A COMPUTER METHOD FOR INTERPRETING MAGNETIC ANOMALIES OVER DIKE-LIKE STRUCTURES

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KEITH F. STANDING

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Report of Thesis Examiners

THIS IS TO CERTIFY THAT the members of the examining committee of the Master's (x) Ph.D. (   ) thesis of:

KEITH F. STANDING

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Chris Anderson
Chairman

D. H. Hall

Paul Gilsen

ABSTRACT

Two computer programs have been prepared for the purpose of interpreting magnetic data.

One program is designed to extract magnetic profiles of arbitrary length and direction from digitized aeromagnetic maps, compute the regional trend by a least squares method, and yield a profile of equispaced residual values.

The second program takes magnetic profile data and computes the parameters of dip, depth, width, and susceptibility for a dike-like structure which would have a response most like the observed data.

In matching the theoretical to the observed response, a weighting function was used to emphasize the peak area of the curve.

The program was then tested on 30 theoretical cases using 1) no weighting function, 2) a step type weighting function, and 3) a gaussian weighting function. In over 50% of cases, the weighting function improved the interpretation made by the program.

The Gaussian curve was chosen as the most suitable weighting function and the program was then used to interpret five profiles taken from ground magnetic survey data and twenty-four profiles from aeromagnetic maps.

ACKNOWLEDGEMENTS

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LIST OF SYMBOLS

Symbol		Page
a	Half maximum distance	18
A	Inclination of the earth's field	21
B	$2C - \delta - \pi/2$	21
C	$\tan^{-1}(A/s)$	21
C_F	Coefficient term	12
h	Difference between respective points on the theoretical and observed curves	20
I_o	Inclination of the earth's field	10
I_o'	Effective inclination	10
k	Susceptibility	8
N	Number of points on the theoretical curve	20
R	w/z	12
r_1, r_2	Distances from point of observation to the edges of the dike	21
s	Strike of the dike	21
t	Thickness of the dike	12
T_o	Magnitude of the earth's magnetic field	10
T_o'	Effective total intensity	10
T_s	Component of T_o lying parallel to the x'-axis	10
w	Dike width	13
x, y	Coordinates of points on magnetic maps - measured from the south-east corner	59
z	Depth to the top of the dike	7
α	Strike of the dike	8

		Page
β'	Angle between T_o' and the dike	12
γ	Magnitude of the magnetic field	45
δ	Dip of the dike	8
ΔF	Magnetic anomaly (any component)	12
ΔT	Anomaly in total field	21
ψ	Angle	12
θ_F	Index paramater	12
θ	Angle	21

CHAPTER 1

INTRODUCTION

During the past few years, projects have been under way at the University of Manitoba to make use of digital computors (e.g. I.B.M.-360-model 65) in the processing of magnetic data. A large number of the published aeromagnetic maps of the Province of Manitoba have been digitized and programs for contouring and filtering of randomly spaced data have been prepared (McGrath and Hall, 1969; Hall, Richards and Anderson, in preparation).

The present study was undertaken to find a rapid system for interpreting magnetic anomalies. A dike model has been chosen for the interpretation because of its simplicity and its frequency of natural occurrence. It was decided that a system of curve matching similar to that described by S. Parker-Gay Jr. (1963) would be most readily adapted. His approach has been modified by the addition of a weighting function which places emphasis on any desired part of the profile. The weighting function is described in more detail in section 3.21.

CHAPTER 2

PREPARATION OF DATA

2.1 Maps Used

The aeromagnetic maps used in this study are from the series prepared by the Department of Mines and Technical Surveys of the Geological Survey of Canada. These maps cover an area of 30' of longitude by 15' of latitude at a scale of 1" = 1 mile. The magnetometer was flown at an altitude of 1,000 feet with a line spacing of approximately ½ mile. The digitizing of these maps was done in metric units and in this system, the scale is 1 mm. = 207.87 feet and the line spacing is approximately 12 millimeters.

The system used for digitizing these maps (Andrews, 1968) is given in Appendix 1.

2.2 Description and Use of Program 'PROFILE'

A program, PROFILE, (Appendix 2), has been prepared to extract a profile from any part of the digitized maps. The required input is the digitized map deck plus one card containing the coordinates of the point from which the profile is to start, the angle it will take, and its length. The coordinates are given in millimeters measured from the south-east corner of the map, the angle is measured clockwise from true north, and the length is given in millimeters.

The program then computes values of field at regular intervals along the profile by averaging all the data points which lie within a 12 mm. square centered at the required point. The influence of the data points is governed by a weighting function which is the inverse of the distance of the point from the center of the square. The intervals at which field values are computed is 1 mm. but this can be easily changed if a different spacing is required.

The 12 mm. square size was chosen because this best matched the real case. Naidu (1970), Horton, Hampkins, and Hoffman (1964), and others, recommend that digital work be done with square sizes approximately equal to the flight line spacing. Although they have used this criteria in preparing digitized maps, it should also hold for extracting profile data.

After computing regularly spaced values of field, the regional trend is calculated by a least squares method and subtracted leaving a profile of residual values. These values and their locations are then printed, punched on cards, and the profile is also drawn out on the plotter.

The following example (Fig. 2-1) of a flight line from the Hambone Lake Map Sheet shows a hand drawn profile compared to mechanically prepared profiles using 6, 12 and 24 mm. squares. It can be seen that the one using a 12 mm.

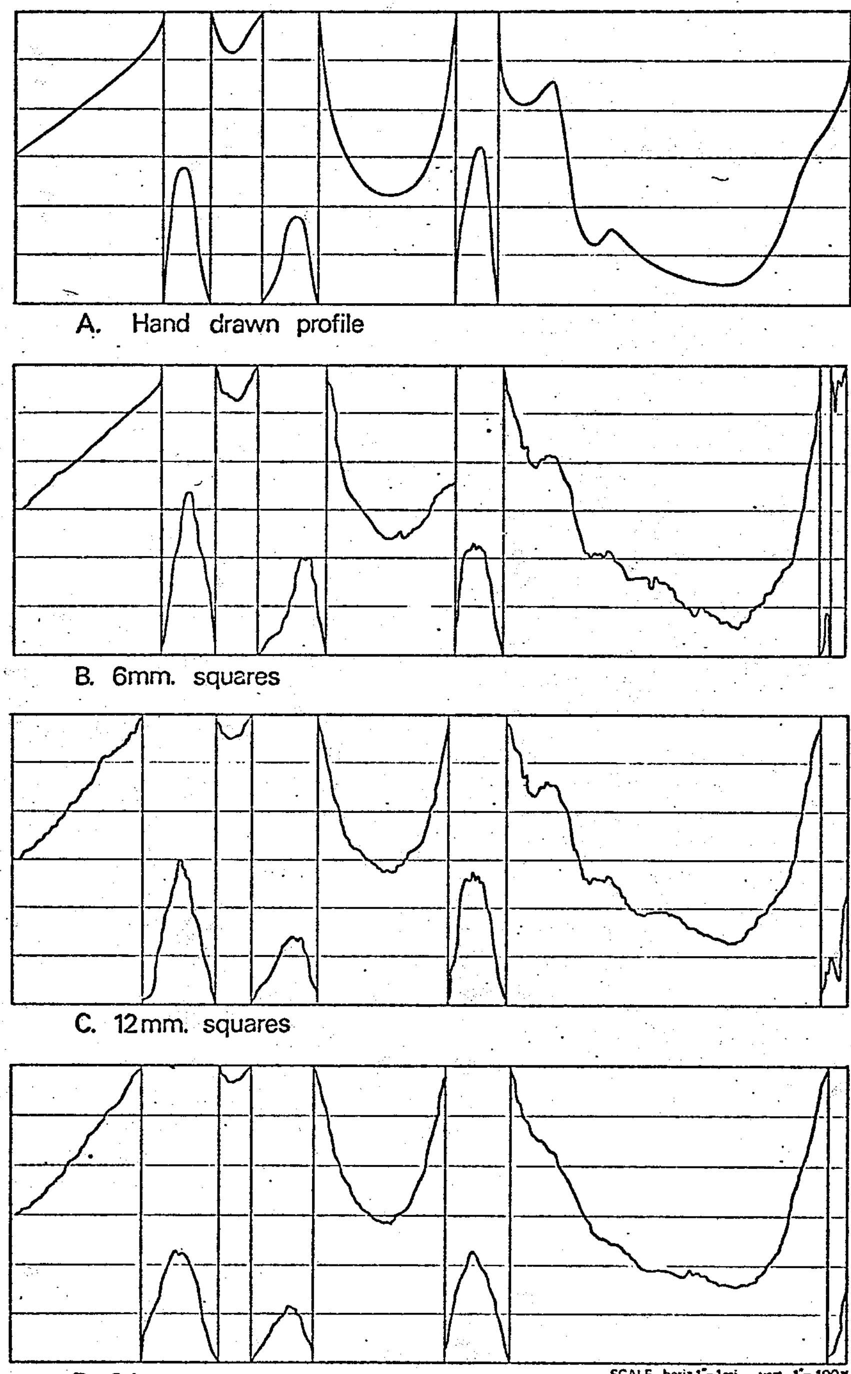

Fig. 2-1 Profiles from map #2592G Hambone Lake showing the effect of varying the square size used in computing field values.

square size more closely resembles the hand drawn line than either of the others. The 6 mm. square size seems to overemphasize small features while the 24 mm. square size tends to smooth out the profile.

Other examples of profiles produced in this manner are shown in Figure 2-2.

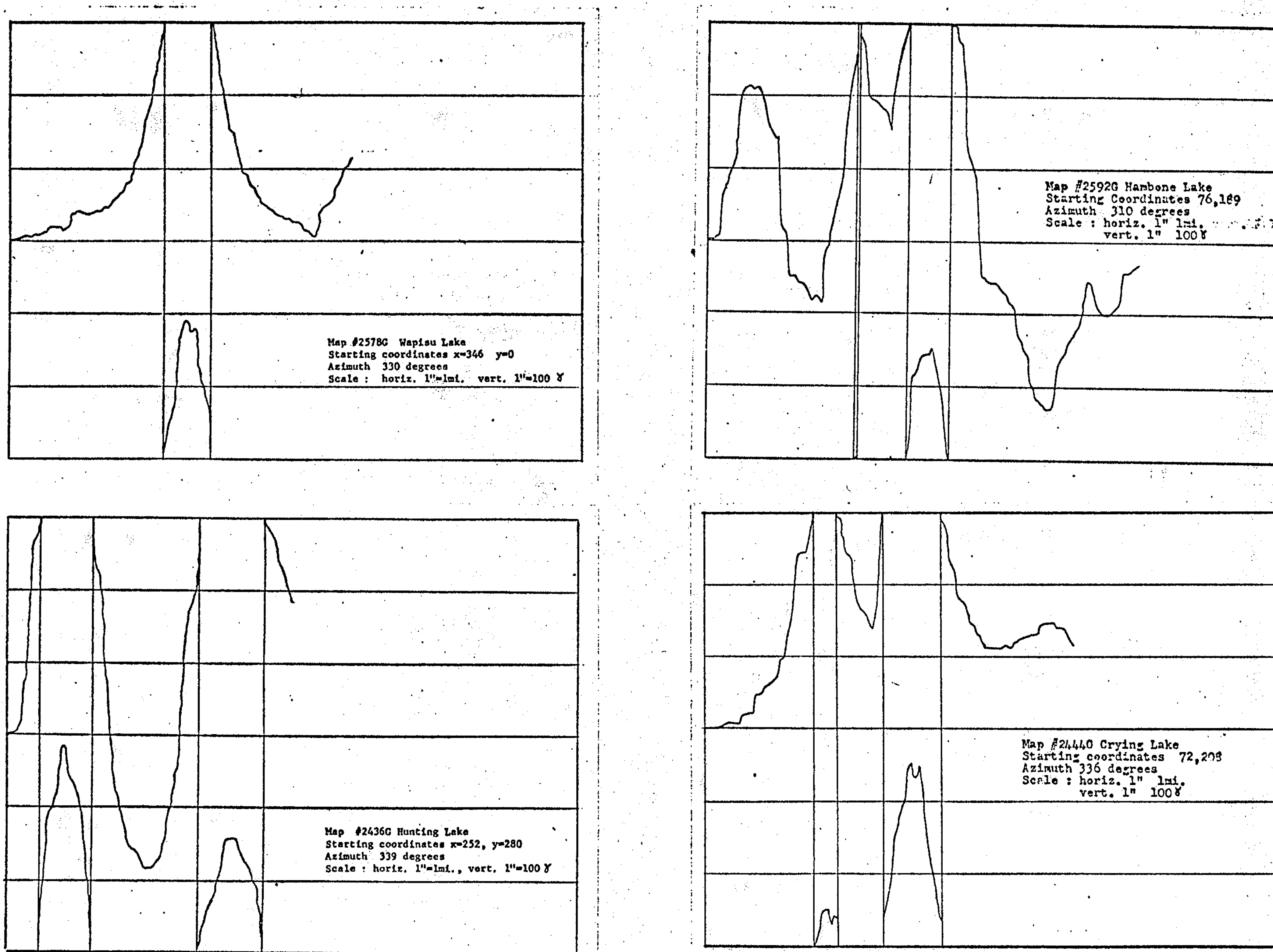

Figure 2-2 Examples of Output from Program Profile.

CHAPTER 3

THEORY OF DIKES AND INTERPRETATION OF MAGNETIC ANOMALIES

3.1 Theory of Dikes as Developed by S. Parker-Gay Jr.

Parker-Gay (1963), in his paper, "Standard Curves for Interpretation of Magnetic Anomalies over Long Tabular Bodies", describes a system for interpreting magnetic anomalies by comparing the entire observed profile to a set of theoretical curves made up for dike-like bodies. He has shown that a single family of curves represent all anomalies in vertical, horizontal, and total field for infinite tabular bodies in any position of dip, strike and field inclination. His mathematical formulas and theory were developed from earlier work by Heiland (1946) and Cook (1950).

The concept of magnetic 'charge' or pole strength is used and the procedure is simplified by first considering a very thin tabular body which is later generalized to thick tabular bodies by integration. The geometry of the dike model, given here, is reproduced from Parker-Gay (1963, pp. 162-164).

"The thin dike extends to infinity in both strike directions and down dip, and its upper edge or apex, is a straight line at constant distance, Z, below the horizontal plane of observation (see Fig. 3-1). The requirement of "thinness" is satisfied only by making Z, much greater than t, the thickness of the dike.

Two left-handed coordinate systems are defined. They share a common origin at any point on the plane of observation directly over the apex and a common z-axis, positive vertically downwards. The unprimed system has its y-axis positive along the magnetic north line; and the primed system has its y'-axis perpendicular to the strike of the dike and positive in the northern half plane of the unprimed system, or to the magnetic east. The magnetic anomaly profile derived will be along the y'-axis perpendicular to the strike of the dike.

The magnetic azimuth, or strike, α, is the clockwise angle from the positive y-axis to the positive x-axis defined within the following limits: $0^\circ < \alpha \leq 180^\circ$.

The dip, δ, of the dike is the angle between the positive y-axis and the plane of the dike and has the limits: $0^\circ \leq \delta \leq 180^\circ$. Defined in this manner it is the 'north dip'. A dike dipping 30° south for example, would be considered to have a dip of 150°.

The material composing the dike has a true magnetic susceptibility k, and the surrounding material is assumed to have zero susceptibility. When it is not zero, the susceptibility contrast is used instead of k.

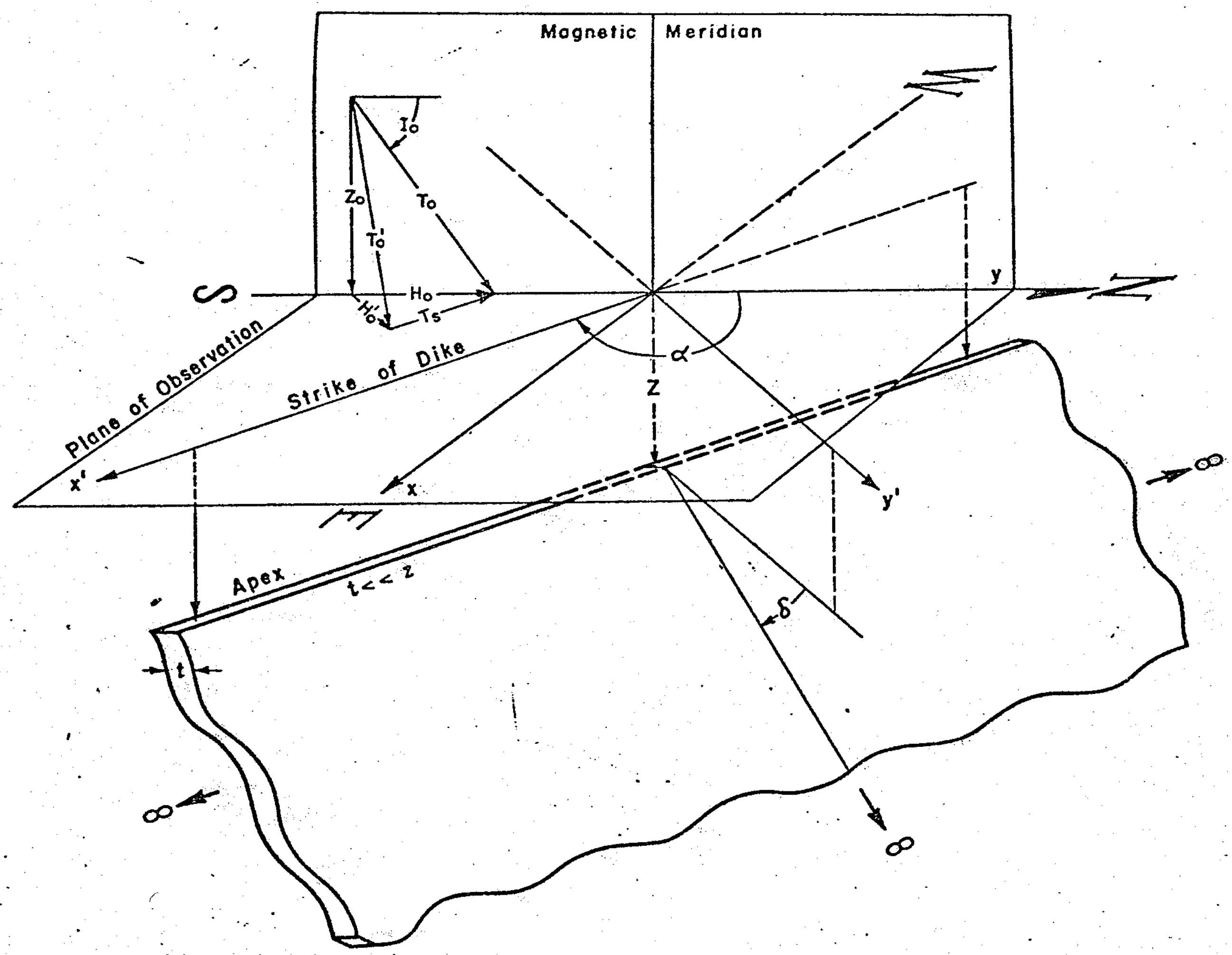

Figure 3-1 Geometry and Spatial Relationships of the Thin Infinite Dike. (after Parker-Gay, 1963)

The earth's magnetic field is represented by a vector of magnitude T_o and inclination I_o lying in the yz-plane. I_o varies from $-90°$ at the south magnetic pole to $+90°$ at the north magnetic pole. T_o is resolved into two components: one lying parallel to the x'-axis, and the other lying in the y'z-plane. The former T_s, is parallel to the plane of the dike and may be neglected since any magnetic poles that it induces lie on the end faces at infinity. The latter is the component of T_o, that is effective in inducing magnetic poles on the dike's surfaces and is so termed the effective total intensity, T_o'. Its inclination in the y'z-plane is termed the effective inclination, I_o'" (see Fig. 3-2). (Parker-Gay, pp. 162-164).

The relationship between real and effective magnetizations, and inclinations are given by:

$$\tan I_o' = \frac{\tan I_o}{\sin \alpha}$$

$$\frac{T_o'}{T_o} = \frac{\sin I_o}{\sin I_o'}$$

Parker-Gay goes on to compute the potential due to the body and the resulting anomalies in the vertical,

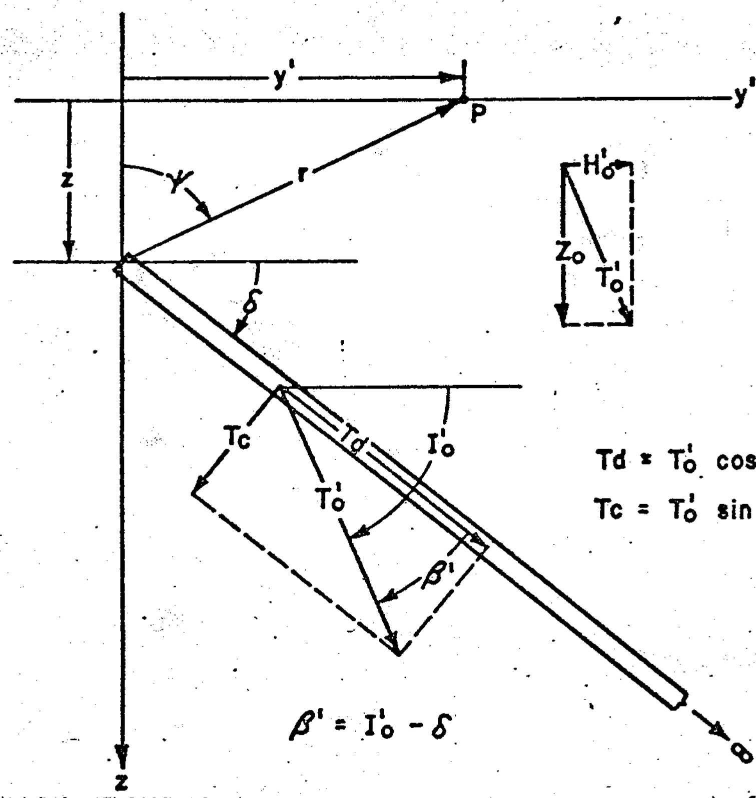

Figure 3-2 Geometry of the Thin Dike in the y'z plane. (after Parker-Gay, 1963)

TABLE 1

COEFFICIENTS

ANOMALY	COEFFICIENT C_F	INDEX PARAMETER Θ_F IN TERMS OF β'	INDEX PARAMETER Θ_F IN TERMS OF δ
ΔZ	$2kT_o' \frac{t}{z}$	β'	$I_o' - \delta$
ΔH	$2kT_o' \frac{t}{z} \sin \alpha$	$\beta' - 90^\circ$	$I_o' - \delta - 90^\circ$
ΔT	$2kT_o' \frac{t}{z} \frac{\sin I_o}{\sin I_o'}$	$\beta' - 90^\circ + I_o'$	$2I_o' - \delta - 90^\circ$

horizontal, and total fields, but these computations will not be reproduced here. The resulting equation for the anomaly is of the form:

$$\Delta F = C_F \cos \psi \cos (\psi - \theta_F)$$

where:

ΔF = the anomaly in the corresponding component of the magnetic field.

C_F = coefficient term = $f(T_o, I_o, \alpha, k, t, Z)$

and

θ_F = the index parameter = $f(\beta', I_o') = f(\alpha, \delta, I_o)$

values of C_F and θ_F are tabulated in Table 1.

For thick dikes he has shown that the equation is of similar form:

$$\Delta F = \left[\left[C_F \quad \frac{\psi_1 - \psi_2}{R} \right] \cos \theta_F + \left[\frac{1}{R} \log \frac{\cos \psi_2}{\cos \psi_1} \right] \sin \theta_F \right]$$

where C_F and θ_F are the same as those for the thick dike case. The geometry of the thick dike is shown in Figure 3-3.

He points out that the thick dike curves do not depart significantly from the thin dike curves until the width is approximately equal to the depth of burial.

"Thick dike geometry breaks down for bodies of near horizontal dip. For actual geological bodies of shallow dip, however, the geometry of the apex is often quite ir-

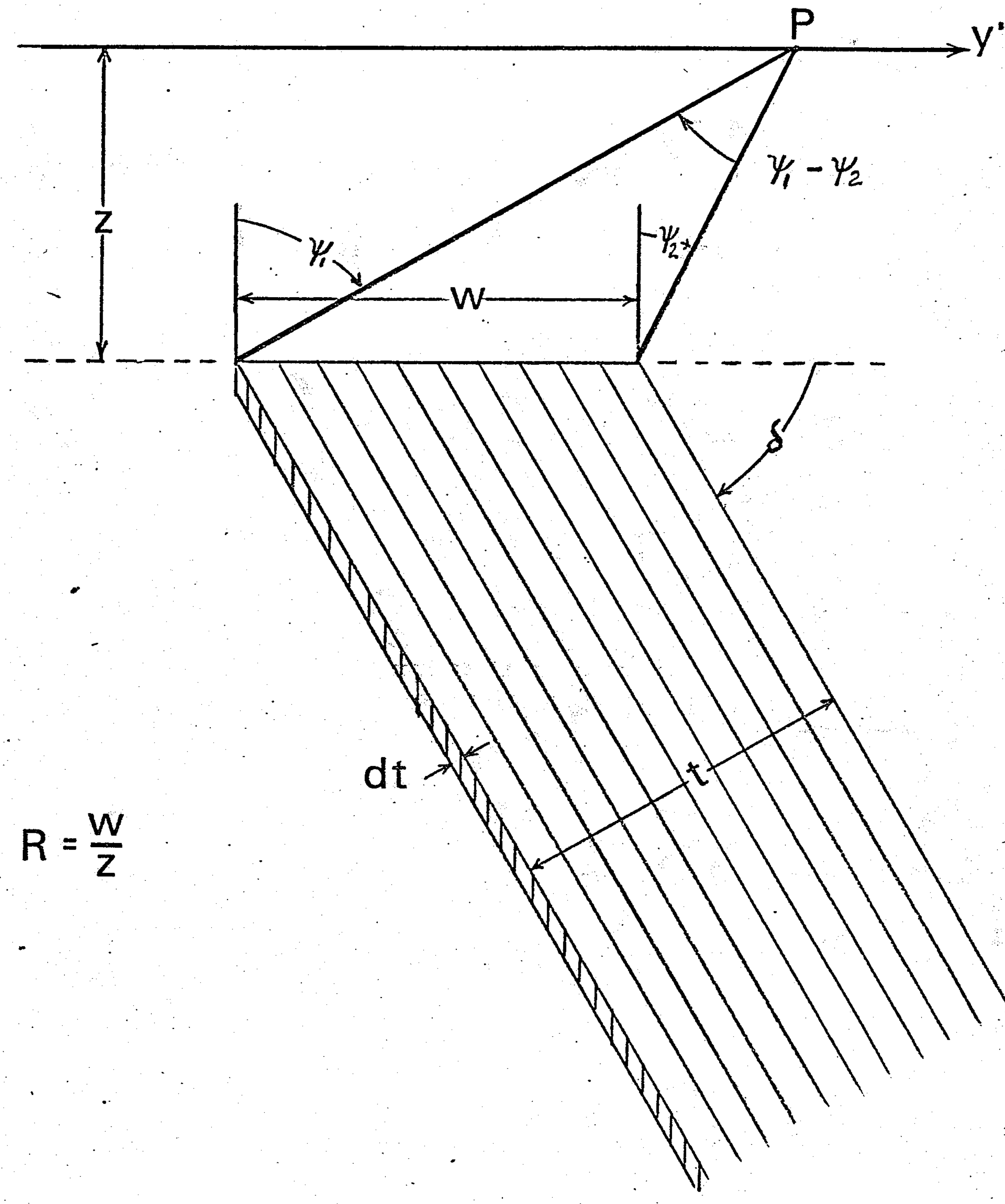

Fig. 3-3 Geometry of the wide dike in the y'z-plane.

regular, resulting in unpredictable variations in the anomaly curve. An equally serious problem in such cases is also that of inhomogeneous susceptibility across the width. It was for these practical considerations that standard curves were not constructed for width indices greater than 4", (Parker-Gay, 1963, p. 186).

A general solution for the thick dike case, taking demagnetization into consideration, is not possible; this effect, therefore, has been ignored. This is not a serious defect because, as Grant and West (1965, p. 318) point out, the effect does not become significant unless the body is largely composed of magnetite.

3.2 Interpretation of Digitized Profiles

3.21 Program Dikefit

A computer program "dikefit" (Appendix 3) has been prepared which accepts the punched output from "Profile" (or similar data prepared by hand), and computes the parameters of dip, depth, width, and susceptibility for the tabular body which would give rise to the best fitting magnetic anomaly curve. The computed susceptibility, of course, is really the susceptibility contrast between the host rock and the dike.

The procedure followed in the program is first of all to select the feature to be interpreted. Anomalies are defined to be the peaks on the profile and are interpreted in order of magnitude with the largest considered first. The program, therefore, detects the maximum value of field, then, proceeding along the profile in both directions from this point, finds the two points which are closest to half of the maximum value. The distance between these two points is then defined as the half-maximum distance. In special cases, the user may enter a value which he wishes to use as the half-maximum distance.

The anomalous part of the profile is then isolated and considered separately. The anomalous region is taken to be three and one half times the half-maximum distance, starting from a point at a distance equal to the half-maximum distance away from the half-maximum point on the side with the least value of the slope (see Fig. 3-4). In the case of a symmetrical curve, the anomalous region is taken to be three times the half-maximum distance, centered at the peak value. The anomaly curve is then normalized so that the amplitude (maximum to minimum) is equal to one.

The next step is to compute a weighting function so that the desired part of the curve is emphasized. In most cases the emphasis will go on the peak area because the tails of the curve are most affected by adjacent anomalies. The function used in this case was a gaussian curve (Fig. 3-5), centered at the peak; as this function is computed in a subroutine, it can readily be changed if

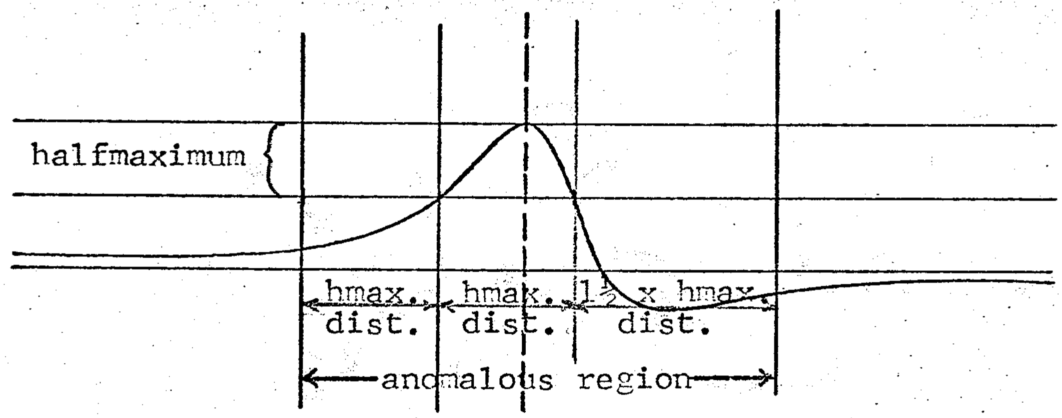

Figure 3-4 Definition of the anomalous region

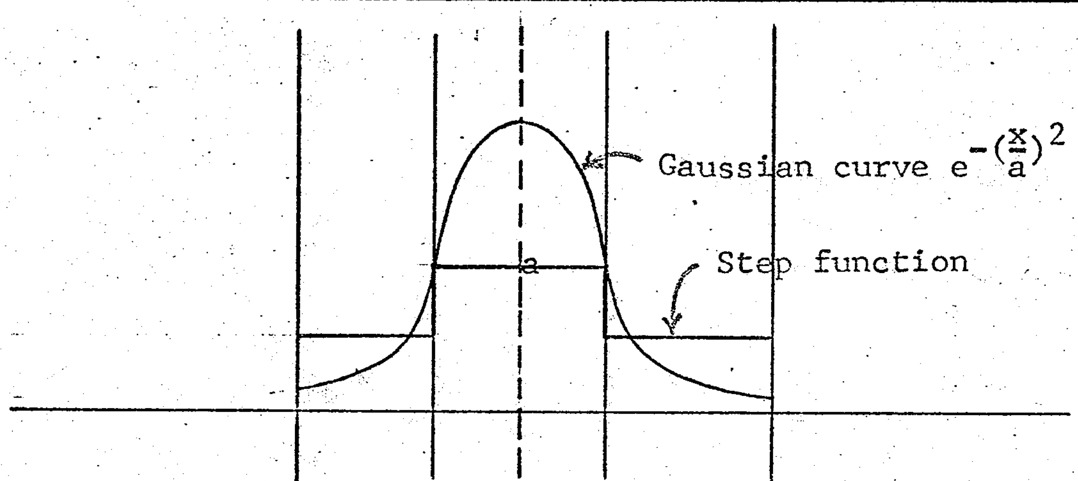

Figure 3-5 Weighting functions

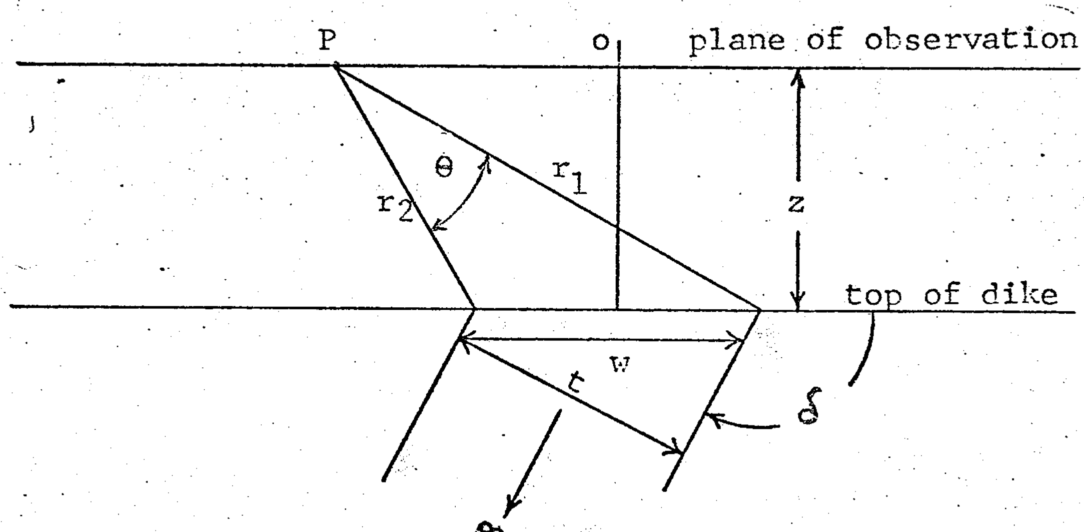

Figure 3-6 Parameters of the thick dike.

a different weighting function is required. A step type weighting function (Fig. 3-5) was also tried and in all cases this gave exactly the same results as the gaussian function. There was, however, a considerable improvement between cases run with a weight function and those run without.

Cases improved by the weight function 16

Cases not improved by the weight function 14

In more than 50% of the theoretical cases tried, it was found that the answer was improved by using a weighting function, and in the remainder the answers were as good as those in which a weighting function was not used.

Even with the weighting function, the resolution of adjacent anomalies is somewhat limited. Hall (1968) has shown that only the portion of the anomaly curve containing one of the turning points is necessary to make an interpretation. In the present case, however, a profile segment of fixed length (fig. 3-4) is matched to a theoretical curve of the same length. If the anomalous region is influenced by neighbouring anomalies then the theoretical curve which best fits the observed data may not be the one which is representative of the actual structure.

To make a valid interpretation it is necessary that a fairly large portion of the anomaly curve be attributable to the structure being studied. A test was made to determine the limit of anomaly resolution, that is, to find out how much of the curve is required to define the anomaly.

Profiles were computed over two adjacent dikes, each one being 100 feet deep, 200 feet wide, and having a susceptibility of 0.003 units. The separation between the two dikes was allowed to vary from 0-700 feet. The interpretations made by the program are listed in Table 2.

As expected, for no separation between the dikes, the program gave a reasonable interpretation for a 400-foot wide dike. For separations of 100 feet and 200 feet, the program chose dikes with shallow dips. The interpretation becomes slightly better at 300 feet and 400 feet and becomes quite reasonable at 500 feet. By looking at the anomaly curves it can be seen that a reasonable interpretation becomes possible when the field drops to approximately one quarter of the maximum value on either side of the peak.

It was decided that for the examples used in this paper, the gaussian function $e^{-(\frac{x}{a})^2}$ (a = half-maximum distance) would be used. This is preferable to

Table 2

Results of Separation Test

INPUT SEPARATION	DIP	DEPTH	WIDTH	SUS.	SEPARATION
0	90	119	356	0.003	
100	140	188	188	0.010	225
	60	80	200	0.002	
200	150	188	19	0.095	350
	65	56	225	0.002	
300	95	130	13	0.043	300
	90	120	120	0.005	
400	55	32	130	0.002	425
	60	140	14	0.056	
500	90	65	195	0.002	500
	90	105	210	0.003	
600	95	81	203	0.002	600
	90	105	210	0.003	
700	90	81	203	0.002	700
	90	105	210	0.003	

the step function because it is a continuous function and its shape more closely resembles the shape of the anomaly curve itself.

Using this weighting function, a comparison is made between the observed curve and a theoretical model curve according to the formula:

$$\text{FIT} = \frac{\sum h^2 w}{N \sum w}$$

where h is the difference between respective points on the two curves, w is the weight at that point, and N is the number of points involved.

The first step in computing the parameters of the dike is to select a value for the depth. As a first estimate we can set the depth equal to the half-maximum distance and, assuming we are dealing with a thin dike, we can set the dike width equal to one tenth of the depth. The susceptibility is arbitrarily set at 0.002 c.g.s. units (this value is arbitrary because the susceptibility effects only the amplitude and the curve will be normalized).

Having chosen three of the parameters, the value of dip can be chosen by generating curves that would exist over dikes having these parameters and dips at five degree intervals over a predetermined range. (It will be apparent from the slopes of the sides of the anomaly curve, to which side the body dips. It is therefore necessary to consider only ninety degrees of arc).

The curves are generated in a subroutine 'GENRAT', according to the expressions given in section 3.1. The basic formula is:

$$\Delta T = 2kT \sin\delta \left(\left(\frac{\sin A}{\sin C} \right)^{2} \right) \left(\theta \cos B + \left(\log \frac{r_2}{r_1}\right) \sin B\right)$$

where:

k = susceptibility

δ = dip of the dike

A = inclination of the Earth's field

C = $\tan^{-1}(A/s)$; s = strike

θ = see Fig. 3-6

B = $2C - \delta - \pi/2$

r_2 = see Fig. 3-6

r_1 = see Fig. 3-6

The computed curves are then normalized and compared to the normalized observed profile. The fit is determined for each curve by the formula previously described and the dip yielding the smallest value of fit is retained.

This value of dip is then used while depth and width are allowed to vary. The maximum depth used to compute the dip, is divided into ten parts, and for each of the ten depths, widths equal to 1/10, 1, 1 1/2, 2, 2 1/2, 3, 3 1/2 and 4 times the depth are tried. These curves are then compared to the normalized observed profile and the best fit is selected.

Using the computed depth and width, a few values of dip are recomputed as a check. If the difference between the new value and the old is five degrees or less, the computed parameters are accepted as being the true ones. If the difference is greater than five degrees, the depth and width are recomputed.

The computed values of dip, depth, and width are now used to compute the susceptibility. A curve is generated using the dip, depth and width and an arbitrary susceptibility of 0.0005 c.g.s. units and the amplitude (maximum to minimum) is calculated. This is then compared to the amplitude of the observed anomaly and the true susceptibility is calculated as:

$$\text{true susceptibility} = \frac{\text{arbitrary susceptibility x true amplitude}}{\text{amplitude of generated curve}}$$

When the width is chosen to be one tenth of the depth, this simply means that the dike is 'thin', in this case, only the width-susceptibility product will be meaningful.

A curve is then generated using the computed values of dip, depth, width, and susceptibility, and compared to the original non-normalized anomaly curve, to give the actual goodness of fit.

Finally a curve is generated, using the computed parameters, with points along the entire profile. This curve is then subtracted from the original profile to leave a residual, which if desired will be processed for the next anomalous feature.

The original curve, the best fitting theoretical curve, and the residual are drawn out by the Calcomp plotter.

3.22 Examples of Use

The program has been used to interpret theoretically produced curves, ground magnetic data, and airborne magnetic data.

A good example of an interpretation of a theoretical curve is #T16 (Fig. 3-7). The parameters used to generate this curve were: dip 110°, depth 300 feet, width 30 feet, and susceptibility 0.005 c.g.s. units; the program yielded: dip 110°, depth 293 feet, width 29 feet, and susceptibility 0.005 units. The error in this case was in the order of 2%.

Figure 3-8 shows a magnetic anomaly observed on

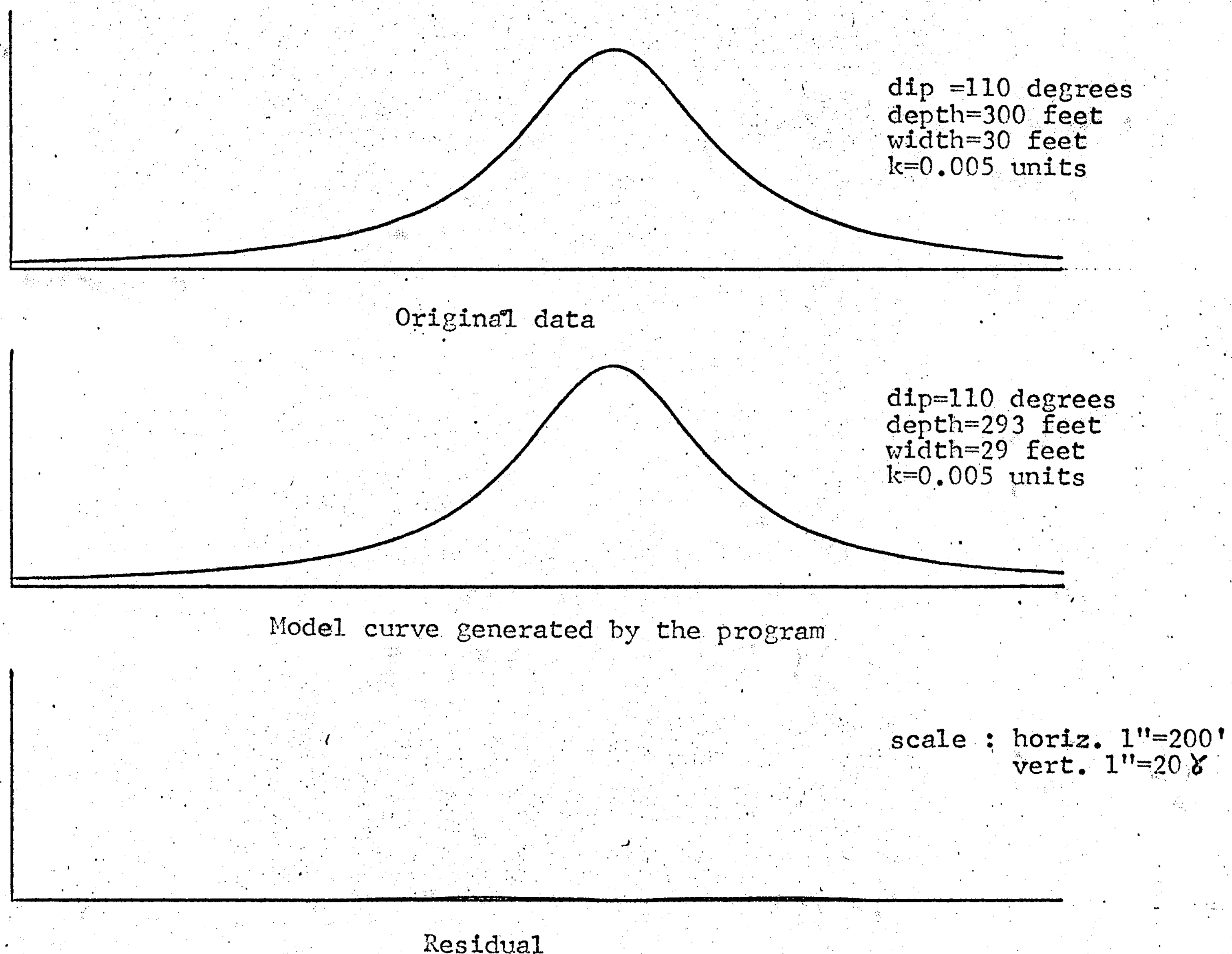

Figure 3-7 Interpretation of theoretical curve #T16.

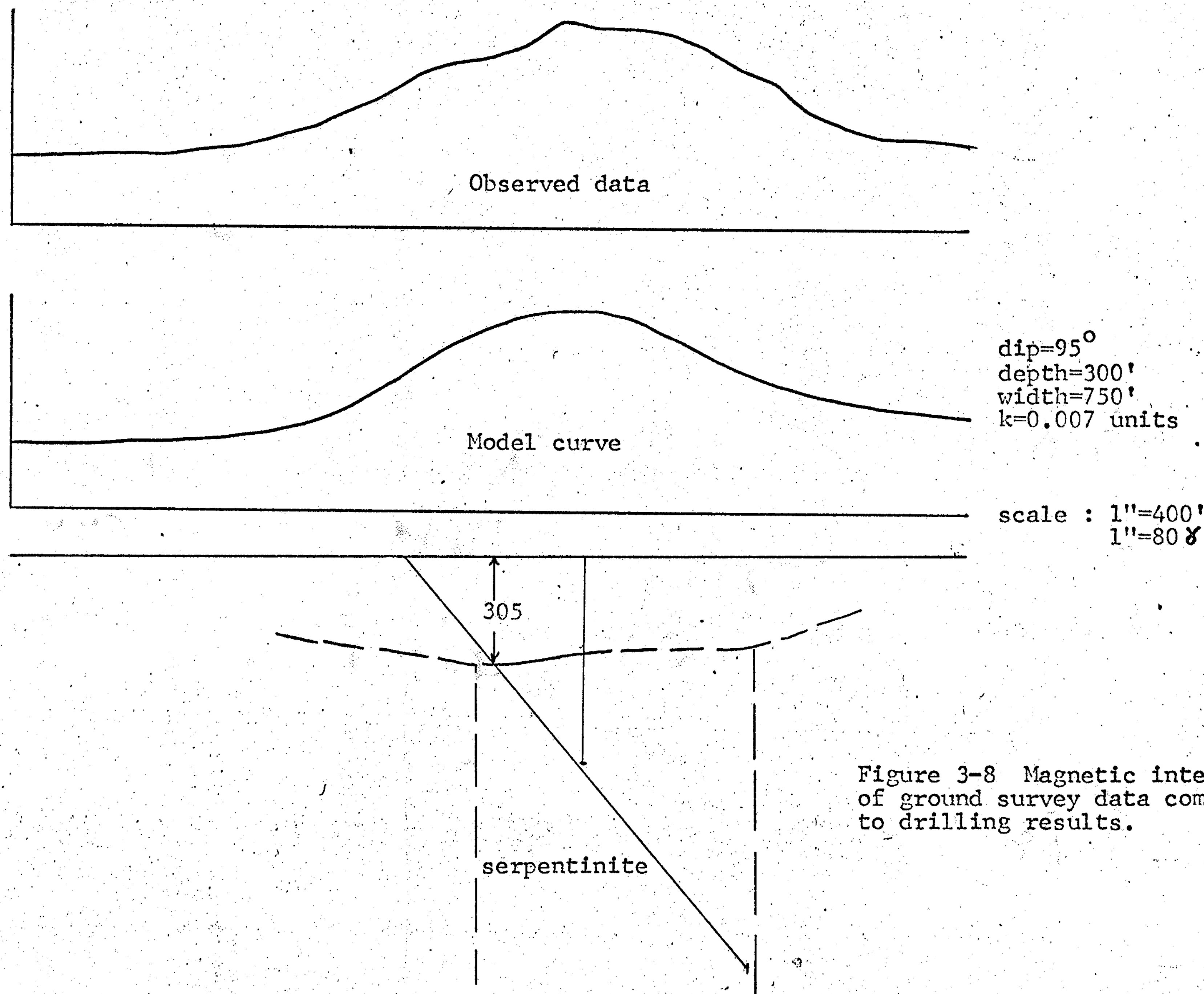

Figure 3-8 Magnetic interpretation of ground survey data compared to drilling results.

a ground magnetic survey along with the interpretation made by the program, and a geological cross section made from drilling data. The program chose a dike with dip 95°, depth 300 feet, width 750 feet, and susceptibility 0.007. This agrees quite favourably with the geologic cross section which shows a vertical serpentinite body, 305 feet deep with an estimated width of 800 feet.

As an example of an interpretation made from an airborne survey, Figure 3-9 shows a profile taken from the Muhigan Lake map sheet. Two adjacent anomalies were interpreted, the results of the first being: dip 95°, depth 1870 feet, width 2806 feet, and susceptibility 0.020. The results of the interpretation of the second feature were: dip 105°, depth 1870 feet, width 3741 feet, and susceptibility 0.010. It must be remembered that the depth given here is the depth below the aircraft and not the depth below ground level.

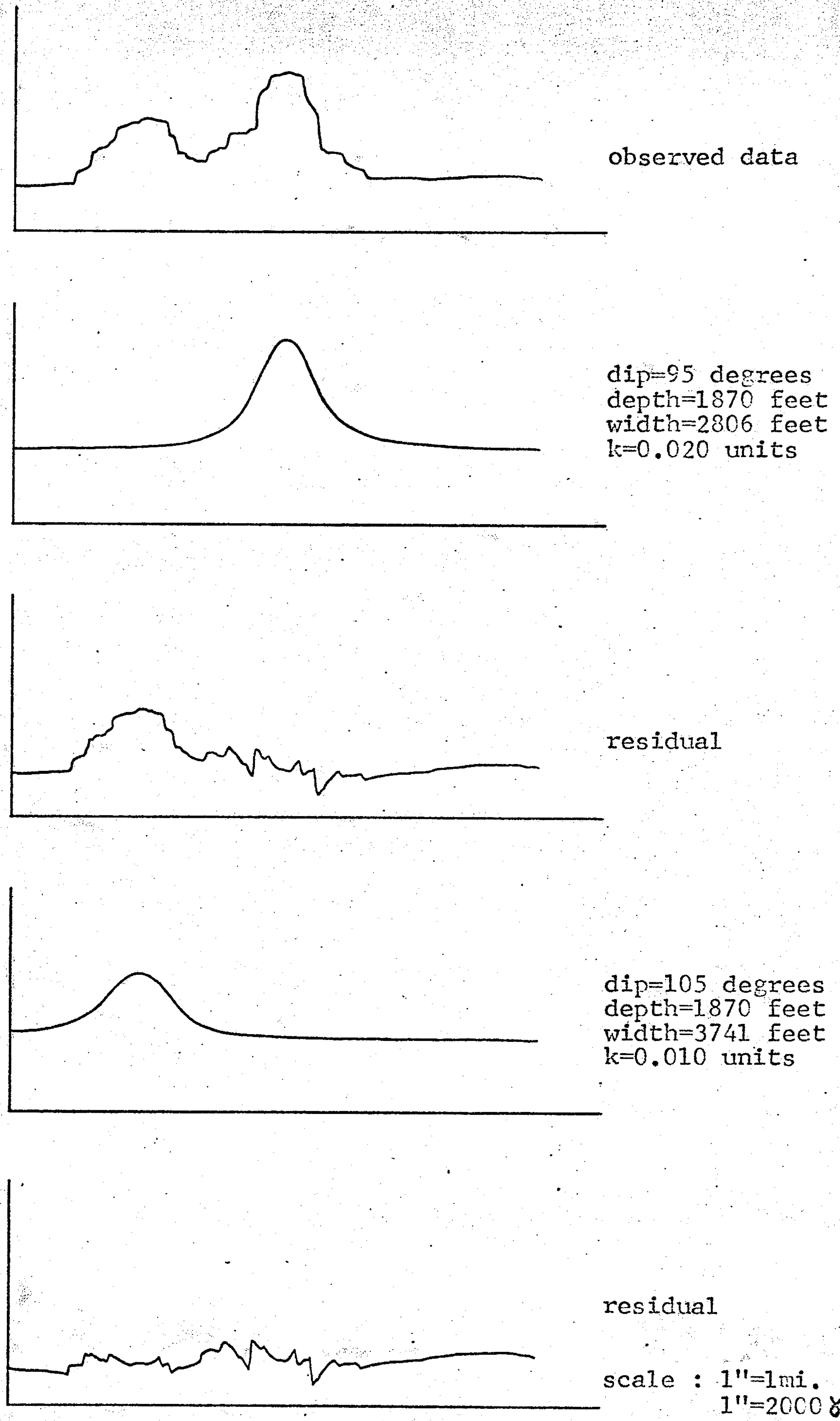

Figure 3-9 Interpretation of airborne survey data.

CHAPTER 4

COMPILATION OF RESULTS

4.1 Theoretical Data

The results of interpretations made on 30 theoretical dike curves are listed in Table 3. The results of the 21 single anomalies are generally good, the errors being about 10% or less. There are some cases with larger errors, for example: T13 in which a thick dike was chosen instead of a thin one, or T5, in which a thin dike was picked for a thick one. These errors, though appearing large, are really not serious because the difference between the curve for a thin dike and the curve for a dike having a small depth to width ratio is very small and it is not likely that a person doing an interpretation manually would be able to get better accuracy.

The interpretations of the remaining 9 cases, involving two adjacent dikes, are generally not good though some, eg. T30, are fairly close. This is due to the fact that the dikes were too close together to be separated, in none of these cases did the field value drop to 1/4 of the maximum between the peaks as was discovered to be necessary in section 3.21.

TABLE 3

INTERPRETATIONS OF THEORETICAL DIKE CURVES

EXAMPLE	INPUT				OUTPUT-NO WT. FCN.				OUTPUT-WT. FCN.				IMPROVED
	DIP	DEPTH	WIDTH	SUS.	DIP	DEPTH	WIDTH	SUS.	DIP	DEPTH	WIDTH	SUS.	BY WT. FCN.
T1	60	200	20	.005	75	236	24	.004	60	210	21	.005	*
T2	60	200	200	.010	75	248	124	.017	65	220	220	.010	*
T3	60	200	400	.015	65	260	260	.026	60	227	341	.019	*
T4	70	300	30	.010	75	315	32	.010	75	315	32	.010	
T5	70	300	300	.003	75	349	35	.028	75	349	35	.028	
T6	70	100	300	.009	85	140	280	.011	80	160	240	.014	
T7	80	100	10	.020	85	100	50	.004	80	100	10	.020	*
T8	80	100	200	.002	90	130	130	.003	80	98	195	.002	*
T9	80	100	400	.008	90	166	333	.012	90	119	416	.009	*
T10	90	400	40	.008	85	383	191	.002	90	383	38	.008	*
T11	90	400	400	.030	90	428	214	.057	90	380	570	.021	*
T12	90	400	400	.060	90	428	214	.114	90	380	570	.043	*
T13	100	200	20	.050	90	127	255	.003	90	149	223	.004	
T15	100	200	400	.007	90	150	450	.005	95	150	450	.005	

EXAMPLE	INPUT				OUTPUT-NO WT. FCN.				OUTPUT-WT. FCN.				IMPROVED
	DIP	DEPTH	WIDTH	SUS.	DIP	DEPTH	WIDTH	SUS.	DIP	DEPTH	WIDTH	SUS.	BY WT. FCN.
T16	110	300	30	.005	115	260	260	.001	110	293	29	.005	*
T17	110	300	100	.050	90	195	390	.010	95	195	390	.009	
T18	110	300	300	.010	90	175	525	.004	95	175	525	.004	
T19	120	200	400	.002	120	210	420	.002	120	210	420	.002	
T20	120	300	400	.003	115	338	338	.004	115	338	338	.004	
T21	120	400	400	.004	120	416	208	.008	120	370	555	.003	*
T22	60	200	200	.002					20	50	200	.001	
	60	200	400	.004	65	298	595	.003	65	340	510	.004	*
T23	75	200	200	.004	75	75	263	.001	80	75	300	.001	
	75	200	400	.002	130	400	800	.004	125	400	800	.003	
T24	80	200	20	.050	80	140	140	.004	80	60	180	.001	
	80	200	600	.002	130	450	900	.005	95	405	1215	.003	
T25	85	300	600	.009					85	110	275	.001	
	85	300	30	.010					85	390	390	.016	*
T26	90	400	400	.010	60	150	600	.003	55	150	600	.003	
	90	400	400	.010	135	600	900	.014	135	600	900	.014	
T27	95	300	30	.020					125	70	210	.0002	
	95	300	300	.004					100	350	525	.004	*

EXAMPLE	INPUT				OUTPUT-NO WT. FCN.				OUTPUT-WT. FCN.				IMPROVED
	DIP	DEPTH	WIDTH	SUS.	DIP	DEPTH	WIDTH	SUS.	DIP	DEPTH	WIDTH	SUS.	BY WT. FCN.
T28	100	300	150	.015					40	350	350	.012	*
	100	300	900	.003					165	195	780	.006	
T29	105	400	200	.015					55	400	400	.008	*
	105	400	800	.005	165	600	60	.285	150	600	600	.016	
T30	110	200	600	.003	90	156	547	.002	85	173	431	.002	
	110	200	100	.030	135	225	23	.196	140	250	25	.216	

4.2 Ground Survey Data

Five examples of ground survey data were digitized and processed with the program. The interpretations along with the mapped geology are given in Table 4.

It can be seen that in three cases the interpretation closely fits the observed geology, the poorer fits being #3 and #5. In case #3 the chosen dike was deeper and thinner than was mapped. This, however, is a common fault with aeromagnetic interpretation, because the curve for a shallow, wide body is very similar to that for a deep, narrow one.

Table 4

INTERPRETATIONS OF GROUND MAGNETIC SURVEY DATA

EXAMPLE	PROGRAM OUTPUT				GEOLOGY
	DIP	DEPTH	WIDTH	SUS.	
1	95	300	750	0.007	approx. vertical serpentinite body, 800' wide, 305' deep
2	110	300	300	0.008	steeply dipping serp. and diss. sulph. body. depth 300 ft. width 300 ft.
3	85	240	24	0.047	steep dip serp. and sulph. depth 120' width approx. 200'
4	70	90	90	0.100	thin trem. serp. body dip 70°, depth 100'
5	85	125	312	0.008	biotite gneiss with high sulph. content dip 85°, depth 65', width 200'

In case #5 the chosen model is deeper and wider than the drilling indicates. This probably means that the body is irregular in shape, and the dike model is not applicable.

It should be noted that the data used in these examples was collected with a vertical field instrument while the interpretation assumed total field. This will mean that the computed dip will be in error by $I_o' - 90^\circ$ and the susceptibility will be low by a factor of $\frac{\sin I_o}{\sin I_o'}$. In the high magnetic latitudes with which we are dealing, I_o will be in the order of 80° and I_o' will be about 82°. The errors, therefore, will be approximately 8° in dip and 1/2 of 1% in susceptibility.

4.3 Airborne Survey Data

Twenty-four examples of airborne data have been processed, the results are compiled in Table 5.

These appear to be reasonable interpretations when one looks at the anomalies on the aeromagnetic maps. As expected, narrow distinct anomalies such as Anderson Point turned out to be shallow bodies while broad low-amplitude features such as Arborg and Riverton were interpreted as large deep bodies. One obviously poor result is Playgreen Lake, where a depth of 728 feet was selected. This is probably caused by the first interpretation being too large,

TABLE 5

INTERPRETATION OF AIRBORNE MAGNETIC SURVEY DATA

EXAMPLE		DIP	DEPTH	WIDTH	SUS.	WK
2436G	Hunting Lake	90	1975	197	.247	48.66
		140	1247	2494	.014	
2586G	Nelson House	75	1247	125	.006	.75
		105	1870	3742	.001	
2592G	Hambone Lake	90	3014	301	.041	12.34
		75	2162	4324	.003	
		125	3087	4630	.003	
2467G	Clark Lake	140	1497	1497	.014	
		90	1351	2027	.003	
2581G	Muhigan Lake	95	1870	2806	.020	
		105	1870	3741	.010	
2582G	Pakwa Lake	75	1767	2650	.006	
		100	1455	5093	.003	
2444G	Crying Lake	95	1236	2437	.002	
		115	1351	2702	.002	
4072G	Manigotagan Lake	85	3087	6174	.002	
2601G	Thompson	80	1829	1829	.040	
4192G	Playgreen Lake	95	2182	4365	.003	
		95	728	1091	.0003	
2592G	Hambone Lake	150	2494	3742	.009	
		70	1351	135	.013	1.74
2482G	Kettle Lake	50	2598	260	.214	55.64
		150	1663	166	.229	38.01
2499G	Fifer Lake	130	1819	3638	.003	
2573G	Ponton	160	2993	299	.214	63.99
4084G	Garner Lake	95	2245	4490	.027	
4122G	Anderson Point	85	1143	114	.073	8.32

4144G	Arborg	95	4781	4781	.003
4120G	Riverton	90	2526	6314	.001
4098G	Shallow Lake	90	987	3456	.016
4099G	Minago Creek	130	1414	2827	.004
2578G	Wapisu Lake	95	1684	2526	.003
2444G	Crying Lake	95	1237	3092	.002
2586G	Nelson House	90	1330	1996	.001
2436G	Hunting Lake	90	1497	3742	.004

leaving the residual below the zero level. For this reason the second interpretation will yield a smaller, shallower body than really exists.

CHAPTER 5

CONCLUSIONS AND SUGGESTIONS

5.1 Summary of Results

From the previous chapter it can be seen that the interpretation of magnetic anomalies by computer methods can yield very satisfactory results. The 59 cases run have been categorized according to the degree with which they fit the known or expected structure.

Excellent interpretations	29
Satisfactory interpretations	18
Poor interpretations	12

The poor results appear to be due to the interference between two adjacent anomalies. It has been shown that the weighting function is a considerable aid to interpretation, but even this is not adequate to handle cases in which the anomaly curves intersect at a point above 1/4 of the peak value.

5.2 Suggestions for Improvements to, and Further Applications of, the Program 'Dikefit'

1) It was observed in section 4.3 that when multiple interpretations are made, the second or third may be erroneous due to the mean level of the profile being less than zero. This situation may be improved by adding a routine to subtract out a regional trend after each

interpretation, therefore assuring that the zero level is in a suitable position.

2) At the present time, the program is limited to interpreting magnetic anomalies in areas with a high angle of field inclination, that is, Canada and the northern United States. A different method of anomaly definition would be necessary to expand the program for use in lower magnetic latitudes.

3) Interpretation of magnetic anomalies is now done in two stages: 1) constructing the profile, and 2) finding the best theoretical model, with a visual inspection between the two steps. If this intermediate step is not desired, the two programs can be linked together as follows:

```
//MAGNETIC  JOB   '    ETC.   '
//STEP1 EXEC FORTGCLG,SIZE=165K
//FORT.SYSIN  DD *
     PROGRAM PROFILE
//GO.PLOTTAPE DD DSN=PLOT,DISP=SHR
//GO.FT02F001 DD UNIT=2314,DISP=(NEW.PASS),
               SPACE=(TRK,(5,1)),DCB=(RECFM=FB,
               LRECL=80,BLKSIZE=7280)
//GO.SYSIN DD *
     DATA
/*
//EXEC FORTGCLG,SIZE=92K
//FORT.SYSIN DD *
     PROGRAM DIKEFIT
```

```
//GO.PLOTTAPE DD DSN=PLOT,DISP=SHR
//GO.FT02F001 DD DSN=*.STEP1.GO.FT02F001,DISP=(OLD,PASS)
//GO.SYSIN DD *
    DATA
/*
```

With this arrangement, the first program does not produce punched output, but instead writes on a disc. The second program then reads from disc instead of from cards. To use this system, two small changes must be made in the program:

1) The cards D1K144 and D1K151 must be changed to read from unit 2 instead of unit 5.

2) An extra 15K of core space must be allocated on each GO step to allow for the buffer space necessary for reading and writing on disc.

4) Some preliminary work has been done on the possibility of using this dike-model program for the purpose of interpreting magnetic anomalies over finite prismatic bodies, and the results are encouraging. Two examples from Vaquier et al. (1963) have been tried with results as follows:

		Input	Output
1200 x 400 prism	dip	90	90
	depth	200	174
	width	400	434
	susceptibility	0.003	0.0024

800 x 1200 prism	dip	90	90
	depth	200	313
	width	1200	1097
	susceptibility	0.003	0.0029

This seems to indicate that the end effects are not serious with even a short strike length. Further tests must be made to determine the exact limitations of the program's usefulness in cases with limited strike extent.

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APPENDIX 1

DIGITIZING PROCEDURE

REF. NO. GEO-0001

TECHNIQUE FOR TAKING MAGNETIC VALUES FROM CONTOURED AEROMAGNETIC MAPS USING LONGITUDES, LATITUDES AND INTERSECTION OF FLIGHT LINES

by J. S. ANDREWS

1968

Department of Geology
University of Manitoba

INTRODUCTION:

The following report shall endeavor to explain the process of taking data from contoured aeromagnetic maps and recording this data in a prescribed, organized manner. The data is usually written onto "80-column Data Sheets" and these sheets are given to a key-puncher who puts the information on cards.

The maps with which we are working on this project are the Aeromagnetic Series published and distributed by the Geological Survey of Canada. The magnetic data on the maps was compiled from information recorded along the flight lines flown at an altitude of 1,000 feet above ground level.

Each map has a scale of 1" = 1 mile, and covers a distance laterally of $0^{\circ}30'$ of longitude, and vertically of $0^{\circ}15'$ of latitude.

The map itself is contoured in such a manner that the value of each line can be determined. Figure 1 shows a typical series of contour lines, and Table 2 identifies them.

TABLE 1

1	2530	6	2660
2	2540	7	2490
3	3000	8	2700
4	2580	9	2560
5	2520	10	2540

Table 1. Shows some contours with their values. These values are taken from Fig. 1.

TABLE 2

500 gammas	....
100 gammas	....
20 gammas	....
10 gammas	....
Magnetic depression	......

Magnetic Depression: This is identified by a contoured line with small shaded triangles on one side of it. This suggests that as you go in the direction of points of triangles, the magnetic values along the contours decrease. As you go away from the points, the values increase. Referring to Fig. 1, every line has a definite value and one must become proficient in recognizing the value of each contour with the least amount of time and the greatest amount of accuracy.

SETTING UP MAP DATA CARDS (DIGITIZATION)

In order to take the values of magnetic anomalies from a map, it is necessary to follow certain steps in the correct order.

For each map, a card must be punched to identify the map number and the name of the map. For an example, we will use Map 2467G CLARK LAKE. The first card of each deck (i.e., each deck represents one complete map) must be a colored card, usually blue. This is needed in order to identify the beginning of each deck.

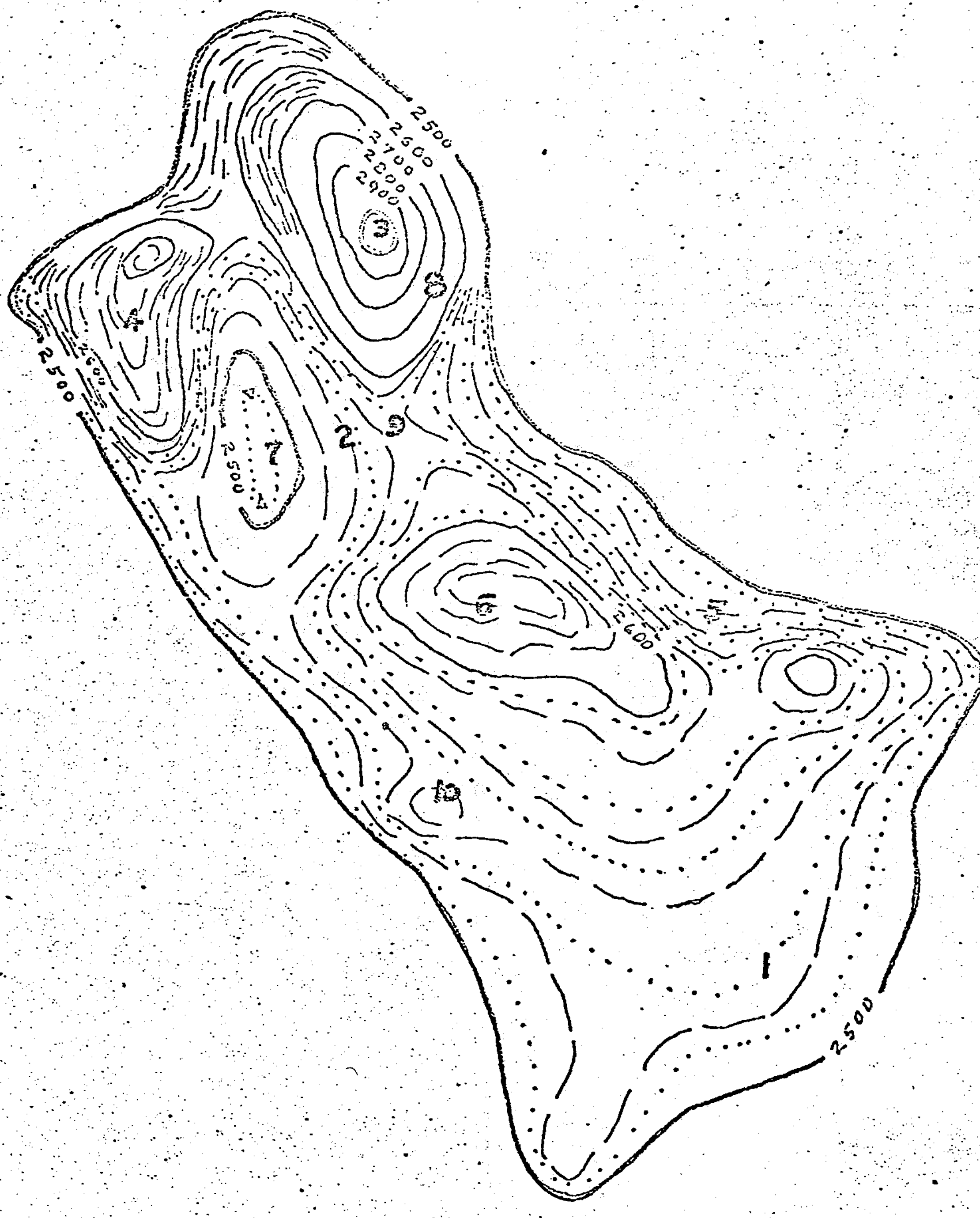

2500
2600
2700
2800
2900
3
8
4
2500
2600
7
2500
2
9
6
2600
5
10
1
2500

FIGURE 1

MAP NO. 2467G CLARK LAKE

BLUE CARD

The second card of the deck defines the parameters of each map, i.e., the corners of each map must be defined in terms of longitudes and latitudes. This is shown for the following example; Map 2467G.

Start at the bottom right-hand corner going towards increasing longitude and latitude coordinates. First, the longitude coordinates are marked off in degrees, and then in minutes, as shown. The leading zeros are not necessary but the values must be aligned in the correct columns.

0095	0030	0096°	0000	0056	0015	0056°	0030
longitude coordinate				latitude			

Also on the same card is punched a value of 0060. The 60,000 is subtracted from the data in order to simplify it since it is common to all the data taken. Thus it reduces the number of figures to be written. Also on the same card the horizontal and vertical measurements in that order must be defined in cm. The length is taken from the bottom of the map since the maps are in the form of a trapezoid.

The second card should appear as shown below:

```
0095 0030 0096 0000 0056 0015 0056 0030 0060 0486 0434      1
|_________A_________| |________B________| |_C_| |__D__|     E
```

A - represents the longitude parameters of the map, first in degrees, then in minutes of the first corner, then longitude parameter of the other corner.

B - represents the latitude parameters of the map, first in degrees, then in minutes.

C - 0060 represents the number which is common to all the data. This is 60,000 gammas.

D - The first number represents the length of the map measured at the bottom. The second number represents the vertical distance of the map.

E - The character "1" is placed in column 73 of the computer card. This number "one" is a control device which indicates to the computer that these are the values of the parameter of the map.

CARD FORMAT:

The above numbers are first printed on coding sheets, then punched on IBM cards. Each number is placed, right justified, in a FIELD. A FIELD must consist of numbers and may have leading zero's. The fields for the above numbers are 1-4, 6-9, 11-14, 16-19, 21-24, 26-29, 31-34, 36-39, 41-44, 46-49, 51-54, 56-59 61-64, 66-69.

Flight lines:

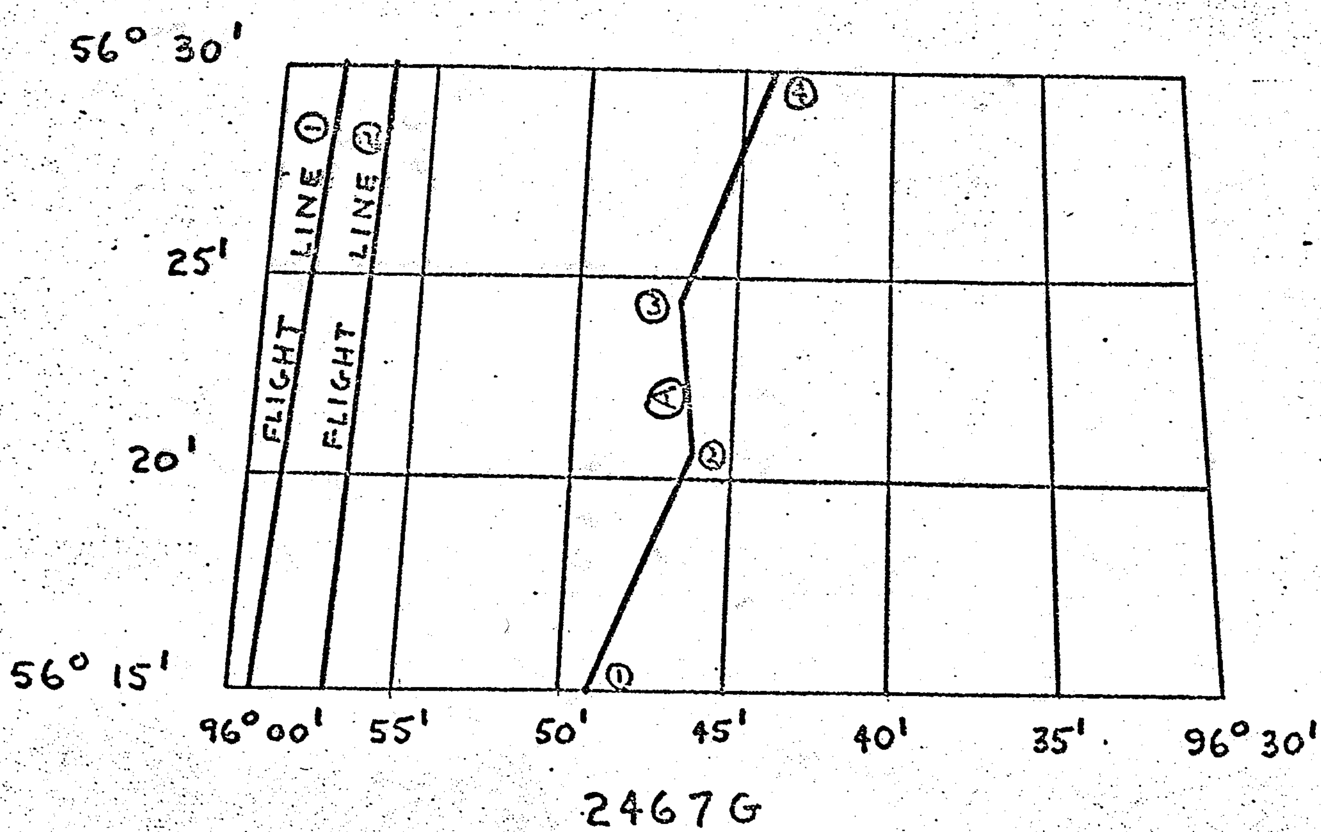
The values of the magnetic anomalies are read at the intersection of the flight lines with the contour line. The flight lines on the map indicate the route the pilot has taken when recording the data. The values at the intersection of the flight lines are therefore an accurate measure of the magnetic anomalies. The rest of the contour lines are an approximation since they have been drawn by hand.

The purpose of the digitization of the map is basically: given the magnetic anomaly values at these intersections, the computer can then use this information to perform mathematical operations on the map (i.e., filtering, smoothing, etc.). In order for the computer to do this, it requires the longitude and latitude coordinates of each intersection of the flight line with the contour. Since this is time consuming (as was found out this summer) and difficult, an easier approach was devised to overcome this difficulty. The computer computes the longitude and latitude value at the intersections from information given by the input cards. In this simplified method, we define only the coordinates of each flight line and distance from the bottom of the coordinates to the point of intersection.

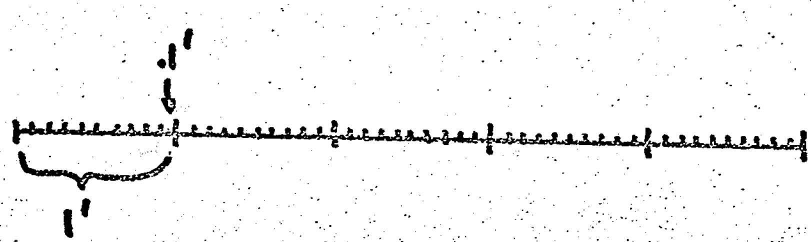
DETAIL PROCEDURE USING FLIGHT LINES

The first thing that must be done with each new map is to divide it into 5' x 5' rectangles. This is easily accomplished since there are marks on the map in 5' intervals. Flight lines, which are defined in minutes, are found by measuring the distance from the nearest 5' mark.

FIGURE 3



For this reason a small linear scale can be made to measure the longitude co-ordinates of flight lines.



On the map we see that it is marked off in 5' intervals by measuring the distance between the 5' intervals, divide in 5 equal parts each 1', then divided into 10 equal parts. Thus, the co-ordinates can be read to 4 place figures. For the top of the map a new scale must be made since the 5' are smaller distances apart as is shown by the exaggerated map drawn.
Also, a vertical scale is necessary for flight lines that are not straight (this will be discussed later). However, all maps have the same height so only one scale is required for all maps.

Flight line

When the flight line is approximately a straight line from the bottom to the top, then two co-ordinates are sufficient to define the flight line.

In determining whether a flight line is straight, the criterion is that it must not deviate more than 0040' from a straight line drawn from bottom to top.

Also, in defining a straight flight line, the distance along the flight line must be defined.

For example: see Map 2467 CLARK LAKE

Flight line (1) is approximately a straight line; therefore, the co-ordinates from bottom to top of the map will be sufficient.

5940 1500	5910 3000	0434
Bottom co-ordinate	Top co-ordinate	Distance along FL

Flight lines which deviate more than 0040' must be broken up into segments and treated separately as shown in Fig. 3, Flight line A,

4850 1500	4650 2080	160	4700 2470	114	4400 3000	150
Point 1	Point 2	B	Point 3	B	Point 4	B

B = represents distance from one co-ordinate to the next co-ordinate. This is measured in mm.

CARD FORMAT:

is the same as mentioned previously, only a 1 (one) is put in column 72 and the flight line identification is put in column 74-80.

The computer card for defining flight lines is as follows:

```
                                                              FLIGHT LINE I.D.
                                                                    ↓
4850 1500 4650 2080 0160 4700 2470 0114 4400 3000 160   1 X X X X
```

The character is punched in column 72 in order for the computer to distinguish flight line parameters from the rest of the data. Also (F NO. FLIGHT) is before the flight line.

READING DATA AND RECORDING:

A ruler is placed from one co-ordinate to the next co-ordinate and held by tape or by hand. At each intersection of the flight line with the contour, the magnetic anomaly value is recorded and also the distance from the co-ordinate to the intersection. The magnetic values are read going upwards on the map.

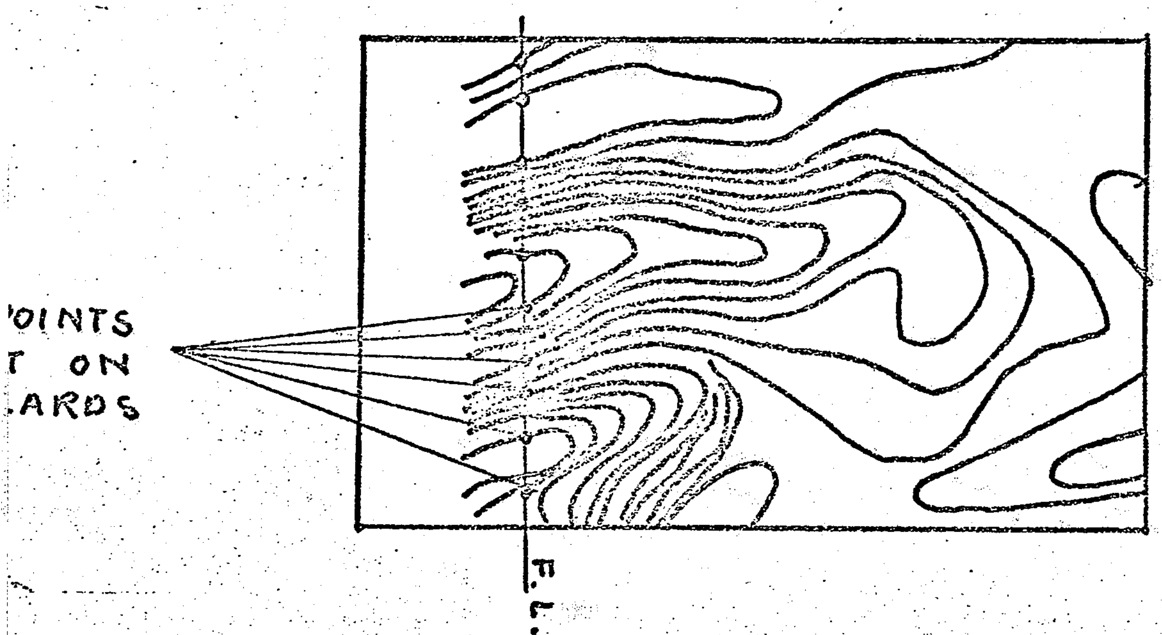
CARD FORMAT:

Same as before but with a card sequence number in columns 74-80.

If the contours become too dense, then every 50 gammas or 100 gamma intervals can be taken.

For example, see Map 2467G CLARK LAKE.

On flight line around 56°25' latitude and 9600° longitude, we notice that the contours are very closely spaced. Therefore, we could use intervals of 100 gammas.



Sometimes it is necessary to use intervals of 500 gammas but this will occur when the contour interval is very large.

TRANSFER OF DATA TO COMPUTER SHEETS

An example has been done with map 2467 CLARK LAKE which shows clearly how the data is set up (see next page - page 11). At the end of the deck of data, two cards with one card having the character "1" in column 72 and the other card with the number "2" in column 73, is necessary for each deck.

80 COLUMN DATA SHEET

PROGRAM

BY

DATE

MAP NO 24676 CLARK LAKE

0095	0.030	0.096	0.000	0.056	0.015	0.056	0.030	0.060	486	434	(1)

5940	1500	5910	3000	434	1 F 1

VALUE DIST

2120	10	2120	34	2140	46	2160	59	2180	79	2200	88	2220	98	1
2240	105	2260	125	2280	136	2320	149	2400	151	2400	159	2360	163	2
2300	165	2300	170	2320	187	2340	193	2340	207	2340	218	2400	229	3
2440	232	2440	237	2400	243	2400	252	2400	262	2460	261	2460	272	4
2440	274	2400	286	2400	292	2500	297	2700	300	3000	303	3100	305	5
3300	309	3340	311	3300	313	3000	319	2700	322	2500	325	2440	328	6
2440	334	2500	341	2520	345	2520	358	2520	369	2580	377	2600	380	7
2600	396	2580	400	2560	407	2540	412	2520	427	2500	432			8

END OF DECK

SUMMARY

In taking data, the following steps should be taken:

(1) Define the map "no." and name of map - on a coloured card.

.... Card 1.

(2) Define parameters of the map, i.e., longitude, latitude, the common value 0060, dimensions of map
Also: a "1" is placed in column 73.

.... Card 2.

(3) Construct the grid for the map and also a smaller scale marked out in divisions of 1' (this is to help define flight lines accurately).

(4) Start at the left-hand corner of map. Define the flight line. If it deviates, break it up into segments. Place a number "1" at column 72 for each flight line card, also number the flight line in column 74-80 on the computer card.

(5) Place the ruler joining the co-ordinates of the flight line.

(6) At each intersection, record the magnetic value and also distance.

(7) Once completed one flight line, start on the next one.

(8) Once completed the data, punch 1, 2 separately on different data cards and place at the end of the data.

(9) Check the data as outlined by "checking aeromagnetic DATA", GEO-0007.

(10) Your job is done for one map.

APPENDIX 2

PROGRAM PROFILE

Fortran IV Program

University of Manitoba

Department of Earth Sciences

Geophysics Division

A. Identification

Title: Profile

Category: Data sorting

Programmer: K. Standing

Date: May 1970

B. Purpose

This program sorts out data along a designated profile across a digitized aeromagnetic map. It computes the regional trend and subtracts it out to leave a residual field with data points at one millimeter intervals. It then punches the output on cards and draws the profile on the CALCOMP 763 plotter.

C. Usage

1. This is a Fortran IV program.

2. Parameters: (These are placed on one card, format (3F10.2,2I5), which follows the digitized map deck.)

XSTART - the horizontal coordinate of the point at which the profile is to start. This is given in millimeters, measured from the east side of the map.

YSTART - the vertical coordinate of the point at which the profile is to start. This is given in millimeters, measured from the south side of the map.

ANGLE - The angle at which the profile is required. Measured clockwise from north.

LEN - The desired length of the profile in millimeters.

NDEG - The degree (1,2,3) of the polynomial to be used for the regional trend.

NOTE: A straight line is the best choice for the regional trend, higher order polynomials may produce erroneous data.

3. <u>Printout</u>: The X and Y coordinates, the distance from the starting coordinates, and the value of field for each point are listed.

4. <u>Core required</u>: 146 K-bytes.

5. <u>Timing</u>: Compilation 7.5 seconds
   Execution 14 seconds per map

6. Tape mounting: A tape is required for the CALCOMP plotter.

D. <u>Method</u> - described in Chapter 1.

```
C
C     PROGRAM TO EXTRACT REQUIRED DATA FROM AEROMAGNETIC MAP AND SUBTRACT
C     OUT THE REGIONAL FIELD
C
      DIMENSION IBUF(1000),NAME(20),G(600),D(600),XE(4),YE(4),DIST(4),
     1X(7000),Y(7000),F(7000),P(600),Q(600),W(50),H(50),FF(600),A(6)
      COMMON /PLTR/NAME,XSTART,YSTART,ANGLE
      REAL MLS,MLE,MLAS,MLAF
      CALL PLOTS(IBUF,1000)
C
C     READ MAP DATA ONE FLIGHT LINE AT A TIME. COMPUTE X AND Y COORDINATES
C     OF EACH DATA POINT. STORE DATA IN THREE ARRAYS X Y F
C     X AND Y ARE MEASURED IN MILLIMETERS WITH THE ORIGIN AT THE SOUTH EAS
C     CORNER OF THE MAP SHEET
C
   10 FORMAT(20A4)
   11 READ(5,10,END=999)(NAME(I),I=1,20)
      NT=0
   20 FORMAT(11(F4.0,1X),16X,2I1)
      READ(5,20)DLS,MLS,DLE,MLE,DLAS,MLAS,DLAE,MLAE,CONST,XMAX,YMAX,JJ,
     1KK
      IF(MLE.EQ.0.)MLE=60.00
      IF(MLAE.EQ.0.)MLAE=60.00
   30 FORMAT(14(F4.0,1X),1X,2I1)
   31 L=1
      M=7
   32 READ(5,30)(G(I),D(I),I=L,M),JJ,KK
      IF(JJ.EQ.1)GO TO 45
      IF(KK.EQ.2)GO TO 70
      L=M+1
      M=L+6
      GO TO 32
   45 IF(M.NE.7)GO TO 55
   50 XS=G(L)
      YS=D(L)
      XE(1)=G(L+1)
      YE(1)=D(L+1)
      DIST(1)=G(L+2)
      XE(2)=D(L+2)
      YE(2)=G(L+3)
      DIST(2)=D(L+3)
      XE(3)=G(L+4)
      YE(3)=D(L+4)
      DIST(3)=G(L+5)
      XE(4)=D(L+5)
      YE(4)=G(L+6)
      DIST(4)=D(L+6)
      IF(YS.EQ.0..AND.MLAE.EQ.60.)YS=6000.
      IF(XS.EQ.0..AND.MLE.EQ.60.)XS=6000.
      GO TO 31
   55 M=M-7
   56 IF(D(M).NE.0.)GO TO 57
      M=M-1
      GO TO 56
```

```
 57 XS=(((XS/100.)-MLS)/30.)*XMAX
    YS=(((YS/100.)-MLAS)/15.)*YMAX
    DO 60 J=1,4
    XE(J)=(((XE(J)/100.)-MLS)/30.)*XMAX
 60 YE(J)=(((YE(J)/100.)-MLAS)/15.)*YMAX
    N=NT+1
    J=1
    NT=N+M-1
    DO 65 I=N,NT
    IF(I.EQ.N)GO TO 63
    IF(D(I-N+1).LT.D(I-N))GO TO 68
 63 R=D(I-N+1)/DIST(J)
    X(I)=XS+R*(XE(J)-XS)
    Y(I)=YS+R*(YE(J)-YS)
    F(I)=G(I-N+1)
    GO TO 65
 68 XS=XE(J)
    YS=YE(J)
    J=J+1
    GO TO 63
 65 CONTINUE
    GO TO 50
C
C     READ DATA FOR REQUIRED PROFILE. COORDINATES AND LENGTH ARE GIVEN IN
C     MILLIMETERS . ANGLE IS MEASURED CLOCKWISE FROM NORTH. NDEG IS THE
C     ORDER OF THE POLYNOMIAL TO BE USED FOR THE REGIONAL TREND
C
 70 READ(5,80)XSTART,YSTART,ANGLE,LEN,NDEG
 80 FORMAT(3F10.2,2I5)
    ANGLE=ANGLE*3.14159/180.
C   COMPUTE COORDINATES OF POINTS ON THE LINE
    L=LEN+1
    DO 100 I=1,L
    M=0
    V=6.
    P(I)=XSTART-(I*SIN(ANGLE))
    Q(I)=YSTART+(I*COS(ANGLE))
 85 V=V+3
C
C     COMPUTE VALUE OF FIELD AT EACH POINT ON THE PROFILE BY AVERAGING
C     ALL DATA POINTS WITHIN A SMALL SQUARE. VALUES ARE WEIGHTED BY THE
C     INVERSE OF THEIR DISTANCE FROM THE CENTER OF THE SQUARE
C
    DO 90 J=1,NT
    IF(ABS(X(J)-P(I)).GT.V)GO TO 90
    IF(ABS(Y(J)-Q(I)).GT.V)GO TO 90
    M=M+1
    G(M)=X(J)
    D(M)=Y(J)
    H(M)=F(J)
 90 CONTINUE
    IF(M.EQ.0)GO TO 85
    FSUM=0.
    WSUM=0.
```

```
      DO 95 J=1,M
      W(J)=SQRT((P(I)-G(J))**2+(Q(I)-D(J))**2)
      IF(ABS(W(J)-1))93,96,93
   93 W(J)=1./W(J)
      FSUM=FSUM+W(J)*H(J)
      WSUM=WSUM+W(J)
   95 CONTINUE
      FF(I)=FSUM/WSUM
      GO TO 100
   96 FF(I)=H(J)
  100 CONTINUE
C
C     COMPUTE RESIDUAL FIELD
C
      D(1)=1.
      DO 110 I=2,L
  110 D(I)=D(I-1)+1
      CALL RESID(NDEG,L,D,FF)
      ANGLE=ANGLE*180./3.14159
C
C     PRINT OUTPUT
C
  145 FORMAT('1')
  150 FORMAT(20X,20A4)
      WRITE(6,150)(NAME(I),I=1,20)
  160 FORMAT(//10X,'STARTING CO-ORDINATES',2F10.2//10X,'HEADING',F10.2//
     110X,'LENGTH',I5//20X,'PROFILE'//)
      WRITE(6,160)XSTART,YSTART,ANGLE,LEN
  170 FORMAT(16X,'X',9X,'Y',5X,'DISTANCE',5X,'RESIDUAL'//)
      WRITE(6,170)
  180 FORMAT(10X,4F10.2)
      WRITE(6,180)(P(I),Q(I),D(I),FF(I),I=1,L)
      WRITE(6,145)
C
C     PUNCH OUTPUT
C
      WRITE(2,10)(NAME(I),I=1,20)
  190 FORMAT('STARTING CO-ORDINATES',2F6.2)
      WRITE(2,190)XSTART,YSTART
  195 FORMAT('HEADING',F6.2,'DEGREES',5X,'LENGTH',I5)
      WRITE(2,195)ANGLE,LEN
  200 FORMAT('THE REGIONAL TREND HAS BEEN APPROXIMATED BY A POLY. OF ORD
     1ER',I5)
      WRITE(2,200)NDEG
  205 FORMAT(10F8.2)
      WRITE(2,205)(D(I),FF(I),I=1,L)
      D(L+1)=99999.99
      FF(L+1)=99999.99
      WRITE(2,205)D(L+1),FF(L+1)
C
C     PLOT OUTPUT
C
      CALL PLOTER(D,FF,L)
      GO TO 11
```

```
999 CALL PLOT(0.,0.,999)
    CALL EXIT
    END
```

```
      SUBROUTINE PLOTER(X,Y,N)
      COMMON /PLTR/NAME,XSTART,YSTART,ANGLE
      DIMENSION NAME(20),X(N),Y(N)
C
C     POSITION PEN
C
      CALL PLOT(0.,-11.,-3)
      CALL PLOT(0.,3.,-3)
C
C     SCALE DATA
C
      DO 10 I=1,N
      X(I)=X(I)/25.4
      Y(I)=Y(I)/100.
   10 CONTINUE
C
C     CHOOSE AXIS LENGTH
C
      IF(X(N)-8.)20,20,15
   15 IF(X(N)-16.)30,30,40
   20 V=8.
      GO TO 50
   30 V=16.
      GO TO 50
   40 V=24.
   50 CALL AXIS(0.,0.,NAME,-50,V,0.,0.,25.4)
      CALL AXIS(0.,0.,' ',1,6.,90.,-300.,100.)
C
C     DRAW GRID
C
      A=0.
      CALL PLOT(0.,0.,3)
      CALL PLOT(0.,6.,2)
      CALL PLOT(V,6.,2)
      CALL PLOT(V,0.,2)
   60 A=A+1.
      CALL PLOT(V,A,2)
      CALL PLOT(0.,A,2)
      A=A+1.
      CALL PLOT(0.,A,2)
      CALL PLOT(V,A,2)
      IF(A.GE.5)GO TO 70
      GO TO 60
   70 CALL PLOT(0.,3.,-3)
C
C     PLOT DATA
C
      YFIRST=Y(1)
      DO 75 I=1,N
   75 Y(I)=Y(I)-YFIRST
      DO 100 I=1,N
   79 IF(Y(I).GT.3.)GO TO 80
      IF(Y(I).LT.-3.)GO TO 90
      CALL PLOT(X(I),Y(I),2)
```

```
      GO TO 100
   80 CALL PLOT(X(I),-3.,2)
      DO 85 J=I,N
   85 Y(J)=Y(J)-6.
      GO TO 79
   90 CALL PLOT(X(I),3.,2)
      DO 95 J=I,N
   95 Y(J)=Y(J)+6.
      GO TO 79
  100 CONTINUE
      YFIRST=YFIRST*100.
C
C     WRITE HEADINGS
C
      V=V/2.-2.
      CALL SYMBOL(V,-4.,0.14,'STARTING CO-ORDINATES  X=',0.,25)
      Z=V+3.5
      CALL NUMBER(Z,-4.,0.14,XSTART,0.,-1)
      Z=Z+0.5
      CALL SYMBOL(Z,-4.,0.14,' Y= ',0.,4)
      Z=Z+0.7
      CALL NUMBER(Z,-4.,0.14,YSTART,0.,-1)
      CALL SYMBOL(V,-4.3,0.14,'AZIMUTH',0.,7)
      Z=V+1.1
      CALL NUMBER(Z,-4.3,0.14,ANGLE,0.,-1)
      Z=Z+0.5
      CALL SYMBOL(Z,-4.3,0.14,'DEGREES',0.,7)
      CALL SYMBOL(V,-4.6,0.14,'INITIAL VALUE OF FIELD',0.,22)
      Z=V+3.5
      CALL NUMBER(Z,-4.6,0.14,YFIRST,0.,-1)
      Z=Z+0.5
      CALL SYMBOL(Z,-4.6,0.14,'GAMMAS',0.,6)
      V=(V+4.)*2.
      CALL PLOT(V,0.,-3)
      RETURN
      END
```

```
      SUBROUTINE RESID(K,L,LENGTH,GAMMA)
C
C     SUBROUTINE TO SUBTRACT OUT A REGIONAL TREND BY LEAST SQUARES
C
      DIMENSION GAMMA(L),LENGTH(L)
      REAL LENGTH
      SUMX=0.
      SUMX2=0
      SUMX3=0
      SUMX4=0
      SUMX5=0
      SUMX6=0
      SUMY=0
      SUMXY=0
      SUMYX=0
      SUMYX2=0
      SUMYX3=0
      GO TO (100,200,300),K
C
C     USING A STRAIGHT LINE FOR REGIONAL
C
  100 DO 110 I=1,L
      SUMX=SUMX+LENGTH(I)
      SUMX2=SUMX2+(LENGTH(I)*LENGTH(I))
      SUMY=SUMY+GAMMA(I)
      SUMXY=SUMXY+(GAMMA(I)*LENGTH(I))
  110 CONTINUE
      SLOPE=((SUMY*SUMX)-(L*SUMXY))/((SUM*SUMX)-(L*SUMX2))
      B=(SUMXY-SLOPE*SUMX2)/SUMX
      DO 120 I=1,L
  120 GAMMA(I)=GAMMA(I)-((SLOPE*LENGTH(I))+B)
      RETURN
C
C     USING A QUADRATIC CURVE FOR THE REGIONAL
C
  200 DO 210 I=1,L
      SUMX=SUMX+LENGTH(I)
      SUMX2=SUMX2+(LENGTH(I)**2)
      SUMX3=SUMX3+(LENGTH(I)**3)
      SUMX4=SUMX4+(LENGTH(I)**4)
      SUMY=SUMY+GAMMA(I)
      SUMXY=SUMXY+(LENGTH(I)*GAMMA(I))
  210 SUMYX2=SUMYX2+(GAMMA(I)*(LENGTH(I)**2))
      TERM1=(L*L*SUMYX2*SUMX3)-(L*SUMYX2*SUMX2*SUMX)-(L*SUMXY*SUMX4)-(S
     1UMY*SUMX*SUMX4)-(L*SUMX2*SUMY*SUMX3)+(2.*(SUMX2**2)*SUMX*SUMY)+(L
     2*SUMXY*(SUMX2**2))
      TERM2=((SUMX**2)*SUMX4)-(L*SUMX2*SUMX4)+(L*SUMX3)**2+(L*(SUMX2**3)
     1)-(2.*L*SUMX*SUMX2*SUMX3)
      B=TERM1/TERM2
      TERM3=(L*SUMXY)-(B*L*SUMX2)+(B*(SUMX**2))+(SUMY*SUMX)
      TERM4=(L*SUMX3)-(SUMX2*SUMX)
      A=TERM3/TERM4
      C=(SUMY-(A*SUMX2)-(B*SUMX))/L
      DO 220 I=1,L
```

```
  220 GAMMA(I)=GAMMA(I)-((A*(LENGTH(I)**2))+(B*LENGTH(I))+C)
      RETURN
C
C...  USING A CUBIC CURVE FOR THE RESIDUAL
C
  300 DO 310 I=1,L
      SUMX=SUMX+LENGTH(I)
      SUMX2=SUMX2+(LENGTH(I)**2)
      SUMX3=SUMX3+(LENGTH(I)**3)
      SUMX4=SUMX4+(LENGTH(I)**4)
      SUMX5=SUMX5+(LENGTH(I)**5)
      SUMX6=SUMX6+(LENGTH(I)**6)
      SUMY=SUMY+GAMMA(I)
      SUMYX=SUMYX+(LENGTH(I)*GAMMA(I))
      SUMYX2=SUMYX2+(GAMMA(I)*(LENGTH(I)**2))
  310 SUMYX3=SUMYX3+(GAMMA(I)*(LENGTH(I)**3))
      T1=((SUMX3*SUMX6)-(SUMX5*SUMX4))/((SUMX4*SUMX6)-(SUMX5*SUMX5))
      T2=((SUMX2*SUMX6)-(SUMX3*SUMX5))/((SUMX4*SUMX6)-(SUMX5*SUMX5))
      T3=T1*((SUMX4*SUMX5)-(SUMX3*SUMX6))+(SUMX2*SUMX6)-(SUMX4*SUMX4)
      T4=T1*((SUMX3*SUMX5)-(SUMX2*SUMX6))+(SUMX*SUMX6)-(SUMX4*SUMX3)
      T5=(SUMYX*SUMX6)-(SUMX4*SUMYX3)-(T1*((SUMYX2*SUMX6)-(SUMX5*SUMYX3
     1)))
      T6=T2*((SUMX4*SUMX5)-(SUMX3*SUMX6))+(SUMX*SUMX6)-(SUMX4*SUMX3)
      T7=T2*((SUMX3*SUMX5)-(SUMX2*SUMX6))+L*SUMX6-(SUMX3*SUMX3)
      T8=(SUMY*SUMX6)-(SUMX3*SUMYX3)- T2*((SUMYX2*SUMX6)-(SUMX5*SUMYX3))
      D=((T8*T3)-(T6*T5))/((T7*T3)-(T4*T6))
      C=(T5-(D*T4))/T3
      B=((SUMYX2*SUMX6)-(SUMX5*SUMYX3)+C*((SUMX4*SUMX5)-(SUMX3*SUMX6))+
     1D*((SUMX3*SUMX5)-(SUMX2*SUMX6)))/((SUMX4*SUMX6)-(SUMX5*SUMX5))
      A=(SUMYX3-(B*SUMX5)-(C*SUMX4)-(D*SUMX3))/SUMX6
      DO 320 I=1,L
  320 GAMMA(I)=GAMMA(I)-((A*(LENGTH(I)**3))+(B*LENGTH(I)*LENGTH(I))+(C*
     1LENGTH(I))+D)
      RETURN
      END
```

APPENDIX 3

PROGRAM 'DIKEFIT'

Fortran IV Program

University of Manitoba

Department of Earth Sciences

Geophysics Division

A. Identification

Title:	Dikefit
Category:	Interpretation of magnetic field data
Programmer:	K. Standing
Date:	July 1970

B. Purpose

This program interprets magnetic field data by finding the theoretical dike-like body which causes a magnetic anomaly most like the observed field.

C. Usage

1. This is a Fortran IV program.
2. Parameters: refer to list of variables used.
3. Printout: As well as repeating the input parameters the program gives the dip, depth, width, and susceptibility of the best fitting dike. The quality of fit of the theoretical to the observed curve is also given. (A perfect fit = 0).

4. Plotting: A plot is made on the CALCOMP 763 plotter of the original profile, the best model curve, and the residual.

5. Core required:

	Compilation	104K bytes
	Execution	76K bytes

6. Timing:

	Compilation	11 seconds.
	Execution	5-15 seconds per feature analyzed.

This depends on the number of points on the profile and the number of iterations required in computing the parameters of the dike.

7. Tape Mounting: A tape is required for the CALCOMP 763 plotter.

D. Method - described in section 3.21.

```
C
C*****************************************************************************
C
C                       P R O G R A M   D I K E F I T
C
C
C        PROGRAM 'DIKEFIT' INTERPRETS MAGNETIC FIELD DATA BY FINDING THE
C       THICK OR THIN DIKE CURVE WHICH BEST FITS AN OBSERVED PROFILE
C         THE PROCEDURE FOLLOWED IS SIMILAR TO THAT DESCRIBED BY S. PARKER
C       GAY JR. (GEOPHYSICS ,VCL. 28, NO. 2, P. 161-200, 1963)
C
C       PROGRAMMER   K.F. STANDING
C
C        DATE  AUGUST 1970
C
C*****************************************************************************
C
C
C       RESTRICTIONS
C
C
C                   1) A PROFILE MAY NOT CONTAIN MORE THAN 600 POINTS
C                   2) ONLY THE THREE MOST PROMINENT FEATURES CAN BE
C                      ANALYSED IN ONE RUN
C                   3) THE DATA MUST BE REGULARLY SPACED (IF RANDOMLY
C                      SPACED DATA IS TO BE USED,A SUBROUTINE 'SPACER'
C                      IS AVAILABLE WHICH CCNVERTS RANDOM DATA INTO
C                      REGULAR DATA)
C
C*****************************************************************************
C
C       INPUT DATA
C
C
C         THE FIRST CARD ( FCRMAT(9F8.2,I3)) IS USED TO ENTER ALL THE
C       REQUIRED PARAMETERS   A,T,S,D,SP,FACT,HM,AND NPASS. (THESE ARE
C       DESCRIBED IN THE TABLE OF VARIABLES USED)
C
C         THE NEXT FOUR CARDS CONTAIN ANY ALPHABETIC OR NUMERIC DATA THAT
C       THE USER WISHES TO RECORD.(NOT USED IN COMPUTATION) . IF NO
C       INFORMATICN IS REQUIRED , BLANK CARDS MUST BE USED.
C
C         THE REMAINDER CF THE CARDS (FORMAT(10F8.2)) CONTAIN A STRING
C       OF X AND F(X) VALUES. THE LAST CARD IS PUNCHED WITH A 9 IN EACH
C       COLUMN FCLLOWING THE LAST DATA PCINT.
C
C*****************************************************************************
C
C                      TABLE CF VARIABLES USED
C
C
C       A        - ANGLE OF INCLINATION OF THE EARTH'S FIELD
C       ADD      - INCREMENT CF CEPTH
C       ANAME    - VARIABLE USED FCR READING AND WRITING PREAMBLE
```

```
C      AXL    - AXIS LENGTH, MAY BE 8,16,OR 24 INCHES
C      BOTM   - MINIMUM VALUE OF FIELD
C      CHK    - ACCEPTABILITY OF RECOMPUTED DIP,CAN BE 'GOOD' OR 'BAD'
C      D      - DECLINATION (EAST IS POSITIVE)
C      DELTA  - DIP OF THE THEORETICAL MODEL
C      DOWN   - MINIMUM VALUE OF THE THEORETICAL CURVE
C      DW     - WIDTH OF THE THEORETICAL DIKE
C      FACT   - MAP SCALE FACTOR
C      FIT    - DEGREE OF CORRESPONDENCE BETWEEN THEORETICAL AND
C               OBSERVED CURVES
C      FXO    - OBSERVED FIELD (NORMALIZED)
C      FXT    - THEORETICAL FIELD
C      HM     - A PARAMETER BY WHICH THE USER CAN ENTER A HALFMAXIMUM
C               DISTANCE FOR ANY OF THE FEATURES TO BE ANALYSED. THIS
C               OVERRIDES THE COMPUTATION OF THIS DISTANCE WITHIN THE
C               PROGRAM
C      HMAX   - THE HALFMAXIMUM DISTANCE
C      HTOP   - HALF THE MAXIMUM VALUE OF THE FIELD
C      IBUF   - A BUFFER ZONE REQUIRED BY THE PLOTTER ROUTINE (1000 BYTES)
C      ISAVE  - THE X SUBSCRIPT AT THE CENTER OF THE DIKE
C      JJ     - THE SUBSCRIPT OF THE BEST FITTING DIP
C      JJJ    - THE SUBSCRIPT OF THE BEST DIP,USED TO CHECK WITH THE NEW
C               VALUE AFTER RE-COMPUTATION
C      KK     - THE SECOND SUBSCRIPT OF THE BEST FITTING WIDTH
C      KSAVE  - THE X SUBSCRIPT AT THE BEGINNING OF THE ANOMALY
C      L1     - A SUBSCRIPT USED IN COUNTING THE  NUMBER OF INPUT VALUES
C      L2     - THE NUMBER OF POINTS ON THE PROFILE
C      L3     - THE NUMBER OF POINTS PLUS TWO (REQUIRED BY SCALE ROUTINE)
C      LL     - THE SUBSCRIPT OF THE BEST FITTING DEPTH
C      LOC    - THE X-SUBSCRIPT AT THE CENTER OF THE DIKE
C      MAX    - THE X SUBSCRIPT AT THE PEAK
C      NL     - THE X SUBSCRIPT (LESS THAN MAX) OF THE HALF MAXIMUM VALUE
C      NM     - THE X SUBSCRIPT (MORE THAN MAX) OF THE HALFMAXIMUM VALUE
C      NP     - THE NUMBER OF PASSES BEING MADE THROUGH THE DATA
C      NPASS  - AN INPUT PARAMETER GIVING THE NUMBER OF PASSES REQUIRED
C      NPOS   - THE SUBSCRIPT OF THE X VALUE AT THE CENTER OF THE DIKE
C      NTPC     THE NUMBER OF TIMES THE PLOT ROUTINE IS CALLED.(SCALE
C               PARAMETERS ARE ONLY COMPUTED THE FIRST TIME FOR EACH PASS)
C      NX     - COUNTS THE NUMBER OF DATA SETS BEING USED (REQUIRED FOR
C               LOCATING THE ORIGIN WHEN PLOTTING)
C      OG     - THE OBSERVED FIELD VALUES IN GAMMAS
C      OL     - THE OBSERVED X POSITIONS IN ANY UNITS
C      POSN   - THE POSITION OF THE CENTER OF THE DIKE IN MAP UNITS
C      RANGE  - THE AMPLITUDE (MAX TO MIN) OF THE OBSERVED ANOMALY
C      RATIO  - THE RATIO OF THE OBSERVED AMPLITUDE TO THE THEORETICAL
C      S      - THE STRIKE OF THE MAGNETIC FEATURE
C      SL     - THE SLOPE OF THE 'NL' SIDE OF THE ANOMALY
C      SM     - THE SLOPE OF THE 'NM' SIDE OF THE ANOMALY
C      SP     - THE STATION SPACING
C      SUS    - THE SUSCEPTIBILITY IN C.G.S. UNITS
C      T      - THE TOTAL FIELD IN THE MAP AREA
C      TEST   - THE FACTOR FOR COMPARING ONE QUALITY OF FIT TO ANOTHER
C      TOP    - THE MAXIMUM VALUE OF THE OBSERVED FIELD
C      TRANGE - THE AMPLITUDE (MAX TO MIN) OF THE THEORETICAL CURVE
```

```
      C       UP      - THE MAXIMUM VALUE OF THE THEORETICAL CURVE
      C       VB      - THE VALUE CF 'CHK' FOR A BAD CHECK
      C       VG      - THE VALUE OF 'CHK' FOR A GOOD CHECK
      C       WT      - THE WEIGHT USED AT EACH POINT WHEN COMPUTING 'FIT'
      C       XO      - THE CBSERVED X POSITICNS (NORMALIZED)
      C       XORIG   - THE X PCSITION CF THE ORIGIN USED IN PLOTTING
      C       XT      - THEORETICAL X VALUES
      C       Y       - CBSERVED FIELD VALUES (NOT NORMALIZED)
      C       YORIG   - THE POSITION CF THE ORIGIN IN THE Y DIRECTION
      C       Z       - DEPTH OF THE THEORETICAL MODEL
      C
      C***********************************************************************
      C
      C                         SCURCE PROGRAM
      C
      C
            COMMON A,T,S,D,SP
            DIMENSION XT(605),FXT(605),OL(605),OG(605),IBUF(1000),WT(605),
           1XO(605),FXO(605),ANAME(20),DELTA(45),Z(15),SUS(5),DW(10,8),Y(605)
           2,HM(3)
            DOUBLE PRECISION FIT
            DATA VG/'GOOD'/,VB/'BAD'/
          5 FORMAT('1')
      C
      C.....READ IN INFORMATION CBSERVED FROM MAP
      C
            NX=0
          7 WRITE(6,5)
            READ(5,10,END=600)A,T,S,D,SP,FACT,(HM(I),I=1,3),NPASS
         10 FORMAT(9F8.2,I3)
            NX=NX+1
            NP=1
            S=S-D
            IF(S.LT.0)S=180+S
      C
      C.....READ IN CBSERVED DATA AND WRITE OUT HEADINGS
      C
            DO 20 I=1,4
            READ(5,30)(ANAME(J),J=1,20)
            WRITE(6,40)(ANAME(J),J=1,20)
         20 CONTINUE
         30 FORMAT(20A4)
         40 FORMAT(10X,20A4/)
            L1=1
            L2=5
         55 READ(5,60)(OL(I),OG(I),I=L1,L2)
         60 FORMAT(10F8.2)
            IF(OL(L2).GT.999998.)GC TO 70
            L1=L2+1
            L2=L1+4
            GO TO 55
         70 L2=L2-1
            IF(OL(L2).GT.999998.)GC TO 70
            IF(FACT.EQ.0.)GO TO 72
```

```
      DO 69 I=1,3
   69 HM(I)=HM(I)*FACT
      SP=SP*FACT
      DO 71 I=1,L2
   71 OL(I)=CL(I)*FACT
C
C     CHOOSE THE AXIS LENGTH
C
   72 IF(FACT.EQ.0.)FACT=1.
      IF((OL(L2)/(25.4*FACT))-8.)800,800,810
  800 AXL=8.
      GO TO 840
  810 IF((OL(L2)/(25.4*FACT))-16.)820,820,830
  820 AXL=16.
      GO TO 840
  830 AXL=24.
  840 L3=L2+2
      XORIG=AXL+4.
      IF(NX.EQ.1)XORIG=0.
      YORIG=25.
      XORIG=C.
      NTPC=1
      YORIG=-4.
C
C.....FIND MAXIMUM VALUE
C
   74 TOP=OG(1)
      DO 80 I=2,L2
      IF(TOP-OG(I))75,80,80
   75 TOP=OG(I)
      MAX=I
   80 CONTINUE
  190 FORMAT(///25X,'PASS',I5//)
      WRITE(6,190)NP
C
C.....FIND HALFMAXIMUM DISTANCE
C
      IF(HM(NP).NE.0)GC TO 105
      HTOP=TCP/2.
      N=1
   82 NL=MAX-N
      IF(NL.EQ.0)GO TO 98
      IF(OG(NL).LE.HTOP)GO TC 90
      N=N+1
      GO TO 82
   90 N=1
   92 NM=MAX+N
      IF(NM.EQ.L2)GO TC 99
      IF(OG(NM).LE.HTCP)GO TC 100
      N=N+1
      GO TO 92
   98 NL=1
      GO TO 90
   99 NM=L2
```

```
      100 HMAX=ABS(OL(NM)-OL(NL))
          GO TO 107
      105 HMAX=HM(NP)
          NL=MAX-(HMAX/(2*SP))
          NM=MAX+(HMAX/(2*SP))
    C
    C
    C.....DETERMINE WHICH SIDE HAS THE STEEPER SLOPE
    C
      107 SL=(TOP-CG(NL))/ABS(OL(MAX)-OL(NL))
          SM=(TOP-CG(NM))/ABS(CL(MAX)-OL(NM))
    C
    C.....DETERMINE THE NUMBER OF STATIONS AND SEPARATE OUT THE ANOMALY
    C     AND SELECT AN INITIAL VALUE OF DIP
    C
          IF(SL-SM)110,120,130
      110 N=3.5*HMAX/SP
          IF(N.GT.L2)N=L2
          DELTA(1)=90.
      111 K=NL-(HMAX/SP)
      112 IF(K.LE.C)K=1
          KSAVE=K
          MAX=MAX-K+1
          DO 115 I=1,N
          XO(I)=CL(K)
          FXO(I)=OG(K)
          Y(I)=FXO(I)
          K=K+1
      115 CONTINUE
          GO TO 140
      120 N=3*HMAX/SP
          IF(N.GT.L2)N=L2
          DELTA(1)=50.
          GO TO 111
      130 N=3.5*HMAX/SP
          IF(N.GT.L2)N=L2
          DELTA(1)=5.
          K=NL-1.5*(HMAX/SP)
          GO TO 112
      140 IF((N+KSAVE-1).GT.L2)N=L2-KSAVE+1
    C
    C     FIND THE MINIMUM VALUE AND AMPLITUDE
    C     MAXIMUM VALUE HAS ALREADY BEEN CALCULATED
    C
          BOTM=FXO(1)
          DO 160 I=2,N
          IF(FXO(I)-BOTM)150,160,160
      150 BOTM=FXO(I)
      160 CONTINUE
          RANGE=TOP-BOTM
          ISAVE=10
    C
    C.....NORMALIZE THE ANCMALY CURVE
    C
```

```
      CALL NORM(XO,FXO,N,ISAVE)
C
C     CALCULATE THE WEIGHT FUNCTION
C
      CALL WEIGHT(XO,WT,N,HMAX)
C
C.....ROUTINE TO SELECT PARAMETERS FOR THEORETICAL CURVE
C     CHOOSE INITIAL VALUES OF DEPTH,WIDTH AND SUSCEPTIBILITY
C     INITIAL VALUE OF DELTA IS ALREADY SELECTED
C     MAXIMUM DEPTH IS ONE HALF OF THE HALFMAXIMUM DISTANCE
C     FOR A THIN DIKE,THE DIKE WIDTH CAN BE SET TO ONE TENTH THE DEPTH
C
C     FIND THE BEST VALUE OF DIP
C     DELTA IS INCREMENTED BY FIVE DEGREES AT A TIME
C
      SUS(1)=0.002
      Z(1)=HMAX/2.
      DW(1,1)=Z(1)/10.
  191 FORMAT(10X,'FIRST GUESS      DEPTH',F8.0,5X,'WIDTH',F8.0/)
      WRITE(6,191)Z(1),DW(1,1)
      TEST=1000.
      DO 200 M=1,18
      CALL GENRAT(N,SUS(1),DW(1,1),Z(1),DELTA(M),XT,FXT,MAX)
      CALL NORM(XT,FXT,N,ISAVE)
      CALL ALIGN(FXT,N,MAX,ISAVE)
      CALL MATCH(XO,FXO,FXT,FIT,N,WT)
      DELTA(M+1)=DELTA(M)+5.00
      IF(FIT.LT.TEST)GO TO 210
      GO TO 200
  210 JJ=M
      TEST=FIT
  200 CONTINUE
  192 FORMAT(26X,'COMPUTED DIP   ',F8.0/)
      WRITE(6,192)DELTA(JJ)
      ADD=HMAX/20.
  201 TEST=1000.
C
C.....LOOP FOR DEPTH
C
      DO 400 M=1,10
      IF(Z(M).LT.1.)GO TO 400
C
C.....COMPUTE WIDTHS TO BE TRIED
C
      DW(M,1)=Z(M)/10.
      DW(M,2)=DW(M,1)*10.
      DO 260 K=3,8
  260 DW(M,K)=DW(M,2)*(((K-2)*0.5)+1)
C
C.....LOOP FOR WIDTH
C
      DO 300 J=1,8
      CALL GENRAT(N,SUS(1),DW(M,J),Z(M),DELTA(JJ),XT,FXT,MAX)
      CALL NORM(XT,FXT,N,ISAVE)
```

```
      CALL ALIGN(FXT,N,MAX,ISAVE)
      CALL MATCH(XO,FXC,FXT,FIT,N,WT)
      IF(FIT.LT.TEST)GO TO 310
      GO TO 300
  310 KK=J
      LL=M
      LOC=ISAVE
      TEST =FIT
  300 CONTINUE
      Z(M+1)=Z(M)-ADD
  400 CONTINUE
  193 FORMAT(10X,'COMPUTED PARAMETERS          DEPTH',F8.0,5X,'WIDTH',F8.0)
      WRITE(6,193) Z(LL),DW(LL,KK)
C
C     CHECK THE DIP AGAIN
C
      M=JJ
      JJJ=JJ
      TEST=1000.
      DO 550 I=1,5
      K=I-3
      IF((M+K).EQ.0)K=K+1
      IF((M+K).GT.18)K=K-1
      CALL GENRAT(N,SUS(1),DW(LL,KK),Z(LL),DELTA(M+K),XT,FXT,MAX)
      CALL NORM(XT,FXT,N,ISAVE)
      CALL ALIGN(FXT,N,MAX,ISAVE)
      CALL MATCH(XO,FXC,FXT,FIT,N,WT)
      IF(FIT.LT.TEST)GO TO 555
      GO TO 550
  555 JJ=M+K
      LOC=ISAVE
      TEST=FIT
  550 CONTINUE
  194 FORMAT(/20X,'CHECK DIP  'F8.0/)
      WRITE(6,194)DELTA(JJ)
      IF(IABS(JJJ-JJ).GT.1)GO TO 560
      CHK=VG
      WRITE(6,195)CHK
      GO TO 570
  195 FORMAT(15X,'THIS IS A ',A4,'CHECK'/)
  560 CHK=VB
      WRITE(6,195)CHK
      GO TO 201
  570 WRITE(6,196)
  196 FORMAT(10X,'PARAMETERS OF THE BEST FITTING DIKE'/)
C
C.....GENERATE THE BEST FITTING THEORETICAL CURVE AND CALCULATE
C     SUSCEPTIBILITY
C     SUSCEPTIBILITY AFFECTS ONLY AMPLITUDE SO NORMALIZING NOT NECESSARY
C
      SUS(1)=0.0005
      CALL GENRAT(N,SUS(1),DW(LL,KK),Z(LL),DELTA(JJ),XT,FXT,MAX)
C
C.....FIND THE MAXIMUM AND MINIMUM VALUES OF THE THEORETICAL CURVE
```

```
C
      UP=FXT(1)
      DOWN=FXT(1)
      DO 520 I=2,N
      IF(UP-FXT(I))518,519,519
  518 UP=FXT(I)
  519 IF(DOWN-FXT(I))520,520,521
  521 DOWN=FXT(I)
  520 CONTINUE
      TRANGE=UP-DOWN
      RATIO=RANGE/TRANGE
      SUS(2)=SUS(1)*RATIO
C
C.....GENERATE A CURVE WITH THE TRUE AMPLITUDE
C
      CALL GENRAT(N,SUS(2),DW(LL,KK),Z(LL),DELTA(JJ),XT,FXT,MAX)
      CALL ALIGN(FXT,N,MAX,LCC)
C
C.....COMPARE THIS WITH THE OBSERVED CURVE
C
      CALL MATCH(XO,Y,FXT,FIT,N,WT)
C
C.....PRINT OUTPUT
C
      NPOS=KSAVE-1+LCC
      POSN=OL(NPOS)
      IF(FACT.LE.1.)GO TO 199
      POSN=POSN/FACT
  198 FORMAT(10X,'THE CENTER OF THE DIKE IS LOCATED',F8.0,3X,'MAP UNITS
     1FROM THE START OF THE PROFILE'/)
  199 WRITE(6,198) POSN
  180 FORMAT(10X,'SAMPLING INTERVAL',F7.2,'  FEET'//10X,'TOTAL FIELD',
     1F10.2,'  GAMMAS'//10X,'INCLINATION',F10.2,'  DEGREES'//10X,'DECLIN
     2ATION',F10.2,'  DEGREES'//10X,'STRIKE',F10.2,'  DEGREES EAST OF NO
     3RTH'//10X,'DIP',F10.2,'  DEGREES TO THE NORTH SIDE'//10X,'DIKE WID
     4TH',F10.2,'  FEET'//10X,'DEPTH',F10.2,'  FEET'//10X,'SUSCEPTIBILIT
     5Y CONTRAST',F10.5,'  C.G.S. UNITS'//10X,'QUALITY OF FIT',F20.16)
      WRITE(6,180) SP,T,A,D,S,DELTA(JJ),DW(LL,KK),Z(LL),SUS(2),FIT
C
C.....GENERATE A CURVE WITH POINTS ON THE ENTIRE PROFILE
C
      MAX=MAX+KSAVE-1
      CALL GENRAT(L2,SUS(2),DW(LL,KK),Z(LL),DELTA(JJ),XT,FXT,MAX)
      CALL ALIGN(FXT,L2,MAX,LCC)
      NTPC=NTPC+1
      DO 580 I=1,L2
      OG(I)=OG(I)-FXT(I)
  580 CONTINUE
      IF(NP.EQ.NPASS)GO TO 7
      NP=NP+1
      GO TO 74
  600 CALL EXIT
      END
```

```
      SUBROUTINE WEIGHT(X,W,N,H)
C
C.....THE WEIGHT FUNCTION IS DERIVED FROM A GAUSSIAN CURVE
C
      DIMENSION X(N),W(N)
      DO 10 I=1,N
      W(I)=EXP(-((X(I)/H)**2))
   10 CONTINUE
C
      RETURN
      END
```

```
      SUBROUTINE ALIGN(FXT,N,MAX,ISAVE)
C
C.....ROUTINE TO ASSURE THAT THE MAXIMA OF THE TWO CURVES ARE COINCIDENT
C
      DIMENSION FXT(N)
C
C.....FIND THE MAXIMUM OF THE THEORETICAL CURVE
C
    2 TMAX=FXT(1)
      DO 10 I=2,N
      IF(TMAX-FXT(I))5,10,10
    5 TMAX=FXT(I)
      IMAX=I
   10 CONTINUE
C
C.....SHIFT THE CURVE CVER CNE POSITION
C
      M=N-1
      IF(IMAX-MAX)30,40,20
   20 DO 25 I=1,M
   25 FXT(I)=FXT(I+1)
      ISAVE=ISAVE-1
      GO TO 2
   30 DO 35 I=1,M
      K=N+1-I
   35 FXT(K)=FXT(K-1)
      ISAVE=ISAVE+1
      GO TO 2
   40 RETURN
      END
```

```
      SUBROUTINE MATCH(XC,FXC,FXT,FIT,N,D)
      DIMENSION XO(N),FXO(N),FXT(N),D(N)
      DOUBLE PRECISION G   ,FIT,SUM1,SUM2
      SUM1=0.
      SUM2=0.
      DO 10 I=1,N
      G=(FXO(I)-FXT(I))*1.E5
    8 SUM1=SUM1+(G*G)*D(I)
      SUM2=SUM2+D(I)
   10 CONTINUE
      FIT=SUM1/(N*SUM2*1.E25)
      RETURN
      END
```

```
      SUBROUTINE NORM(X,FX,N,ISAVE)
      DIMENSION X(N),FX(N)
C
C.....DETERMINE MAXIMUM AND MINIMUM VALUES OF THE ANOMALY AND THE
C     RANGE, X COORDINATES ARE GIVEN AS DMAX AND DMIN
C
      FMAX=FX(1)
      FMIN=FX(1)
      DMAX=X(1)
      DMIN=X(1)
      DO 50 I=2,N
      IF(FMAX-FX(I))20,30,30
   20 FMAX=FX(I)
      DMAX=X(I)
   30 IF(FMIN-FX(I))50,50,40
   40 FMIN=FX(I)
      DMIN=X(I)
   50 CONTINUE
      RANGE=FMAX-FMIN
C
C.....DETERMINE X COORDINATE CF POINT HALFWAY BETWEEN FMAX AND FMIN
C
      XHF=X(1)
      DO 80 I=1,N
      IF(DMAX-X(I))70,70,80
   70 W=(RANGE/2.)-(FX(I)-FMIN)
      IF(W)80,75,75
   75 XHF=X(I)
      GO TO 90
   80 CONTINUE
   90 CONTINUE
C
C.....NORMALIZE FX AND X
C
      DO 100 I=1,N
      FX(I)=(FX(I)-FMIN)/RANGE
      X(I)=(X(I)-DMAX)/(XHF-DMAX)
  100 CONTINUE
C
C.....FIND THE X SUBSCRIPT AT THE CENTER OF THE DIKE
C
      DO 95 I=1,N
      IF(X(I))95,96,95
   95 CONTINUE
   96 ISAVE=I
      RETURN
      END
```

```
      SUBROUTINE GENRAT(N,SUS,DW,Z,DELTA,X,FX,MAX)
      COMMON A,T,S,D,SP
      DIMENSION X(N),FX(N)
      DO 5 I=1,N
      X(I)=0.
    5 FX(I)=0.
      DELTA=180.-DELTA
      S=S/57.295779
      A=A/57.295779
      DELTA=DELTA/57.295779
      HDW=DW/2.
C
C.....CALCULATE THE INDEX PARAMETER B
C
      IF(S.EQ.0.)GO TO 6
      C=TAN(A)/SIN(S)
      C=ATAN(C)
      GO TO 7
    6 C=3.14159/2.
    7 B=2.*C-DELTA-(3.14159/2.)
C
C.....CALCULATE THE AMPLITUDE FACTOR CW/R
C
      CW=(2.*SUS*T*SIN(DELTA))*((SIN(A)/SIN(C))**2)
C
C ....CALCULATE X AND FX
C
      X(1)=(-MAX+1)*SP
      DO 10 I=2,N
   10 X(I)=X(I-1)+SP
      DO 20 I=1,N
      W=ABS(X(I)-HDW)
      WW=ABS(X(I)+HDW)
      WA=ABS(X(I))-HDW
C
C.....ANGLE TERM
C
      IF(WA)11,12,13
   11 THETA=3.14159-ATAN(Z/W)-ATAN(Z/WW)
      GO TO 14
   12 THETA=ATAN(DW/Z)
      GO TO 14
   13 THETA=ATAN(Z/WW)-ATAN(Z/W)
      THETA=ABS(THETA)
   14 CONTINUE
C
C.....LOG TERM
C
      R1=SQRT((WW*WW)+(Z*Z))
      R2=SQRT((W*W)+(Z*Z))
      FLN=R2/R1
      FLN=ALOG(FLN)
C
C.....CALCULATE FX
```

```
      C
            FX(I)=CW*((THETA*COS(B))+(FLN*SIN(B)))
         20 CONTINUE
            DELTA=DELTA*57.295779
            DELTA=180.-DELTA
         27 S=S*57.295779
            A=A*57.295779
            RETURN
            END
```