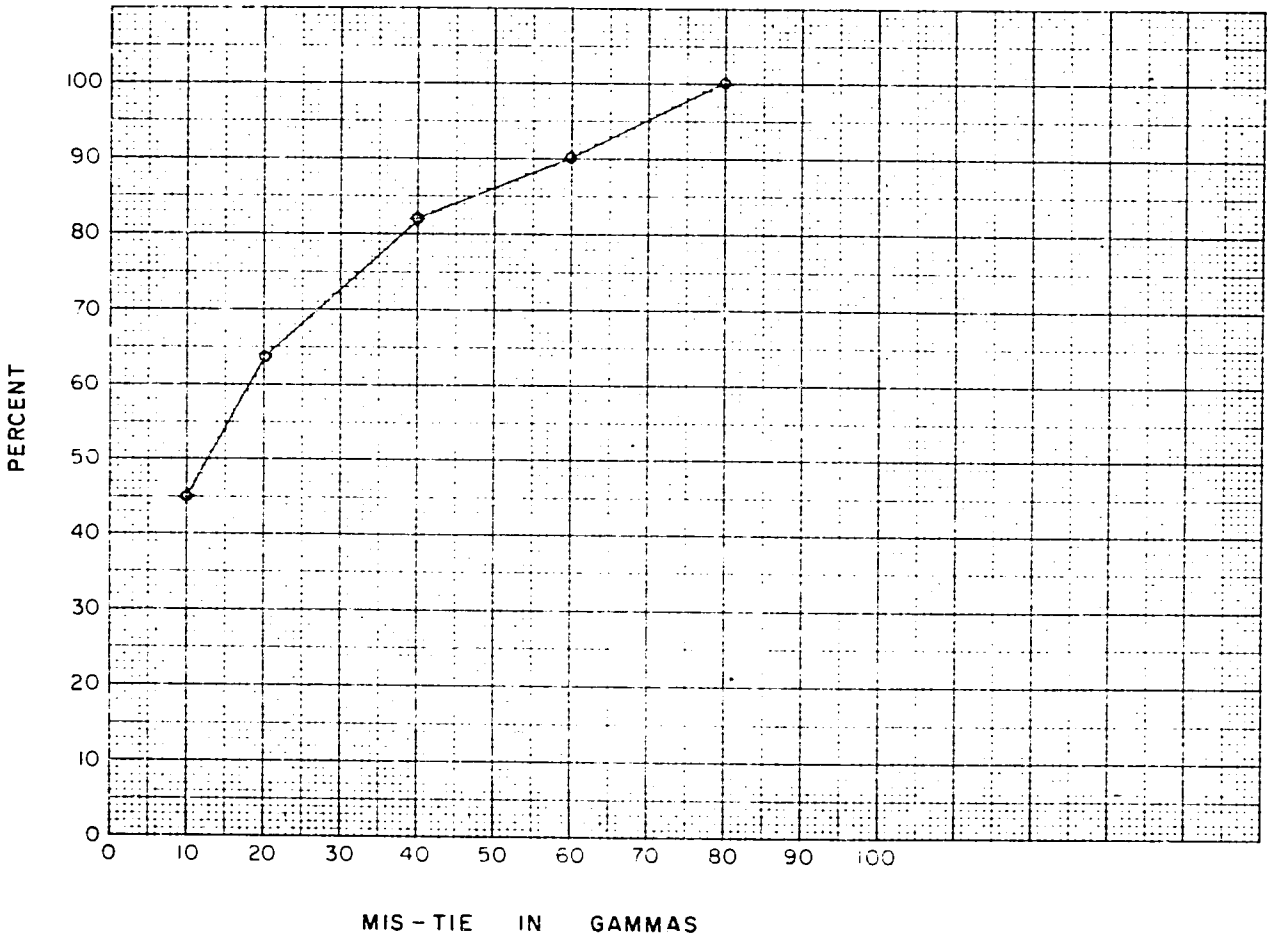
FIGURE 3 Percentage Of Magnetometer Check Errors Versus Check Error Level