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A SIMPLE CORRELATION-COINCIDENCE VALUE (CCV)
TECHNIQUE FOR USE DURING ROUTINE COMPUTER PROCESSING
OF AERORADIOMETRIC AND AEROMAGNETIC DATA

by

© George W. Cameron, B.Sc.

A thesis submitted to the Faculty of
Graduate Studies and Research in partial
fulfillment of the requirements for the
degree of Master of Science.

Department of Geology
Carleton University
Ottawa, Ontario
September, 1982

"How do you ever expect me to finish my Masters Thesis if you keep knocking my paper around....This is the last time I'm ever going to help you with your 'M.S.' Thesis".

R. Cameron (age 3_yrs.)

to his sister

C. Cameron (age 1_yr.)

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11

ABSTRACT

A simple technique for correlating profile data of any two geophysical parameters has been developed. The correlation-coincidence value (CCV) technique detects all anomaly peaks along a flight line of data; peak maxima values are of less significance than the occurrence of a peak. The CCV technique assigns a value at each data point which is indicative of complete or partial peak coincidence between the correlated parameters. The CCV technique is applied to concurrently collected aeroradiometric and aeromagnetic data. By combining CCV and approximate depth values, areas where unmapped geological features may exist or areas where radioactivity may be continuous at depth are indicated. Geological data confirms the usefulness of the CCV approach as an aid to geological modelling and as a 'first look' indicator in areas of exploration interest.

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TABLE OF CONTENTS

	Page
ABSTRACT	ii
ACKNOWLEDGEMENTS	iii
TABLE OF CONTENTS	iv
LIST OF TABLES	vi
LIST OF FIGURES.....	vii
INTRODUCTION	x
CHAPTER 1: RADIOACTIVITY AND GEOPHYSICS	1
1.1. Radioactivity	1
1.1.1. Decay Series and Equilibrium	2
1.1.2. Sources of Terrestrial Radioactivity	8
1.2. Instrumentation and Calibration	9
1.2.1. Energy Calibration.....	13
1.2.2. Calibration Factors.....	14
1.2.3. Background Radiation	17
1.3. Units of Measurement	18
1.4. Interrelated Survey Parameters	19
1.5. Airborne Surveys and Data Publication	20
CHAPTER 2: THE EARTH'S MAGNETIC FIELD AND GEOPHYSICS	24
2.1. The Earth's Magnetic Field	24
2.1.1. Components of Main Field	26
2.1.2. Origin of Main Field	28
2.1.3. External Magnetic Field	28
2.1.4. Local Variations in Main Field	29
2.2. Basic Considerations in Magnetic Interpretation	29
2.2.1. Magnetic Units in Geophysical Prospecting	30

2.3. Magnetic Materials in the Earth	30
2.4. Factors Affecting Magnetic Surveys	31
 CHAPTER 3: A CORRELATION TECHNIQUE - PEAK COINCIDENCE	 35
3.1. Introduction	35
3.2. Computer Programs	38
3.3. Correlation-Coincidence Value (CCV) Determinations	38
3.3.1. Other Considerations of CCV	44
3.4. Depth Estimates Techniques Using Magnetic Data	46
 CHAPTER 4: APPLICATION OF THE CCV TECHNIQUE TO REAL DATA	 52
4.1. Geology of the Study area	52
4.1.1. Magnetic Data	54
4.1.2. Radiometric Data	57
4.2. Data Reduction Problems	59
4.3. Correlation-Coincidence Value Interpretation .	62
4.4. Conclusions and Recommendations For future Study	73
4.4.1. Recommendations For Future Study.....	75
 References	 78
 Appendix A	 84
A.1 Computer Software	84
A.2 Calling Sequence of Subroutines	88
A.3 Algorithm For CCV Subroutine	90
A.4 Listings of Computer Software	91

LIST OF TABLES

	Page
1.1 U^{238} decay series	6
1.2 Th^{232} decay series	7
1.3 Spectral window widths	12
2.1 Magnetic susceptibilities of various rocks	32
2.2 Magnetic susceptibilities of various minerals ..	33

LIST OF FIGURES

	Page
1.1 Approximate distance of travel of alpha, beta and gamma radiation	3
1.2 Relative frequency (wavelength) bands of the electromagnetic spectrum	4
1.3 Typical gamma-ray spectrum (at an altitude of 120 m)	10
1.4 Schematic representation of the interaction between the K, U and Th energy windows and associated "stripping factors"	16
1.5 Source-detector geometries (encountered in field measurements)	21
2.1 Geocentric dipole magnetic field of the earth..	25
2.2 Orientation of magnetic field components at a point on the earth's surface.....	27

viii

3.1	Correlation-coefficient value (CCV) evaluation for profiles of two geophysical parameters	39
(a)	Arbitrary profile curves (parameter 1 and parameter 2).....	39
(b)	Binary histogram (parameter 1).....	39
(c)	Binary histogram (parameter 2).....	39
(d)	Correlation-coincidence value (CCV) 'profile'	39
3.2	Low valued CCV (apparent low correlation) calculated from profiles of related geological sources.....	45
3.3	"Rule of thumb" depth estimate techniques using magnetic anomaly profiles.....	47
3.4	Depth determination techniques from magnetic anomaly profiles (Peters half slope, Sokolov and straight slope).....	49
3.5	Depth estimate interpretation (Peters factor = 1.6).....	50

4.1	Generalized geology of study area.....	53
4.2	Aeromagnetic map of study area	55
4.3	Regional magnetic field (1965.0), Nova Scotia	56
4.4	eU map (ppm), Chedabucto Bay area (Nova Scotia).....	58
4.5	Multiparameter profiles for sample line across study area	60

INTRODUCTION

The superposition of anomaly profiles or maps is part of a geophysical data correlation procedure. Many potentially significant, small-amplitude anomalies are ignored because they are not visually apparent or are considered insignificant. A simple correlation technique to detect all peak areas along data profiles has been developed. The correlation technique assigns new values to all data points along a flight path based on whether peak overlap (coincidence) occurs between data profiles. The correlation-coincidence technique can be applied during routine computer processing of geophysical data. The technique is applied to concurrently collected airborne radiometric and magnetic data for the Chedabucto Bay area of Nova Scotia.

Computer software for a modified 'Peters Half Slope' depth estimate technique has been developed to facilitate data interpretation. Geological data along a flight path confirms the usefulness of combining the correlation and depth estimate techniques as: an aid to geological mapping; an indication of radioactivity at depth; a 'first look' indicator of areas for further exploration.

CHAPTER 1

RADIOACTIVITY AND GEOPHYSICS

1.1 Radioactivity:

The detection of spontaneous emissions in some naturally occurring substances was first used as a geophysical technique in the early part of the century. Advances in instrumentation since that time have seen geiger counters replaced by scintillation counters used in conjunction with multichannel analyzers. These spectrometers have been developed for use in prospecting on the ground, in borehole logging systems and in airborne systems.

The nuclei of a few naturally occurring, unstable, isotopes spontaneously break up by radioactive disintegration emitting alpha (α) or beta (β) particles and may be accompanied by electromagnetic radiation (Dobrin, 1960; Telford et al, 1976).

Alpha particles, after neutralization become helium atoms. Alpha particles are completely attenuated by a few centimetres of air or a sheet of paper (Telford et al, 1976). Beta particles are electrons and are smaller and more

penetrating than alpha particles (Livesey, 1966). However, complete attenuation of beta particles occurs in approximately one metre of air (Figure 1.1).

Gamma-rays are of exactly the same physical nature as X-rays (Lapp and Andrews, 1948; Feynman et al., 1963). Both are electromagnetic photons and for the same wavelength of radiation are physically indistinguishable. The difference between gamma-rays and X-rays is one of origin: photons originating from the nucleus are gamma-rays, whereas photons arising from electron transitions in the inner electron shells of an atom are X-rays (Lapp and Andrews, 1948). Gamma-rays can have energies as low as a few thousand electron volts ($\text{keV} = 10^3 \text{ eV}$) up to several million electron volts ($\text{MeV} = 10^6 \text{ eV}$); i.e., wavelengths between 10^{-8} cm and 10^{-11} cm (Figure 1.2). Gamma ray energies in the 0.2 MeV (200 keV) to 3.5 MeV (3500 keV) range are of interest in geophysical surveying. Gamma rays are attenuated by approximately one meter of overburden, up to 30 cms of rock or several hundred metres of air.

1.1.1. Decay Series and Equilibrium:

During radioactive disintegrations, several unstable daughter products with characteristic half-lives may form a radioactive decay series. Decay products in the 238-Uranium (Table 1.1) and 232-Thorium (Table 1.2) decay series have half

APPROXIMATE DISTANCE OF TRAVEL OF ALPHA, BETA AND GAMMA RADIATION

Figure 1.1

RELATIVE FREQUENCY (WAVELENGTH) BANDS OF THE ELECTROMAGNETIC SPECTRUM

Figure 1.2

lives that vary from fractions of seconds to billions of years. An assumption made in radiometric surveying is that both the parent nuclide and daughter products in a decay series are in secular equilibrium.

Secular equilibrium exists when the number of atoms of a particular daughter product produced in a decay series is equal to the number of atoms of that daughter being lost by radioactive decay. If N_1 is the number of atoms of radioelement 1 present at time t , the rate of loss of decay is given by:

$$d N_1 / d t = - \lambda_1 \times N_1 \dots\dots(1-i)$$

where λ_1 is the decay constant for element 1.

In any given decay series, N_1 decays into N_2 at the rate given in equation (1-i). N_2 , with decay constant λ_2 , decays into N_3 etc. for the remainder of the decay series. If a parent radioelement has a long half life, the amount of any given daughter product eventually becomes constant and the series is in a state of secular equilibrium. That is:

Table 1.1 (Lang et al., 1962)

The U-238 Series Decay Chain

<u>Isotope</u>		<u>Half Life</u>
^{238}U	Uranium	$4.507 \times 10^9 \text{ y}$
^{234}Th	Thorium	24.1 d
^{234}Pa	Protactinium	1.18 m
^{234}U	Uranium	$2.48 \times 10^5 \text{ y}$
^{230}Th	Thorium	$7.52 \times 10^4 \text{ y}$
^{226}Ra	Radium	1600 y
^{222}Rn	Radon	3.825 d
^{218}Po	Polonium	3.05 m
^{214}Pb	Lead	26.8 m
^{214}Bi	Bismuth	19.7 m
^{214}Po	Polonium	$1.58 \times 10^{-4} \text{ s}$
^{210}Pb	Lead	22.3 y
^{210}Bi	Bismuth	5.02 d
^{210}Po	Polonium	138.4 d
^{206}Pb	Lead	STABLE

Isotopes constituting less than 0.2 per cent of the decay products are omitted.

Table 1.2 (Lang et al., 1962)

The Th-232 Decay Series

<u>Isotope</u>		<u>Half-Life</u>
^{232}Th	Thorium	$1.39 \times 10^{10} \text{ y}$
^{228}Ra	Radium	6.7 y
^{228}Ac	Actinium	6.13 h
^{228}Th	Thorium	1.91 y
^{224}Ra	Radium	3.64 d
^{220}Rn	Radon (Thoron)	55.3 s
^{216}Po	Polonium	0.158 s
^{212}Pb	Lead	10.64 h
^{212}Bi	Bismuth	60.5 m
<div style="display: flex; align-items: center; justify-content: center;"> <div style="text-align: center; margin-right: 20px;"> ^{212}Po <— (64%) — </div> <div style="text-align: center; margin-right: 20px;"> — (36%) —> </div> <div style="text-align: center;"> ^{212}Po <— (64%) —> Polonium </div> </div>		
^{208}Tl	Thallium	$3.04 \times 10^{-7} \text{ s}$
^{208}Pb	Lead	3.1 m
		STABLE

$$\lambda_1 \times N_1 = \lambda_2 \times N_2 = \dots = \lambda_n \times N_n \quad \dots(1-ii)$$

Intermediate daughter products can be leached out or mechanically removed from a decay series. If this happens with a radionuclide of relatively short half life (e.g. ^{216}Po - Th series or ^{218}Po - U series), disequilibrium is relatively unimportant; a state of 99% equilibrium would be re-established after approximately 7 half lives (Killeen, 1979). However, if a series element of long half-life is removed, disequilibrium could be significant. In general, equilibrium exists in surface rocks in Canada (Charbonneau et al., 1981).

1.1.2. Sources of Terrestrial Radioactivity:

The three main sources of natural terrestrial gamma radiation from rocks and soils and the prime photopeaks that are used in geophysical surveys to detect this radiation are:

- (1) ^{40}K (.012% of total potassium) of energy 1.46 MeV,
- (2) Decay products in the ^{238}U decay series (in particular, ^{214}Bi of 1.76 MeV), and
- (3) Decay products in the ^{232}Th decay series (in particular, ^{208}Tl of 2.62 MeV).

Due to the complexity of gamma ray spectra from the uranium and thorium decay series, photons of energy 1.76 MeV from 214-bismuth in the uranium series and photons of energy 2.62 MeV from 208-thallium in the thorium series are normally used to discriminate between the uranium and thorium decay series (Darnley and Grasty, 1971). Photons of 1.46 MeV from 40-potassium are used, to measure potassium. All three photopeaks occur in the higher energy part of the spectrum and are readily discriminated. A typical airborne gamma-ray spectrum obtained at a survey altitude of 120 metres is illustrated in Figure 1.3.

1.2. Instrumentation and Calibration:

Descriptions of the instrumentation required for airborne radiometric surveying can be found in the literature (Grasty and Darnley, 1971; Grasty and Holman, 1974; Grasty and Charbonneau, 1974; Bristow, 1979). Detector crystals are manufactured in various shapes and volumes from different materials. Airborne detection systems frequently consist of crystals of thallium activated sodium iodide 102 mm x 102 mm x 406 mm (4 in. x 4 in. x 16 in.) in size. Each detector crystal is optically coupled to a photomultiplier tube (PMT). The electrical output of a PMT is amplified, passed through a multichannel analyzer, converted to digital form and stored in a minicomputer for subsequent recording on magnetic tape.

TYPICAL GAMMA-RAY SPECTRUM (at altitude = 120m)

(Adapted from Foote, 1968; Grasty, 1979)

Figure 1.3

Most portable spectrometers are window-type spectrometers which usually accumulate and display only the data acquired in four windowed energy bands (total count, potassium, uranium and thorium). These broad energy windows (commonly 200 keV and 400 keV in width) are centered on the photopeaks of interest. The spectral data for energies between the windows is neither displayed nor recoverable.

A multi-channel spectrometer records a continuous spectrum of data in a large number of uniformly distributed channels, each channel representing a narrow energy band. The recording of a complete spectrum in narrow energy bands rather than only data from broad energy windows, provides recoverable data for the specified energy ranges even if channel 'drift' should occur in the spectrometer while recording.

Some spectrometer systems, such as the airborne, borehole and laboratory systems at the Geological Survey of Canada (GSC), have both window and multi-channel recording capabilities. The four 'fixed' spectral window widths used in the airborne system are shown in Table 1.3 (see also Figure 1.3).

Table 1.3 (From Grasty, 1979)

Spectral Window Widths
used in
Geological Survey of Canada Airborne Spectrometer

			Gamma Ray
Element	Isotope	Energy	Energy Window
<u>Analyzed</u>	<u>Used</u>	<u>(MeV)</u>	<u>(MeV)</u>
Potassium	^{40}K	1.46	1.37 - 1.57
Uranium	^{214}Bi	1.76	1.66 - 1.86
Thorium	^{208}Tl	2.62	2.41 - 2.81
Total Count			0.41-2.81

1.2.1. Energy Calibration:

A spectrometer system assigns all energy pulses (electrical signals) from the detector (crystal plus PMT) to particular channels or windows. The cumulative number of times (number of counts) a particular signal occurs in a channel or window over a fixed period of time determines the count rate for that channel or window. The designated channel or window in which a signal (voltage) falls is determined by the energy of the gamma-ray interacting with the crystal and by the energy calibration of the system.

Energy calibration of a spectrometer requires adjusting the appropriate controls (high voltage on PMT; amplifier) until the photopeak of a known radioactive source occurs in a desired channel. Common energy calibration sources used and their photopeak energies are ^{137}Cs (0.661 MeV) or ^{88}Y (0.898 and 1.836 MeV-two peaks).

Problems of 'drift' in a system from the pre-set energy calibrated channel may be minimized by monitoring the peak location of one of the radioelements being detected, the peak location of an internal low energy source or by frequently analyzing an energy calibration source. Monitoring the energy calibration is imperative with any spectrometer and even more so with portable spectrometers because the count rate data between the selected windows is not recorded. Corrections for 'drift' with the complete spectral data recorded by

multi-channel analyzers is done during subsequent computer processing.

1.2.2. Calibration Factors:

Another essential part of a gamma ray spectrometer calibration procedure is the determination of spectral stripping coefficients, radioelement sensitivities and calculated backgrounds. These calibration factors are unique to each spectrometer system.

Calibration factors for a system are determined from count rate data accumulated over sources of known radioelement concentrations. The known sources attempt to approximate the physical characteristics of areas to be surveyed. In Canada, potassium, uranium and thorium calibration sources for spectrometer systems exist as:

- (1) five 7.6 m x 7.6 m x 0.46 m concrete pads located at Uplands International airport in Ottawa (for aircraft systems),
- (2) a calibration test strip, for which ground concentrations are known, near Breckenridge, Quebec. The test strip is used to relate airborne count rates to ground concentrations (sensitivities).

- (3) ten ~3.5 m diameter and 0.46 m thick concrete pads at Bell Corners (for portable spectrometers) and
- (4) nine 3.9 metre high concrete columns consisting of 1.2 m thick barren zones above and below 1.5 m thick 'ore' zones, also at Bells Corners (for bore hole logging systems).

Similar calibration facilities exist at Calgary, Alberta (portable systems only), Saskatoon, Saskatchewan (boreholes only) and at Fredricton, New Brunswick (boreholes only).

Due to the finite size of detector crystals and the scattering of gamma rays, a certain fraction of higher energy photons from an element A, e.g., ^{208}Tl , are incompletely absorbed by the detector crystal and may appear as counts in the lower energy window used for element B, e.g., ^{214}Bi or C, e.g., ^{40}K . The fraction of counts are referred to as the spectral stripping coefficients. Similarly, incompletely absorbed B photons can also appear in the C window and upward stripping may also be applied (C counts in B window; B counts in A window).

Figure 1.4 is a schematic representation of the spectral stripping coefficients as they relate to the radioelement windows. For example, alpha (α) is used to 'strip off' the counts due to thorium gamma rays that appear in the uranium window, beta (β) to 'strip off' the counts due to thorium gamma rays that appear in the potassium window and gamma (γ)

SCHEMATIC REPRESENTATION OF THE INTERACTION BETWEEN THE 'K, U, AND Th ENERGY WINDOWS AND ASSOCIATED "STRIPPING FACTORS"

Figure 1.4

is used to 'strip off' uranium counts that appear in the potassium window. The upward stripping factors (a,b,g) are frequently ignored since the effect of upward scatter in most cases is negligible. Ignoring the upward factors permits a more simplified method of computing radioelement concentrations (Killeen and Cameron, 1977).

Other calibration factors determined from count rate data obtained at calibration facilities are the system sensitivities which relate concentrations to count rates and calculated backgrounds.

Much of the previously published literature describing calibration facilities and calibration procedures for borehole logging, airborne and ground spectrometers is summarized in Killeen (1979).

1.2.3. Background Radiation:

Background radiation is defined as radiation detected by the spectrometer that does not originate from the source being analyzed. Background count rate data is subtracted from all radioelement count rate data before the radioelement concentrations can be determined. There are a variety of ways of determining background radiation.

'Calculated background' count rates are some of the previously described calibration factors for a spectrometer system. 'Local background' count rates are the mean value of all the radioelement count rates obtained in the area being surveyed (Killeen, 1979). 'Over water' background count rates are the most meaningful measure of background radiation. Gamma radiation is completely attenuated by approximately ten inches of water. Because the background radiation can vary from one area to another along a flight line (or ground traverse), only the 'over water' background permits a good comparison of data from different survey areas. A further discussion of background radiation and current operational procedures as used by the Geological Survey of Canada is given in Grasty, 1979.

1.3. Units of Measurement:

Geophysical field measurements of radioactivity acquire the 'raw' data as count rates - counts per second (cps), per minute (cpm) or per arbitrary counting time. Subsequent background (count rate) subtraction and application of stripping factors (no units) provides corrected data with the same units as the raw data. The radioelement concentrations are obtained by applying the sensitivity factors to the corrected data. The potassium sensitivity factor has units of

count rate per one percent potassium whereas the uranium and thorium sensitivity factors have units of count rate per part per million. Therefore potassium concentrations are calculated in percent (%K) whereas uranium and thorium concentrations are calculated as parts per million (ppm).

Since gamma emissions from daughter products in their respective decay series are used to determine uranium and thorium count rates, concentrations of uranium and thorium are given as equivalent uranium (eU) in ppm or equivalent thorium (eTh) in ppm. These calculations imply that the amount of parent ^{238}U or ^{232}Th present is equivalent to that which would be in radioactive equilibrium with the amount of ^{214}Bi or ^{208}Tl detected.

In an effort to standardize the units for total count gamma radiation, a more recent unit called the Ur (unit of radioelement concentrations) has been suggested (IAEA, 1976) and recommended by the IAEA. One Ur is equivalent to one part per million uranium in equilibrium.

1.4. Interrelated Survey Parameters

Some interrelated parameters of importance in radiometric surveying, other than the calibration factors, are detector size (Grasty and Holman, 1974), detector resolution (Bristow,

1979), sample volumes, circle of investigation (Grasty, 1976a; Duval et al, 1971), and the 'field of view' of a spectrometer (Grasty, 1976b). Detailed descriptions are given in the literature.

Because the amount of radiation detected is related to the size and shape of a source, as well as the intensity of radiation, the 'geometry' of the source in relation to the detector receiving the radioactive emissions is another interrelated parameter that must be considered (Killeen, 1979). Figure 1.5 illustrates what is referred to as 2-pi, 3-pi or 4-pi geometry. Generally, radiometric measurements made above the surface of the earth (portable, car-borne or airborne spectrometers) are considered measurements in 2-pi geometry.

1.5. Airborne Surveys and Data Publication

In geophysical exploration, aircraft systems are used for regional surveys to ascertain potential areas for subsequent more detailed exploration. Most survey aircraft are equipped with detection systems for at least two geophysical parameters. The parameters being detected determine the survey altitude. For example, the Geological Survey of Canada airborne radiometric surveys are carried out at an altitude of approximately 120 metres (400 feet) which is satisfactory for

SOURCE-DETECTOR GEOMETRIES

(ENCOUNTERED IN FIELD MEASUREMENTS)

Figure 1.5

G.W. Cameron-1982

gamma radiation detection and more than satisfactory for detection of variations in the magnetic field.

Flight line spacing for a survey is arbitrary. Darnley et al. (1975) support aeroradiometric reconnaissance survey line intervals of about 5 km, but in some areas longer intervals of about 25 km line spacing are used. Detailed uranium exploration surveys are often carried out with line spacings as close as 0.5 km whereas surveys for more specific purposes (e.g., surveys of mine or townships) have line spacings as close as 67 m (200 feet) (Richardson, personal communication, 1982). Cameron et al. (1976) have shown that a 5.0 km flight line spacing is sufficient to indicate regional areas of anomalous radioactivity.

Airborne radiometric survey data are published by the Geological Survey of Canada as:

- (1) contour maps for each of 7 radiometric parameters. These parameters are total count (Ψ r), potassium (%), equivalent uranium (eU) and equivalent thorium (eTh) in parts per million (ppm) and the eU/eTh, eU/k and eTh/K ratios, and
- (2) as stacked profiles of the seven radiometric parameters, altimeter and magnetometer (when available) trace for each flight line.

Due to the voluminous amount of information presented, radiometric data is normally released as microfiche cards.

Total intensity aeromagnetic maps published by the Geological Survey of Canada represent data acquired at a 300 m (1000 ft.) mean terrain clearance with a 800 m (0.5 mile) flight line spacing.

CHAPTER 2

THE EARTH'S MAGNETIC FIELD AND GEOPHYSICS

2.1. The Earth's Magnetic Field

The discovery of the directional properties of a magnetized needle in the Earth's magnetic field is dated by some to 4500 years ago (Jacobs, 1963). William Gilbert, in 1600, published the fact that the Earth's magnetic field resembled that of a geocentric dipole field, i.e., similar to that of a permanent magnet lying in a general north-south direction near the earth's rotational axis (Figure 2.1). Gauss, in 1839, by a spherical harmonic analysis, showed that the regular and irregular components of the earth's field were mainly of internal origin (Jacobs et al., 1959).

On October 25, 1968, an International Geomagnetic Reference Field (IGRF) was endorsed by the World Magnetic Survey Board (Fabiano and Peddie, 1969). The IGRF is based on a mathematical model of the earth's magnetic field defined by a set of spherical harmonics. A synthesis of IGRF values is presented by Barraclough et al. (1971). Spherical harmonic analysis of the observed magnetic field shows that at least

GEOCENTRIC DIPOLE MAGNETIC FIELD OF EARTH

GMN and GMS - Geomagnetic North and South

GN and GS - Geographical North and South

ME - Magnetic Equator

Figure 2.1

99% is due to sources inside the earth, the remaining 1% to sources outside the earth (Telford et al, 1976).

The geomagnetic field for purposes of exploration geophysics is composed of three main parts (Telford et al, 1976):

- i) main field - of internal origin,
- ii) external field - a small fraction of the main field which originates outside the earth, and
- iii) variations in the main field - caused by local magnetic anomalies in the near-surface crust of the earth. These are the targets of 'magnetic prospecting'.

2.1.1. Components of Main Field

At any point on the Earth's surface, a compass needle free to rotate in all directions, will point in the direction of the resulting total intensity magnetic field (F in Figure 2.2) inclined to the horizontal at an angle i and deflected from the geographic North-South line at an angle d . It is this field, or some component of this field, that is measured in geophysics.

ORIENTATION OF MAGNETIC FIELD COMPONENTS AT A POINT ON THE EARTH'S SURFACE

plane containing H and F defines MAGNETIC MERIDIAN

i - angle of INCLINATION

d - angle of DECLINATION

ISOGONIC maps - lines of EQUAL DECLINATION

ISOCLINIC maps - lines of EQUAL INCLINATION

ISODYNAMIC maps - lines of EQUAL INTENSITY

In any of X, Y, Z, H, F

Figure 2.2

2.1.2. Origin of Main Field

Although several hypotheses have been suggested for mechanisms to generate the internal magnetic field, the current one supports the theory that the field is caused by electric currents circulating in the earth's liquid outer core (Telford et al, 1976). The source is considered a self-excited dynamo in which a highly conductive fluid moves about in complex motions while chemically or thermally caused electric currents flow through it. The combination of motion and current creates a magnetic field, which varies slowly with time relative to variations in the external field.

2.1.3. External Magnetic Field

The external field comprises approximately 1% of the main field and is associated with electric currents in the ionized layers of the outer atmosphere. Several effects associated with the external field include an 11 year cycle associated with sunspot activity, solar (24 hour) and lunar (25 hour) diurnal variations, periodic (27 day) and erratic magnetic storms (Telford et al, 1976).

2.1.4. Local Variations in Main Field

Changes occur in the main magnetic field due to variations in magnetic mineral content of crustal rocks. Local variations caused by the magnetism of near surface material are the main targets of geophysical exploration.

2.2. Basic Considerations in Magnetic Interpretation

Any magnetic material, when placed in a magnetic field (in exploration geophysics, the Earth's field) has poles induced on its surface. The proportionality factor between the measured intensity of magnetization of a magnetic material and the applied field is called the magnetic susceptibility (X) of the material and is a significant variable in magnetic interpretation. Susceptibilities are measured 'in situ' or in a laboratory. Positive susceptibility materials are called ferro- or para-magnetic whereas negative susceptibility materials are referred to as diamagnetic materials. For detailed explanations of these terms and the magnetism of rocks and minerals, the reader is referred to the literature (Dobrin, 1960; Kipp, 1962; Grant and West, 1965; Strangway, 1970; Telford et al., 1976).

The measured magnetization (J) of any rock sample is attributed to the induced component of the Earth's field (F) and a remanent magnetization (R) of the rocks magnetic constituents. Remanent magnetization is the magnetization

acquired by the rock as it cooled below its Curie temperature (temperature above which any magnetic material loses its magnetic properties) in the Earth's magnetic field. Therefore, the measured magnetic intensity is:

$$\vec{J} = \vec{R} + \chi \times \vec{F} \quad \text{.....(2.i)}$$

where χ is the magnetic susceptibility.

2.2.1. Magnetic Units in Geophysical Prospecting

In magnetic prospecting, variations in intensity (or some component of intensity) of the earth's magnetic field are measured. The unit of field intensity is the oersted. The total magnetic field of the earth is of the order of 0.5 oersted. The oersted is too large a unit for practical use in geophysical prospecting (Dobrin, 1960). Consequently, a smaller unit of magnetic intensity called the gamma is used. One gamma is equal to .00001 oersted (1 gamma = 10^{-5} oe).

2.3. Magnetic Materials in the Earth

The magnetic properties of most common rocks can be attributed to minerals in the ternary system $\text{FeO-Fe}_2\text{O}_3\text{-TiO}_2$, which includes magnetite and ilmenite. Pyrrhotite also

possesses ferromagnetic properties similar to those of hematite (Grant and West, 1965, Strangway, 1970). Almost all rocks contain small percentages of iron oxide and sulfide minerals with ferri-magnetic properties. The minerals carrying the magnetism are usually iron or manganese rich. These oxides and sulfides occur as small grains dispersed through a usually diamagnetic matrix.

Tables 2.1 and 2.2 (from Telford et al 1976; p. 121) list magnetic susceptibilities of various rocks and minerals. Magnetic susceptibility is normally lower in sedimentary rocks than in basic igneous rocks.

2.4. Factors Affecting Magnetic Surveys

One important factor in magnetic surveys is a compensated magnetometer system; i.e., a system free of effects from aircraft manoeuvring. If a magnetometer system is not compensated, spurious signals which are a reflection of 'noise' rather than significant magnetic features may occur in the data. A test strip for magnetometer compensation is located south of Ottawa at Bourget, Ontario. Data obtained over the strip during calibration of an aircraft magnetometer system are compared to values obtained at the Blackburn Geomagnetic Observatory near Bourget.

TABLE 2-1
Magnetic Susceptibilities of Various Rocks

Type	Susceptibility x 10 ⁶ emu Range	Average	Type	Susceptibility x 10 ⁶ emu Range	Average
Sedimentary			Igneous		
Dolomite	0-75	10	Granite	0-4000	200
Limestones	2-280	25	Rhyolite	20-3000	
Sandstones	0-1660	30	Dolerite	100-3000	1400
Shales	5-1480	50	Augite-Syenite	2700-3600	
Av. Var. Sed. (48)	0-4000	75	Olivine-Diabase		2000
Metamorphic			Diabase	80-13,000	4500
Amphibolite		60	Porphyry	20-16,700	5000
Schist	25-240	120	Gabbro	80-7200	6000
Phyllite		130	Basalts	20-14,500	6000
Gneiss	10-2000		Diorite	50-10,000	7000
Quartzite		350	Pyroxenite		10,500
Serpentine	250-1400		Peridotite	7600-15,600	13,000
Slate	0-3000	500	Andesite		13,500
Av. Var. Met. (61)	0-5800	350	Av. acid Ign.	3-6530	650
			Av. basic Ign.	44-9710	2600

TABLE 2-2

Magnetic Susceptibilities of Various Minerals

Type	Susceptibility x 10 ⁶ emu Range	Average	Type	Susceptibility x 10 ⁶ emu Range	Average
Graphite		-8	Siderite	100-310	
Quartz		-1	Pyrite	4-420	130
Rock Salt		-1	Limonite		220
Anhydrite, Gypsum		-1	Arsenopyrite		240
Calcite	-0.6- -1		Hematite	40-3000	550
Coal		2	Chromite	240-9400	600
Clays		20	Franklinite		36,000
Chalcopyrite		32	Pyrrhotite	10 ² -5 x 10 ⁵	125,000
Sphalerite		60	Ilmenite	2.5 x 10 ⁴ -	
Cassiterite		90			
			Magnetite	3 x 10 ⁵	1.5 x 10 ⁵
				10 ⁵ -1.6 x 10 ⁶	5 x 10 ⁵

In field operations, diurnal variations in the magnetic field during a survey are monitored using base stations. Data from these base stations are later used to correct in-flight data.

The corrected results of a magnetic survey are used to produce mainly total intensity aeromagnetic maps. Regional gradients due to the magnetic field of the earth have not been removed from these maps.

CHAPTER 3

A. CORRELATION TECHNIQUE - PEAK COINCIDENCE

3.1. Introduction

Among the numerous examples of correlation techniques applied to geophysical data that exist in the literature are:

- (a) mathematically oriented techniques such as autocorrelation, cross correlation, internal correspondence analysis and cluster analysis techniques which determine trends for the geophysical data and assist in interpreting subsurface geology (Bowen et al., 1978; Agarwal and Kanasewich, 1971; Serson and Hannaford, 1957) and
- (b) non-mathematical techniques which correlate anomaly patterns on geophysical maps (gravity, magnetic, radioactivity) to indicate possible associated surface or subsurface geological features (Griscom and Petersen, 1961; Neuschel, 1970; U.S. ERDA, 1976).

Many mathematical techniques use complex procedures to provide some additional information, whereas non-mathematical techniques are mostly visual comparisons of results for qualitative interpretation.

Whether mathematical or non-mathematical, at some time in the interpretation procedure, correlation of geophysical data frequently requires the superposition of transparencies of one anomaly profile or map on one or more others. Areas for which more detailed surveys would be of value often are areas where anomaly profiles have coincident or adjacent peaks. If the amplitudes of the anomalies are high relative to the rest of the profile, masking of anomalies by profile superposition is not a problem. However, if the amplitudes are small, anomalies that may be of geological significance and exploration interest can often be masked, considered insignificant or overlooked. For example, small amplitude anomalies that occur in airborne radiometric and magnetic data could indicate areas where radioactive mineralization, related to magnetic mineralization, is covered by overburden: such anomalies might be of significant geological or exploration interest and could be masked or overlooked.

Therefore, the remainder of this chapter describes a simple, easily comprehended, point by point correlation technique for any two geophysical parameters. The technique indicates points along the flight path where complete or

partial peak coincidence between the parameter profiles occurs. Because each data point along a profile is assigned a value indicative of peak coincidence between the two geophysical parameters being correlated, the values are referred to as Correlation-Coincidence Values (CCV). The CCV technique is intended as a simple, 'first look' indicator of areas of geological interest and can be applied during routine computer processing of geophysical data. Both masking and human bias are minimized and all potential areas of geological significance should become more obvious.

The CCV technique is applied (Chapter 4) to concurrently collected airborne radiometric and magnetic data. Because 'Peters Half Slope' technique, for determining depths to the top of the causative source of a magnetic anomaly, is a readily understood method, computer software for a modified 'Peters Half Slope' technique was developed and applied to the magnetic profile data. The depth estimates are only approximations and when compared to the CCV, intended as indicators of possible continuity at depth of the causative sources of the radiometric anomalies. The combination of the CCV and depth estimate techniques are referred to as 'the CCV approach' in the remainder of this thesis. Comparison of all profile data for a flight line with the known geology is used to assess the validity of the CCV approach.

3.2. Computer Programs

Computer programs developed to determine the CCV values are presented in the appendices. In the text of the thesis, references to the software are included in brackets; e.g., (SUBRD) is the reading routine. The FORTRAN programs were developed for use on a CYBER computer system.

3.3. Correlation-Coincidence Value (CCV) Determinations

The procedure used to derive CCV values correlating the radiometric and magnetic data is illustrated in Figure 3.1. The two curves (Parameter 1; Parameter 2), are arbitrarily drawn and represent a series of peak and trough coincidences that might occur when two geophysical profiles are plotted for comparison. Either profile could represent aeromagnetic or radiometric data. In Figure 3.1(a), the profile for parameter 1 is based on radiometric data and parameter 2 on magnetic data. Parameter 1 could represent raw count rate data or the background-subtracted, corrected concentration data for any of the seven commonly considered radiometric parameters. Parameter 2, the 'magnetic' profile, indicates the total magnetic field intensity.

As previously indicated, small amplitude peaks along profile curves may be of considerable importance. For example, a small amplitude magnetic anomaly could indicate a

CORRELATION-COINCIDENCE VALUE (CCV) EVALUATION FOR PROFILES OF TWO GEOPHYSICAL PARAMETERS

Figure 3.1

low magnetic susceptibility source filling a fracture in highly radioactive material; the radioactive material could have been covered with sufficient overburden to attenuate most of the gamma emissions, resulting in a low amplitude radiometric anomaly. Coincidence of the low amplitude magnetic anomaly with part or all of the low amplitude radiometric anomaly could be significant in indicating a 'target' area for subsequent exploration. However, if an interpreter superimposed the two profiles, the small perturbations in the profile of one parameter could be 'masked' by the other profile or could be considered insignificant.

In order to eliminate the possibility of ignoring these small but potentially significant peaks, the CCV technique developed here considers the actual values of anomaly amplitudes as less significant than the fact that an increase in amplitude occurs. Amplitudes are used only as indicators of peak or trough areas. The correlation technique considers all amplitude values, not just peak maxima values, when all or part of a large (or small) amplitude magnetic anomaly is coincident with all or part of a large (or small) amplitude radiometric anomaly. The technique assigns a CCV, based on an increase or decrease in profile amplitudes, to each data sampling point along the flight path. A point along the flight path where a high amplitude magnetic anomaly is exactly coincident with a low amplitude radiometric anomaly is

assigned the same CCV as it would be if the radiometric anomaly were of higher amplitude. Amplitude values of peaks along the flight path are of secondary importance; the amount of overlap (in the best case, complete coincidence) between peaks on the anomaly profiles is most significant.

The CCV software considers the peak areas as the higher valued points that occur between points of inflection along the profiles of data. The low value data points between the 'flex' points are considered trough areas. To eliminate possible problems in subsequent data processing, the most negative value (SUBMM) that occurs along a profile is assigned a value of zero (SUBZL) and all other values (for the particular parameter) are adjusted accordingly.

Because amplitude variations, rather than actual amplitude values, are of significance in this technique, the correlation is simplified by first assigning points along a profile as being: (a) in a peak area or (b) outside a peak area. If the 'yes' areas (in a peak) are assigned a value of one (1) and the 'no' areas (in a trough) assigned a value of zero (0), a profile resembling a histogram with values of zero or one; i.e. a 'binary histogram', can be obtained for each of the two data sets (HR(I) for radiometric data; HM(I) for magnetic data in SUBCF). 'Binary histograms' for the arbitrarily drawn radiometric and magnetic profiles of figure 3.1(a), are shown in Figure 3.1(b) and 3.1(c). Note that the

values of 0 and 1 are arbitrary. The profiles of figure 3.1(a) are now reduced to 'binary histograms'. Correlation of the profiles of geophysical data now reduces to comparing 'binary histograms' for the two parameters; correlation-coincidence values are determined by comparing ones and zeros and assigning arbitrary CCV values to the data points for particular areas of overlap.

Although the range of values for the CCV is arbitrary, a logical approach is to have the highest value occur in areas where there is apparent 'binary 1' or 'peak' coincidence for both parameters. Rather than assign all other areas a zero value or no value at all, it would help in the interpretation of the data to 'flag' areas where only a radiometric peak, a magnetic peak or where no peaks occur. Therefore, when comparing the 'binary histogram' profiles of the parameters being correlated, CCV values of 0, 1, 2, 3 were chosen (Figure 3.1(d)). The CCV are assigned as follows:

- (a) CCV=0 when there is a 'binary histogram' zero for both the radiometric and magnetic data; i.e., $HR(I)=HM(I)=0$ in SUBCF. CCV=0 represents 'trough' coincidence areas for the original profiles of data.
- (b) CCV=1 when there is a magnetic 'binary histogram' one coincident with a

radiometric 'binary histogram' zero; i.e., $HM(I)=1$; $HR(I)=0$. $CCV=1$ represents a magnetic peak area coincident with a radiometric trough area on the original profiles of data.

(c) $CCV=2$ when there is a radiometric 'binary histogram' one coincident with a magnetic 'binary histogram' zero; i.e., $HR(I)=1$; $HM(I)=0$. $CCV=2$ represents a radiometric peak area coincident with a magnetic trough area on the original profiles of data.

(d) $CCV=3$ when there is a 'binary histogram' one for both the radiometric and magnetic data; i.e., $HR(I)=HM(I)=1$. $CCV=3$ represents peak coincidence areas for the original profiles of data.

Therefore, the CCV indicate where partial or complete coincidence of anomaly peaks occurs along the profiles of the correlated parameters. Note that a $CCV=1$ is just as significant in terms of coincidence as a $CCV=2$ - the 2 implies only that part of a radiometric 'peak' occurs at the same point as part of a magnetic 'trough'. Similarly, the

- CCV=1 implies that part of a magnetic 'peak' occurs at the same point as a radiometric 'trough' (Figure 3.1).

3.3.1. Other Considerations of CCV

CCV=3 values are considered as primary 'target' areas because these are areas where partial or complete coincidence of profile anomaly peaks occur. However, areas where CCV=0, 1, or 2 should not be completely ignored.

It is possible, when correlating geophysical data, that the profiles for the two geophysical parameters that are being compared would not have any coincident peaks (or parts of peaks) to give a CCV=3. For example, when correlating radiometric and magnetic data, there could be enough separation between the peaks of the anomaly profiles to give one or more CCV=1 values adjacent to one or more CCV=2 values, even though the sources of the anomalies are geologically related; a magnetized layer of folded sediments might create a magnetic anomaly that is associated with a different buried or outcropping radioactive layer of the same sediments (Figure 3.2). The radioactive layer could produce an anomaly peak (CCV = 2) just at or near the 'flex' point peak area of the magnetic profile peak (CCV = 1). Because there is no peak coincidence, a CCV=3 does not occur, yet the anomaly sources are geologically related. Another possible geological

LOW VALUE CCV (APPARENT LOW CORRELATION)
CALCULATED FROM PROFILES OF RELATED GEOLOGICAL SOURCES

Figure 3.2

setting, within folded sediments where radioactive and magnetic minerals are related, could provide radiometric anomalies (CCV=2) which are discontinuous across an area (due to partial or complete shielding of the gamma radiation by overburden) but at certain points the CCV technique indicates values of CCV=1 (magnetics dominant) or CCV=3 (peak coincidence which is an area of primary significance). Comparison of the CCV=1 and CCV=3 data to other available geological or geophysical data could provide an interpretation indicating continuity of CCV=2 (radiometrics dominant) across the area

3.4. Depth Estimate Techniques using Magnetic Data

In order to infer continuity of the source of radiometric anomalies below surface, depth determinations based on the magnetic data are helpful. Qualitative interpretations of magnetic data attempt to relate the anomalous patterns on maps or along profiles to known geology (Kornik, 1969; MacLaren and Charbonneau, 1968; McGrath and Cameron, 1975), whereas quantitative interpretations provide an estimate for the depth of burial to the top of the causative source of the magnetic anomalies (McGrath et al., 1973). Many quantitative interpretation techniques use models to represent geological features (Martin, 1966; Nettleton, 1942; Vacquier et al, 1951). Computer techniques (McGrath and Hood, 1970) and

"RULE OF THUMB" DEPTH ESTIMATE TECHNIQUES USING MAGNETIC ANOMALY PROFILES

Figure 3.3

simple 'Rule of Thumb' techniques (Peters, 1949) for quantitative interpretation also are used.

Some of the 'short cut' techniques for depth estimation to a causative body use the full width-half maximum (FWHM) values of anomaly profiles (Peters, 1949). A multiplication factor is dependent on the assumed shape of the causative body. A FWHM technique is illustrated and explained in Figure 3.3. All of the 'half-maximum' techniques have a weakness in that it is frequently difficult to obtain the correct FWHM value due to interference from adjacent anomalies (Figure 3.3 and Figure 3.5).

Three 'slope' techniques for depth estimation to the source of magnetic anomalies are illustrated in Figure 3.4. 'Peters' half-slope method (Peters, 1949) determines the horizontal distance between points where lines parallel to half the maximum slope line along an anomaly are tangent to the anomaly curve. This distance is then divided by a factor dependent on the assumed dyke width. The "Sokolov" technique uses a maximum slope value also. The "Straight Slope" technique uses areas along profile curves that approximate a straight line. All the techniques use horizontal lengths on "dyke" curves that can be transformed into vertical depths (Reford, 1964).

DEPTH DETERMINATIONS FROM MAGNETIC ANOMALY PROFILES

look for HORIZONTAL LENGTHS on "DYKE" profile
that can be TRANSFORMED into DEPTHS

- HORIZONTAL LENGTHS (1) must use readily identified points
(2) must be sensitive to depth changes
(3) must be insensitive to dyke width and attitude changes
(4) must not interfere with neighbouring anomalies

PETERS and SOKOLOV FACTORS

Horizontal Lengths are DIVIDED by these factors

DYKE WIDTH	PETERS FACTOR	SOKOLOV FACTOR
0	1.2	1.54
1.1 x depth	---	2.0
2.0 x depth	1.6	---
semi-infin	2.0	3.14

Figure 3.4

DEPTH ESTIMATE INTERPRETATION (Peters half-slope factor = 1.6)

Figure 3.5

A modification of Peter's half slope technique (both slopes on any one anomaly peak are used rather than just the maximum slope) is used in this thesis (subroutine SUBPHS). The depths determined are intended only as approximations to infer continuity of radioactivity at depth. Figure 3.5 illustrates that more than one interpretation of the calculated depth estimates is possible; the depth estimate data should be compared to known geological and other geophysical data when they are available.

CHAPTER 4

APPLICATION OF THE CCV TECHNIQUE TO REAL DATA

4.1. Geology Of The Study Area

The Chedabucto Bay area of the Province of Nova Scotia was chosen to test the potential usefulness of the CCV technique. This area was chosen because the concurrently collected aeroradiometric and aeromagnetic data represents a detailed survey (0.5 km flight line spacing) over an area for which detailed geology maps are available (Geological Survey of Canada Maps 379, 381, 1156A; N.S.D.N.E. Geological Map of Nova Scotia). The area is outlined in figure 4.1. The geological maps are used to confirm the usefulness of the CCV technique as an aid to geological mapping and as an indicator of primary exploration 'targets'.

The metasedimentary Meguma Group (Figure 4.1) underlies approximately 30 percent of mainland Nova Scotia and includes the thinly stratified Halifax Formation (Halifax Slates) and the Goldenville Formation (Goldenville Quartzites). Descriptions of the Meguma Group geology are presented as descriptive notes on the Geological Survey of Canada map No. 1156A (compiled by I.H. Stevenson, 1958) and in publications

GENERALIZED GEOLOGY OF STUDY AREA

HORTON GROUP

Undivided

Craignish Formation
(siltstone, sandstone)

UNDIFFERENTIATED

DEVONO-CARBONIFEROUS

(conglomerate, sandstone,
siltstone, shale)

FOUNTAIN LAKE GROUP

(basalt, siltstone,
rhyolitic flows)

GRANITE

MEGUMA GROUP

Halifax Formation
(siltstone, slate)Goldenville Formation
(greywacke, slate,
quartzite)

(Modified from geological map of Nova Scotia, NSDME, 1979)

Figure 4.2

by Taylor and Schiller (1966), Poole (1967) and Schenk (1970). The Horton Group consists of sandstone, siltstone, shale, conglomerate, dolostone and coal.

4.1.1. Magnetic Data

Figure 4.2 is part of an aeromagnetic anomaly map published by the Geological Survey of Canada (Map 7034G). The steady increase in amplitude of the magnetic anomalies from the lower right corner to the upper left corner of Figure 4.2 is due, in part, to the high magnetic gradient (3.8 gammas/km; 6.1 gammas/mile) of the earth's magnetic field (Figure 4.3: from Cameron and Hood, 1975). Removal of the IGRF gradient provides better resolution of the magnetic anomalies. The regional gradient was not removed from the aeromagnetic data used in this thesis.

The cause of the dominant linear and quasi-circular magnetic anomalies (Figure 4.2) over the Meguma Group of Nova Scotia is pyrite (FeS_2), pyrrhotite (Fe_7S_8) and magnetite (Fe_3O_4). The magnetic linears of the Halifax slates are caused by pyrrhotite, whereas magnetic features associated with the Goldenville Formation are caused by magnetite. Quasi-circular magnetic anomalies associated with some of the granitic intrusions (Figure 4.1) are caused by magnetite (McGrath, 1970).

REGIONAL MAGNETIC FIELD (1965.0), NOVA SCOTIA

Figure 4.3 (from Cameron and Hood, 1975)

4.1.2. Radiometric Data.

The radioelement of primary interest in radiometric surveys is uranium. Figure 4.4, the eU (ppm) contour map (G.S.C. Geophysical Series, Map No. 35611(6)g2) for the Chedabucto Bay area of Nova Scotia, represents four separate survey areas compiled into one. The map sheet in the upper left hand quadrant of Figure 4.4 is the Guysborough map sheet. Computer drawn maps are useful to indicate broad scale anomalous areas and to show regional trends across a survey area. However, contouring of data to produce maps requires interpolation to a grid and acts as a filter in itself (Cameron et al., 1976). Therefore profile data along a flight line more accurately reflects radioelement variations and is more reliable for a detailed interpretation.

Magnetic data represent the resultant of all the components that contribute to the total magnetic intensity. Total radioactivity data (Ur) is derived from count rates which include the three main radioelement (K, eU, eTh) channels. Therefore, correlation between total magnetic intensity and total radioactivity, rather than with the radioactivity of an individual radioelement, is a valid test of the CCV technique. The Ur map (total radioactivity) for the Chedabucto Bay area exhibits the same general anomalous patterns evident on the eU map (Figure 4.4) of the area.

eU MAP (ppm) CHEDABUCTO BAY AREA (NOVA SCOTIA)
GUYSBOROUGH MAP SHEET

(combination of 4 map sheets)

Figure 4.4

Profiles of the parameters used for a test line of data across the study area are shown in Figure 4.5. The same general anomalous patterns can be seen in the eU and Ur profiles. The radiometric data have been corrected for dead time, ambient temperature changes, background radiation, spectral scattering and deviations of terrain clearance from the planned survey altitude. The radiometric data represent average surface concentrations and reflect the relative distribution of radioelements at the surface. The magnetic data have not been corrected for altitude fluctuations and the IGRF gradient has not been removed.

4.2 Data Reduction Problems

As indicated in Chapter 3, the CCV technique considers profile 'slope' values along a line of data to determine a peak area. Small and large amplitude peaks are of equal significance. If the data to be used is 'noisy', many 'noise' peaks could appear to be significant. The aeromagnetic data for the study area was collected with an uncompensated magnetometer system (each value has an error of + or - 10 gammas: Holman, personal communication, 1982) and is not corrected for variations in altitude. The magnetic data is acceptable for detecting large amplitude magnetic anomalies but presents additional problems in applying the CCV technique.

MULTIPARAMETER PROFILES

FOR SAMPLE LINE

ACROSS STUDY AREA

FIGURE 4.5

LEGEND FOR FIGURE 4.5

WATER

HORTON GROUP

CANSO GROUP

GRANITE

..GOLDENVILLE QUARTZITE

DEGUA GROUP .

..HALIFAX SLATES

Reference: Geological Survey of Canada, Map 1156A

Compiled by I.H. Stevenson

In an effort to minimize the 'noise' peaks, treat all correlated data the same, minimize the negative effects to the CCV approach and provide data that could be contoured as a map (to indicate trends in the data), a 'running average' (SUBHA) was applied to all 'raw' radiometric and magnetic data. The 'running average' was applied to the 'raw' data several times. The number of points to be included in an average was kept constant along the length of a profile each time. The number of points used in an average ranged between 5 points up to 21 points. The 21 point smoothed profile still exhibited a considerable number of CCV peaks. It was obvious from the CCV profiles, for the complete range of averages applied, that a contour map of CCV would appear as closely spaced, 'stringy' contours. The 'stringy' appearance is also a result of low flight altitude (0.12 km) with wide (relative to altitude) flight line spacing (0.5 kms). A 'stringy' map with closely spaced contours could indicate false trends perpendicular to the flight lines and would not help verify the CCV technique.

The 'stringy' appearance of the map contours can be minimized by more smoothing along the lines of data (Cameron et al., 1976). However, the filtering effects of even more smoothing, combined with the filtering effects of map gridding, would eliminate many of the small amplitude anomalies the CCV technique is designed to detect. The resulting trend map would only provide broad, regional 'trend' information already evident on the radioelement maps

commonly produced. Therefore, a trend map is not included in the thesis.

A 15 point 'running average' was considered sufficient to remove most 'noise' peaks in the radiometric and magnetic data and still preserve all significant anomaly peaks along the profiles. The aeromagnetic and radiometric data of Figure 4.5 have a 15 point 'running average' applied to them. The CCV and the depth estimate profiles are based on the smoothed data. To further minimize inherent 'noise' problems of the magnetic data, the computer software (SUBPHS) requires valid peaks for a depth determination to have more than one value in the peak area before a depth estimate is calculated. Single point peaks are 'flagged' and no depth estimate is calculated for them.

4.3. Correlation-Coincidence Value Interpretation

Figure 4.5 represents the data necessary for a CCV interpretation. The aircraft altitude parameter is included to determine if anomalous magnetic or radiometric data are caused by altitude variations creating source-detector geometry changes which would alter the 'field of view' of the spectrometer. Figure 4.5 represents data recorded at 724 points along flight line 43 of the Chedabucto Bay area survey. Line 43 is one of 82 lines of data used to produce figure 4.4. Line 43 includes most of the significant geological features

of the study area (Figure 4.1) and provides varying magnetic (Figure 4.2) and radiometric (Figure 4.4) anomaly amplitudes.

Peak coincidence areas, denoted by CCV=3 values, are considered to be the primary areas for more detailed geological and geophysical surveys. CCV=3 areas relate radioactive material at or near the surface (gamma radiation is attenuated by approximately one metre of overburden) to magnetic material near the surface or at depth. Because such a large error (+ or - 10 gammas) was allowed in the magnetic data for the study area, many of the numerous CCV=3 peaks evident along the CCV profile of Figure 4.5 were initially attributed to 'noisy' data. Therefore, the CCV=3 peaks were grouped into 51 different 'sets'. The set grouping was arbitrary: CCV=3 points that appeared close to each other were considered a 'set'; individual CCV=3 points that did not appear related to adjacent peaks were considered as a separate 'set' (e.g., sets 8, 21, 26, 27). The 'degree of closeness' before CCV=3 values are grouped into 'sets' is at the discretion of the interpreter. The 'set' grouping from one interpreter to the next would probably not vary too much.

Plan and section views of the geology along the approximate flight path for line 43 are shown at the bottom of Figure 4.5. The geology is based on data published by the Geological Survey of Canada (Maps 379, 381 and 1156A) and Figure 4.1. The CCV profile was further grouped into 9 larger

areas (A to I) based on the geology. Areas A and B represent Horton and Canso Group rocks, areas C, E, G, and I represent Meguma Group rocks and areas D, F, and H represent granitic rocks. A small area of granite is included in area E. The 'groups', 'sets' and other profiles of data in Figure 4.5 are compared to test the validity of the CCV approach in general.

One of the more apparent features of Figure 4.5 are the smooth areas of the total count radioactivity and aeromagnetic profiles. The profiles show some variation in the total radioactivity (broad peak areas) with minimal variation in the aeromagnetic data. Mainly CCV=2 values (dominant radioactivity peaks), with very few CCV=3 values (peak coincidence), would be expected along the profile for these areas. However, the computer software is designed to detect the smallest recorded peaks on both profiles and numerous peak coincidence (CCV=3) areas are indicated. In Figure 4.5, CCV=3 sets 1 to 12, 15 to 19 (area A), 27 to 31 (area D) and 39 to 51 (area I) are all in apparently smooth areas (particularly along the aeromagnetic profile).

Area A represents undifferentiated Horton Group and Canso Group rocks. CCV sets 1 to 14 are associated with the Horton Group and sets 15 to 17 are associated with Canso Group rocks. The CCV values in area A indicate variations in radioactive and magnetic mineral content associated with the two Groups. The depth estimate profile for area A indicates a variation to

the depth of the causative source of the small amplitude magnetic anomalies detected in the data. Since many of the magnetic anomaly peaks are coincident with radiometric anomaly peaks (CCV=3), the radioactive material appears to be associated with subsurface magnetic material. Thus, the CCV approach suggests there are smaller units within the Horton and Canso Groups which may not be mapped or are not evident at the surface. The CCV approach indicates that the source of radioactivity may be continuous at depth.

Because the 'raw' aeromagnetic data has a relatively large error, there is some uncertainty in the above interpretation. However, the 15 point average applied to the data used in the interpretation should have removed any 'noise' problems. To assess the validity of the interpretation for the undifferentiated 'A' area, the CCV approach is applied to other areas along the profile where the geology has been mapped in more detail.

Area B includes sets 20 and 21. The total count radiometric and the magnetic profiles for set 20 show a slight amplitude increase in the magnetic data corresponding to a significant amplitude increase in the radiometric data. Because adjacent areas (sets 18 and 19) are over water, the radiometric increase could be attributed to source-detector geometry effects (2 pi to approximately 3 pi geometry), commonly referred to as 'edge effects' of the land; i.e.,

moving from a 'background' area to a more radioactive land area. The low amplitude broad anomaly of the magnetic profile could be interpreted as due to a small increase in magnetic minerals within or below the Horton Group and due to the fault separating areas B and C (Horton Group and Goldenville quartzites). Set 21 coincides with the fault, indicating possible radiometric and magnetic mineralization associated with the fault. CCV values in set 20 vary between $CCV=3$ and $CCV=2$ (with one $CCV=0$) indicating dominant radioactivity with fluctuating magnetics. Because of the 'noise' effects inherent in the magnetic data, the fluctuating magnetics might be considered misleading. However, the data has had a 15 point 'running average applied to it; the fluctuating magnetics are therefore interpreted as being due to possible bands of magnetic minerals within or below the Horton Group associated with radioactive areas.

The 'depth' profile shows area B is associated with a large trough encompassing all of area B and part of area C. The right hand edge of the trough coincides with the approximate Goldenville-Halifax contact in area C. Set 22 also coincides with this contact. CCV values, from set 20 up to and including set 22, provide useful information for interpreting this 'depth' trough.

Between sets 20 and 21, the CCV values are 1 or 0. The radioactivity would be expected to decrease (which it does)

over water and therefore a CCV=1 (dominant magnetics) is expected. Because the aircraft is climbing at this point (altitude profile) and moving further from the source of the magnetic anomalies, the magnetic intensity could also decrease, creating a 'trough-trough' coincidence between the radiometric and magnetic profile data. This would create the CCV=0 values between sets 20 and 21.

Set 21 coincides with a mapped fault (identified as the Salmon River fault in the descriptive notes of map 1156A). Because set 21 is a CCV=3 and the altitude profile indicates no apparent fluctuations at this point, set 21 is interpreted as coincident radioactive and magnetic material associated with the fault.

Between sets 21 and 22, the CCV values are: 1, 1, 2, 0, 1, 0 and a CCV=3 at set 22. The aircraft descending (altitude profile) at this point is considered a positive effect (detector getting closer to source). The CCV=1 values indicate magnetic peaks coincident with radiometric troughs; the CCV=2 values indicate radiometric peaks coincident with magnetic troughs; the CCV=3 and CCV=0 values represent peak and trough coincidence respectively. Thus, the CCV are interpreted as indicating associated radioactive and magnetic layers within the Goldenville quartzites, some of which are coincident.

Therefore, the interpretation for the source of the broad magnetic anomaly which is causing the depth estimate technique to calculate a subsurface 'trough', is: the anomaly between CCV sets 20 and 22 is created by a considerable number of narrow, geologically associated, magnetic layers at approximately the same depth below the magnetometer. The CCV approach suggests the radioactivity is continuous at depth within the Horton Group, is associated with a mapped fault and is associated with some of the beds of the Goldenville quartzites. Further detailed geological mapping and ground geophysical surveys would have to be carried out to confirm this interpretation.

The flight path indicates sets 18 and 19 occur over water areas. It does appear contradictory that CCV=3 values should occur in this area; the expected radioactivity data would be background readings only and when correlated with the magnetic data, a CCV=1 (dominant magnetics) or a CCV=0 (both profiles have 'trough' areas) would be expected. Peak area radiometric values at set 18 are interpreted as 'edge' effects from the land and fluctuations in background. The CCV=3 values of set 19, implying magnetic and radiometric peaks, are attributed to land effects from aircraft attitude - the altitude profile indicates the aircraft is climbing which would expose more of the detector surface to the land area being approached and therefore detect more than background ('over water') radioactivity. Other possible interpretations for the

apparent radiometric peaks at set 19 are: variations in background radiation along the flight path; the flight path was closer to the small point of land visible just beside (below) it in Figure 4.5. Between set 18 and set 19, CCV=1 values are dominant, as expected.

Sets 23, 24 and 25 in area C are associated with visible peaks on both the magnetic and radiometric data. These sets are also associated with the Halifax slates. The magnetic profile peak area aligned with set 23 coincides with a very small peak to trough area on the radioactivity profile. This peak-trough coincidence could be interpreted as being insignificant if only a visual comparison were made. The CCV values for set 23 are: 3, 1, 1, 3, 1, 3. These CCV values suggest coincident radioactive and magnetic layers (CCV=3) separated by only magnetic layers. Again, continuity of the radioactivity at depth along certain layers is suggested. Because the aircraft was climbing and then descending, corrections for altitude variations should be applied to the magnetic data. More detailed geological mapping is necessary to confirm the interpretation.

Sets 24 and 25 are associated with Halifax slates. They are separated by a CCV=1 area. The centre of the CCV=1 area coincides with a mapped synclinal axis. As the overburden thickness increases above radioactive material (as would happen in a syncline if the material were in a particular

bed), the gamma radiation would be attenuated more and more and eventually the magnetic data (CCV=1) would dominate; as the thickness of the overlying material lessens, the attenuation of gamma radiation decreases and a possible CCV=3 should (and does) occur. The occurrence of radioactive material within particular layers would have to be verified by more detailed geological mapping and gamma-ray spectrometric analyses.

Area D includes set 26 to 32. Visual comparison of area D with the magnetic and radioactivity profiles implies a broad area on the ground providing slow fluctuations in radiation and minimum magnetic variations. The CCV values indicate more fluctuations than are apparent on both the radioactivity and magnetic profiles. The depth estimate profile, which represents the depth to the top of the source of a magnetic anomaly, suggests a relatively non-magnetic, wide, geological feature (large trough area in depth estimate profile), at or near the surface and extending to considerable depth. The suggested geological feature is mapped as the granite which intrudes Meguma Group sediments. Set 32, at the edge of area D, is coincident with the mapped granite contact. Based on the CCV approach, area D is interpreted as having a fluctuating radioactive mineral content near the surface. The radioactive material is associated with minor variations in magnetic material across or within the granite. Because the

granite is a large intrusive body, the radioactivity and magnetism are interpreted as being continuous at depth.

Most of area E (sets 32 to 38) and all of area G (sets 39 to 42) and area I (sets 44 to 51) are mapped as Meguma Group metasediments. If the geology for these areas was not mapped, the depth estimate and CCV profiles could be used (CCV approach). The depth estimate profile suggests undulating depths to the causative sources of magnetic anomalies. The CCV=3 sets are aligned with the more shallow depths and other CCV sets are aligned with deeper areas. This suggests: (a) the radioactivity occurs in narrow areas at or just below the surface (e.g., dyke-like features) and is discontinuous across the area, or (b) the radioactivity follows particular layers in the subsurface. The CCV approach data could be used as a guide for more detailed geological mapping to determine the actual geology.

Depth estimate data and the mapped geology for these areas indicate the undulations in depths conform to the anticlines and synclines that exist in the Meguma Group metasediments. The axes of a mapped syncline (between sets 33 and 34) and two anticlines (between sets 45 and 46; between sets 48 and 49) have CCV=1 or CCV=2 with CCV=3 sets on either side. Because the area consists of layered sediments, the inference again is the existence of radioactive materials continuing at depth along particular layers. The CCV profile

could be used as a guide for further, more detailed geological and geophysical surveys which would confirm the interpretation.

Part of area E (set 35) and all of area F (sets 38 and 39) and area H (sets 43 and 44) are mapped as granites and exhibit the same characteristics as area D. The flight path for line 43 just passes over the edge of the large radiometric anomaly centred in Figure 4.4. The anomaly is directly associated with the granites. Areas of the depth estimate profile in Figure 4.5 which are associated with the granites suggest large, deep bodies, again providing a source for possible continuity of the radioactivity at depth.

Use of the CCV approach as an aid to geological mapping seems to be confirmed by the preceding interpretation for line 43. The interpretation that area A (undifferentiated Horton Group rocks) has variations in radioactivity and magnetism which may be continuous to varying depths, is probably valid. The larger amplitude magnetic anomaly aligned with set 14 is attributed, in part, to the fault separating Horton Group and Canso Group rocks. The anomaly could also be caused by mineralization near or along the fault. As indicated, previously, more detailed geological mapping of this area, particularly in the vicinity of the CCV=3 values, would verify the interpretation.

Continuity of the CCV values, depth estimates and other features of the profiles in Figure 4.5 is evident on other profiles of data for the study area. Detailed interpretations of all the profiles of data used to produce Figure 4.4 should indicate areas where further detailed geological mapping and geophysical surveys would be beneficial.

4.4. Conclusions and Recommendations for Future Study

The conclusions derived from applying the CCV approach to real data are:

1. The CCV approach, which includes a depth estimate technique, may become a valid correlation method for radiometric and magnetic data. What appears initially as numerous CCV values attributable to 'noisy' data, after smoothing provides interpretable profiles. Although there are still numerous CCV values along the smoothed profiles, they do appear to be from real sources, rather than 'noise'. Because contouring the data as it presently exists could provide erroneous trends, further modifications in an effort to produce a good trend map are required.
2. The CCV approach minimizes interpreter bias and eliminates visual 'masking' of potentially significant

areas. All small or large amplitude peaks for the geophysical parameters under study, which may not be visually apparent in the plotted data, are enhanced by the CCV technique.

3. The CCV approach should be useful in geological mapping. Significant CCV values along the test line of data coincide with known faults and geological contact areas. The technique implies changes in geology within areas that are mapped as having no changes. The approach of combining the CCV technique with a depth estimate technique provides additional information to assist in geological mapping.
4. The CCV approach indicates areas where magnetic and radiometric features are dominant and where both are equal. The CCV approach provides data for an interpreter to suggest continuity of radioactivity at depth.
5. The numerous peaks that occur with the CCV approach, as it now exists, prevents contouring the data to produce a map for interpretation purposes. However, application of the CCV approach to profile data may provide a realistic interpretation.

4.4.1 Recommendation for Future Study

In order to further confirm the usefulness of the CCV approach for interpretation of geophysical data, the following is suggested:

1. Application of the CCV approach to the other seven radioelement parameters calculated from the aeroradiometric data. Possibly even better definition of the boundaries for radioactive areas could be obtained.
2. Detailed mapping along several flight paths, using the results implied by the CCV approach as a guide, to further confirm the validity of the technique.
3. Applications of various 'filters' to the profile data. An increase in the number of points in the 'running average' technique may not degrade the CCV data too much. The application of other averaging techniques should also be considered. The objective would be to determine exactly what compromise 'filter' may be valid when using coarse ('noisy') data. The filter should not eliminate any significant 'sets' of CCV, yet might provide CCV values that could be presented as map contours, while avoiding false trends on the map.

Comparison of the present CCV technique with more sophisticated filters would be useful to determine what, if any, additional information may be revealed by the more sophisticated techniques.

4. Application of the CCV approach, as it currently exists, to data collected at a regional scale (5 km line spacing); e.g., data collected by the Geological Survey of Canada under the Uranium Reconnaissance Program (URP). Details of regional trends of radioactive areas may be enhanced. The depth estimate data could be useful for subsurface trends and implying continuity of the radioactive features.
5. Collection of data with a compensated magnetometer system which could minimize some of the 'noise' problems. Correction of the present magnetic data for altitude fluctuations and removal of the IGRF would also be useful.
6. Determination of a 'model' study area (with less complex geology) for which concurrently collected aeroradiometric and aeromagnetic data is available. If the data were not recorded at the same time, then digitization of the available maps and subsequent intermediate data processing,

before applying the CCV approach, would be necessary.

7. Generation of anomaly profiles, based on geometric models, to reproduce the anomaly profiles exhibited by the 'model' study area. Subsequent applications of the current CCV technique or modifications of it would enable a better understanding and interpretation of the resulting data.

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RETURN

.....INPUT FORMAT STATEMENTS

100 FORMAT(A8,7A10)

.....OUTPUT FORMAT STATEMENTS

200 FORMAT(IH)

220 FORMAT(IH,2X,*REVERSED LINE INDICATED-DATA ALSO REVERSED*,2I7)

225 FORMAT(IH,2X,*X(1)=*,F10.3,* X(*,14,*)=*,F10.3)

230 FORMAT(IH,2X,* UNEXPECTED EOF IN INP2, THE FID FILE*)

232 FORMAT(IH,2X,*LINE,NGRD,NREC,NFID = *,A8,3(2X,I6))

235 FORMAT(IH,2X,*ICT,I,FX(I) = *,2(2X,I6),2X,F8.3)

240 FORMAT(IH,2X,* UNEXPECTED EOF IN INP4, THE DAT FILE*)

245 FORMAT(IH,2X,*EOF AT LRD = *,I2,* FOR LINE = *,A8)

C*
51111 CONTINUE
IP=999999

C*

RETURN
END

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APPENDIX A

FORTRAN COMPUTER PROGRAMS

with documentation included

G.W. Cameron

MSc Thesis

Geology Department

Carleton University

----- A.1 -----

Computer programs written for this thesisProgram Name and Purpose1) SCY

- MAIN or CALLING program - to call subroutines for subsequent data processing. Data transfer is mostly through COMMON statements.

2) SUBRD (arg.1, arg.2, ...)

- to READ required data from data files. This program is unique to the particular file structure being accessed and would change with the user.

3) SUBSK (arg.1, arg.2, arg.3)

- to SKIP a set number of records on the data file - unique to the files being accessed.

4) SUBSW (arg.1, arg.2, arg.3)

- a SWITCHING routine - for TWO one dimensional ARRAYS of data. One array contains REAL (decimal) variables; the other array contains INTEGER (no decimal) variables.

5) SUBMM (arg.1, arg.2, ...)

- to calculate a MAXIMUM, MINIMUM and AVERAGE for ONE and TWO dimensional arrays of data.

6) SUBZL (arg.1, arg.2, ...)

- adjusts all data so that the ONE or TWO dimensional array being considered has a MINIMUM value of ZERO. This routine is called only if SUBMM determines a negative minimum value.

7) SUBNA (arg.1, arg.2, ...)

- calculates a MOVING AVERAGE (RUNNING AVERAGE) for ONE or TWO dimensional arrays. The number of points (NMA) to be including in the average are obtained from the calling routine (SCY).

8) SUBCF (arg.1, arg.2, ...)

- calculates a CORRELATION-COINCIDENCE VALUE (CCV) for any two parameters being considered. The radiometric data is stored in TWO dimensional arrays and the aeromagnetic data is stored in a ONE dimensional array.

9) SUBPHS (arg.1, arg.2)

- determines DEPTH ESTIMATES to the top of the source of a magnetic anomaly using PETER'S HALF-SLOPE (PHS) technique. The true PHS technique uses only the maximum slope on any one anomaly. This version uses both positive and negative slopes on an anomaly and calculates a depth estimate for each.

Rather than go through a separate write routine, the data from SUBPHS is output to line printer and tape through SUBPHS also.

10) OUTPUT SUBROUTINES10a-1) SUBWR1 (arg.1, arg.2, ...)

- output original data to LINE PRINTER

10a-2) SUBWT1 (arg.1, arg.2)

- output original data to TAPE

10b-1) SUBWR2 (arg.1, arg.2, arg.3)

- output CCV data to LINE PRINTER

10b-2) SUBWT2 (arg.1, arg.2, ...)

- output CCV data, slopes etc. to TAPE

----- A.2 -----

CALLING SEQUENCE of subroutines

NOTE: The CALLING SEQUENCE of the subroutines is important because many of the subroutines destroy (overwrite) the data previously used in preceding routines.

1) CALL SUBRD

2) CALL SUBMH - 1-D array - aeromagnetic data

CALL SUBHH - 1-D array - altimeter data

- CALL SUBMM - 2-D arrays - radiometric data
- 3) CALL SUBWR1 - original data to output
CALL SUBWT1 - units desired
- 4) CALL SUBZL - if negative values found
CALL SUBWR1 - only partial output to
CALL SUBWT1 - desired output units
- 5) CALL SUBCF - calculate CCV and output
CALL SUBWR2 desired data to output
CALL SUBWT2 units.
- 6) CALL SUBMA - 1-D array moving average
CALL SUBMA - 2-D array moving average
- 7) CALL SUBCF - recalculate CCV and output
CALL SUBWR2 data to desired units
CALL SUBWT2 (partial output).
CALL SUBWR1 -
- 8) CALL SUBPHS - to determine depth estimates
and output to line printer
and tape.

----- A.3 -----

Algorithm for SUBCF (CCV calculations)

The following is a generalized algorithm for subroutine SUBCF, used to determine the CCV of Figure 4.5. The bracketed letters are the particular parameters as they appear in SUBCF.

- 1) calculate slope values for the radiometric (SR(I)) and aeromagnetic data (SM(I)). The x coordinates for these values are the midpoints (XS(I)) of the two values being used to determine a slope.
- 2) by comparing a radiometric slope value with the immediately preceding radiometric slope value, determine if points considered are in a peak or trough area of a curve. If in a trough area, assign a zero (0) value; if in a peak area assign a value of one (1) (HR(I)). The x-coordinates for these values are the same as the x-coordinates of the original data. NOTE: the inflection points on the profile curves occur when the HR(I) values change. The resulting profile has the appearance of a histogram with a values of zero or one: a 'binary histogram'.

- 3) obtain a 'binary histogram' (again zero and one values) for the aeromagnetic profile data (HM(I)).
- 4) by comparing the 'binary' radiometric (HR) and aeromagnetic (HM) values obtained, assign a correlation-coincidence value (CF(I)) to the data sets. The x-coordinates of these CCV are the same as the original x-coordinates for the data. The CCV values, as illustrated in Figure 3.1(d) and Figure 4.5, range between 0 and 3.

----- A.4 -----

LISTINGS OF COMPUTER SOFTWARE USED IN THESIS

MAIN OR CALLING PROGRAM FOR SUBROUTINES TO READ AIRBORNE DATA

DEFINITION OF PARAMETERS.....

IINP = CARD INPUT
 IOUT = LINE PRINTER
 INP1 = SURVLY HEADER DATA FILE
 INP2 = LINE HEADER DATA FILE
 INP3 = BACKGROUND DATA FILE
 INP4 = POINT BY POINT ALONG LINE DATA FILE
 ICT = COUNTERS FROM COUNTER TAPE
 NREC = NUMBER OF RECORDS
 X(I) = X DISTANCE ALONG LINE
 Y(I) = Y DISTANCE ALONG LINES
 NP(I) = NUMBER OF POINTS ALONG LINE OF DATA
 AC(I) = ALTITUDE OF AIRCRAFT
 CN(1,I) = TOTAL COUNTS IN URS
 CN(2,I) = POTASSIUM IN PERCENT K
 CN(3,I) = EQUIVALENT URANIUM IN PPM
 CN(4,I) = EQUIVALENT THORIUM IN PPM
 CR(1,I) = RAW UNCORRECTED TOTAL COUNT DATA (CPS)
 CR(2,I) = RAW UNCORRECTED POTASSIUM COUNTS (CPS)
 CR(3,I) = RAW UNCORRECTED URANIUM COUNTS
 CR(4,I) = RAW UNCORRECTED THORIUM COUNTS
 AM(I) = MAGNETOMETER DATA
 FX(I) = ARRAY FOR FID PT X COORDS
 PX(I) = DIST ARRAY FOR PLOTTING

TITLE(I,J) = TITLE FOR A LINE OF DATA

PROGRAM SCY(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT,TAPE20,TAPE25,TAPE2)

COMMON IINP,IOUT,ITAP,INP1,INP2,INP3,INP4

COMMON X(1200),Y(1200),PX(1200),ICT(1200)

COMMON CN(4,1200),CR(4,1200),AM(1200),AC(1200)

COMMON FX(1200),A1(1200),A2(1200),A3(1200),A4(1200)

COMMON TITLE(100,7),NP(100),CN(100),IFDC(100)

COMMON IWT1,IWT2,IWT3,IWT4,IWT5

IINP=5

IOUT=6

ITAP=2

PROGRAM JLY

73774 OPT=1

110 4.00000

IP1=1

IP2=1

IP3=1

IP4=1

FI=1.0 FU=1.0

K=0

MAIN LOOP START

READ #,NMA

1) CONTINUE

MR=0

NVALS IS THE NUMBER OF VALUES TO BE CONSIDERED IN ARRAYS
AND HAS THE SAME VALUE AS THE DIMENSION STATEMENTS
IF DIMENSIONS ARE DECREASED (OR INCREASED), CHANGE NVALS

NVALS=1200

SKIP TO TOP OF A NEW PAGE

WRITE(10UT,500)

INCREMENT COUNTER

K=K+1

INITIALIZATION PROCESS FOR MOST VARIABLES ETC

NO=0

IP=0

NMA IS NO OF POINTS IN MOVING AVERAGE IF THIS IS TO BE USED

FOLLOWING ZEROS THE ARRAYS

DO 20 J=1,NVALS

X(J)=0.0

Y(J)=0.0

PK(J)=0.0

AM(J)=0.0

AC(J)=0.0

FX(J)=0.0

A1(J)=0.0

A2(J)=0.0

A3(J)=0.0

A4(J)=0.0

ICT(J)=0

DO 15 I=1,4

CN(I,J)=0.0

CR(I,J)=0.0

15 CONTINUE

20 CONTINUE

```
PRINT 5000
5000 FORMAT(1H0,2X,*JUST ZEROED ARRAYS FOR START*)
CALL SUBRD(FI,FU,IP,NF,K,LINE,NGRD)
PRINT 5001, LN(K),LINE,NGRD
5001 FORMAT(1H ,2X,*JUST READ THE NEXT LINE =*,2(A8,1X),I6)
C*
PRINT 502,LINE
IF(IP.EQ.1) GO TO 10
IF(IP.EQ.2) GO TO 10
IF(IP.EQ.999999) GO TO 999
C*
C*
C*      INT3 DETERMINES IF AND WHICH DATA IS WRITTEN TO TAPE
C*      IF INT3 = 0 - DATA IS NOT WRITTEN TO TAPE
C*      = 1 - LINE NUMBER AND TITLE TO TAPE AS WELL AS
C*            NO. OF POINTS, FIDS, MEASURED X, PLOT X AND Y
C*      = 2 - SMOOTHED MAG DATA TO TAPE
C*      = 3 - ALL RADIOELEMENT CONC DATA AND CCV DATA TO TAPE
C*      = 4 - WRITES PETERS HALF SLOPE DATA TO TAPE
C*
IF(INT3.EQ.1) CALL SUBWT3(NF,K,MR)
C*
C*      CALCULATE MAX, MIN AVE FOR LINE OF DATAP
C*
C*      CALCULATE AVERAGE FOR AEROMAG DATA
C*
      NQ=8
      MR=1
      IARR=1
      CALL SUBMM(IARR,MR,K,NQ)
      IF(NQ.GE.20) NQ=100
      IF(NQ.GE.20) WRITE(IOUT,503) NQ
      IF(NQ.GE.20) GO TO 10
C*
C*      CALCULATE AVERAGE FOR ALTIMETER DATA
C*
      NQ=9
      MR=2
      IARR=1
      CALL SUBMM(IARR,MR,K,NQ)
      IF(NQ.GE.20) NQ=120
      IF(NQ.GE.20) WRITE(IOUT,503) NQ
      IF(NQ.GE.20) GO TO 10
C*
C*      CALCULATE AVERAGE FOR RADIOELEMENT CONCENTRATION DATA
C*      MR=3,4
C*
C*      CALCULATE AVERAGE FOR RADIOELEMENT RAW DAT
C*      MR=5,6
C*
      NQ=6
      IARR=2
C*
      DO 25 MR=1,6
      CALL SUBMM(IARR,MR,K,NQ)
      IF(NQ.GE.20) NQ=130
      IF(NQ.GE.20) WRITE(IOUT,503) NQ
```

```
IF(NQ.GE.20) GO TO 10
20 CONTINUE
C*
  MR=0
C*
  WRITE DATA TO LINE PRINTER
C*
  CALL SUBWR1(NF,K,LINE,NGRD,MR)
C*
  ADJUST ZERO LEVEL TO ZERO IF NEGATIVE VALUES
C*
  DO 30 MR=1,10
    IARR=2
    NQ=MR
    IF(NQ.GT.8) IARR=1
    IF(AZ(NQ).LT.0.0) NSMR=1
    IF(AZ(NQ).LT.0.0) CALL SUBZL(IARR,MR,K,NQ)
    IF(NQ.GE.20) NQ=140
    IF(NQ.GE.20) WRITE(IOUT,503) NQ
    IF(NQ.GE.20) GO TO 10
  30 CONTINUE
C*
  IF(NSMR.GT.0) CALL SUBWR1(NF,K,LINE,NGRD,MR)
C*
  NQ=0
C*
  ***** CALCULATE COINCIDENCE VALUE
C*
  DO 40 MR=1,4
    CALL SUBCF(K,MR,NQ,IFR,IFM)
C*
    IF(NQ.GE.20) NQ=150
    IF(NQ.GE.20) WRITE(IOUT,503) NQ
    IF(NQ.GE.20) WRITE(IOUT,505)
    IF(NQ.GE.20) GO TO 10
C*
  WRITE DATA TO LINE PRINTER
C*
  CALL SUBWR2(LINE,NQ,K)
C*
  40 CONTINUE
C*
  SKIP TO TOP OF NEW PAGE
C*
  WRITE(IOUT,500)
C*
  WRITE(IOUT,510) NMA
C*
  NJ=8
  MK=1
  IARR=1
C*
  CALCULATE MOVING AVERAGE ON AEROMAG DATA
C*
  CALL SUBMA(IARR,MR,K,NQ,NMA)
  IF(NQ.GE.20) NQ=160
  IF(NQ.GE.20) WRITE(IOUT,503) NQ
```


IF(NQ.GE.20) GO TO 10

IF(INT3.EQ.2) CALL SUBWT3(NF,K,MR)

IF(NQ.GE.20)
NQ=0

IF(NQ.GE.20) NQ=1,4

CALCULATE MOVING AVERAGE

CALL SUBMA(IARR,MR,K,NQ,NMA)

IF(NQ.GE.20) NQ=170

IF(NQ.GE.20) WRITE(IOUT,503) NQ

IF(NQ.GE.20) GO TO 10

IF(MR.EQ.1) NQ=0

IF(MR.GT.1) NQ=NQ-1

***** CALCULATE COINCIDENCE VALUE

CALL SUBCF(K,MR,NQ,IFR,IFM)

IF(NQ.GE.20) NQ=180

IF(NQ.GE.20) WRITE(IOUT,503) NQ

IF(NQ.GE.20) WRITE(IOUT,505)

IF(NQ.GE.20) GO TO 10

IF(INT3.EQ.3) CALL SUBWT3(NF,K,MR)

WRITE DATA TO LINE PRINTER

CALL SUBWR2(LINE,NQ,K)

GO CONTINUE

WRITE DATA TO LINE PRINTER

CALL SUBWR1(NF,K,LINE,NGRD,MR)

CALCULATE DEPTH ESTIMATES AND OUTPUT THEM

CALL SUBPHS(K,IFM)

IF(IFM.EQ.999999) WRITE(IOUT,530)

IF(IFM.EQ.999999) GO TO 10

IF(INT3.EQ.4) CALL SUBWT3(NF,K,MR)

INDICATE END OF LINE

WRITE(IOUT,590)

RESTART LOOP

GO TO 10

END PROGRAM

999 CONTINUE

IF (I.TB.ST.0) ENDFILE ITAP

OUTPUT FORMAT STATEMENTS

500 FORMAT(1H1)

502 FORMAT(1H,2X,*DATA FOR LINE *,48,* READ FROM TAPE*)

503 FORMAT(1H,2X,*NO=*,14,* DATA PROCESSING STOPED-NEXT LINE*)

505 FORMAT(1H,2X,*WEIRD X-VALS-END LINE PROCESSING*)

510 FORMAT(1H,2X,13,2X,*MOVING AVE WAS DONE*,/)

530 FORMAT(1H,2X,*DECREASING X IN PHS-NO GO TO TAPE*)

590 FORMAT(1H0,2X,40(*EL*),/)

C*

STOP & END

SUBROUTINE SUBRD(FID, FOM, IP, NF, LCT, LINE, NGRD)

..... DEFN OF PARAMETERS

ICT(1) = COUNTERS FROM COUNTER FILE
 NRLE = NUMBER OF RECORDS IN FILE
 IINP = CARDS/KEYBRD
 IOUT = LINEPRINTER
 INP1 = SURVEY HEADER DATA FILE
 INP2 = LINE HEADER DATA FILE
 INP3 = BACKGROUND DATA FILE
 INP4 = POINT BY POINT DATA ALONG LINES
 ICT = COUNTERS FROM *COUNTER TAPE* DATA
 EX(1) = X DISTANCE ALONG LINE OF DATA
 EY(1) = Y DISTANCE ALONG LINE OF DATA
 NP(1) = NUMBER OF POINTS ALONG A LINE OF DATA
 AL(1) = ALTITUDE OF AIRCRAFT
 RCN(1,1) = TOTAL COUNT IN URS
 RCN(2,1) = POTASSIUM IN PERCENT K
 RCN(3,1) = EQUIVALENT URANIUM IN PPM
 RCN(4,1) = EQUIVALENT THORIUM IN PPM
 RCR(1,1) = RAW UNCORRECTED TOTAL COUNT (CPS)
 RCR(2,1) = RAW UNCORRECTED POTASSIUM COUNTS (CPS)
 RCR(3,1) = RAW UNCORRECTED URANIUM COUNTS (CPS)
 RCR(4,1) = RAW UNCORRECTED THORIUM COUNTS (CPS)
 AOM(1) = MAGNETOMETER DATA
 FX(1) = ARRAY FOR FID PT X-COORDS
 LN(1) = LINE NUMBER LOOKING FOR (KNOWN)
 TITL(I,J) = TITLE DESIRED FOR THIS PARTICULAR LINE
 LCT = LINE COUNTER
 IFDC(1) = FID POINT COUNTER STORAGE

.....

COMMON IINP, IOUT, ITAP, INP1, INP2, INP3, INP4
 COMMON EX(1200), EY(1200), DIST(1200), ICT(1200)
 COMMON RCN(4,1200), RCR(4,1200), AOM(1200), AL(1200)
 COMMON FX(1200), A1(1200), A2(1200), A3(1200), A4(1200)
 COMMON TITL(100,7), NP(100), LN(100), IFDC(100)
 COMMON INT1, INT2, INT3, INT4, INT5

IINP=5 & IOUT=6 & INP1=10 & INP2=20 & INP3=30 & INP4=25

ICHK=0
 ISKIP=0
 K=LCT
 10 CONTINUE

ICHK=ICLK+1
 PRINT 5000, ICHK
 READ(IINP,410) LN(K), (TITL(K,I), I=1,7)
 IF (LN(K).EQ.3HNOGRD) GO TO 1111

..... READ A LINE HEADER (FILE 20)

```

20 CONTINUE
  READ(INP2) LINE,NRCD,NREC,IF
  IF(EOF(INP2)) 770,30
30 CONTINUE
  PRINT 5005, LINE
5005 FORMAT(1H,2X,'LINE BEING PROCESSED = ',A8)
  NR(K)=NRCD
  IF(LINE.EQ.LN(K)) GO TO 40
  CALL SUBSK(INP2,NF,IP)
  PRINT 5010, LINE
  CALL SUBSK(INP4,13,IP)
  PRINT 5020, LINE
5010 FORMAT(1H,2X,'SKIPPED FID FILE FOR LINE = ',A8)
5020 FORMAT(1H,2X,'SKIPPED DATA FILE FOR LINE = ',A8)
  ISKIP=ISKIP+2
  GO TO 20
40 CONTINUE
CK2
  ICHK=ICLK+1
  PRINT 5000, ICHK
  READ *,IWT1,IWT2,IWT3,IWT4,IWT5
CK3
  ICHK=ICLK+1
  PRINT 5000, ICHK
  IF(ISKIP.GE.1) WRITE(IOUT,500)
C*
C* READ FID PT X COORDINATES
C*
  DO 30 I=1,NF
    READ(INP2) IFDC(I),FX(I)
    IF(EOF(INP2)) 995,48
  48 CONTINUE
  50 CONTINUE
CK4
  ICHK=ICLK+1
  PRINT 5000, ICHK
C*
C* .....READ DATA RECORDS FROM INP4 .....
C*
  LRD=0
  C1
  LRD=LRD+1
  READ(INP4) (ICT(J),J=1,NREC)
  IF(EOF(INP4).NE.0) GO TO 999
  IF(1CT(1).GT.1CT(NREC)) WRITE(IOUT,520) 1CT(1),1CT(NREC)
  C2
  LRD=LRD+1
  READ(INP4) (EX(J),J=1,NREC)
  IF(EOF(INP4).NE.0) GO TO 999
  WRITE(IOUT,525) EX(1),NREC,EX(NREC)
  C3
  LRD=LRD+1
  READ(INP4) (EY(J),J=1,NREC)
  IF(EOF(INP4).NE.0) GO TO 999
  CK5
  ICHK=ICLK+1
  PRINT 5000, ICHK

```

```
      LRD=LRD+1
      READ(INP4)(AL(J),J=1,NREC)
      IF(EOF(INP4).NE.0) GO TO 999

      ICHK=ICLK+1
      PRINT 5000, ICHK

      LRD=LRD+1
      READ(INP4)(RCN(1,J),J=1,NREC)
      IF(EOF(INP4).NE.0) GO TO 999

      ICHK=ICLK+1
      PRINT 5000, ICHK

C5
      LRD=LRD+1
      READ(INP4)(RCN(2,J),J=1,NREC)
      IF(EOF(INP4).NE.0) GO TO 999

      ICHK=ICLK+1
      PRINT 5000, ICHK

C6
      LRD=LRD+1
      READ(INP4)(RCN(3,J),J=1,NREC)
      IF(EOF(INP4).NE.0) GO TO 999

      ICHK=ICLK+1
      PRINT 5000, ICHK

C7
      LRD=LRD+1
      READ(INP4)(RCN(4,J),J=1,NREC)
      IF(EOF(INP4).NE.0) GO TO 999

      ICHK=ICLK+1
      PRINT 5000, ICHK

C8
      LRD=LRD+1
      READ(INP4)(RCN(5,J),J=1,NREC)
      IF(EOF(INP4).NE.0) GO TO 999

      ICHK=ICLK+1
      PRINT 5000, ICHK

C9
      LRD=LRD+1
      READ(INP4)(RCR(1,J),J=1,NREC)
      IF(EOF(INP4).NE.0) GO TO 999

      ICHK=ICLK+1
      PRINT 5000, ICHK

C10
      LRD=LRD+1
      READ(INP4)(RCR(2,J),J=1,NREC)
      IF(EOF(INP4).NE.0) GO TO 999

      ICHK=ICLK+1
      PRINT 5000, ICHK

C11
      LRD=LRD+1
      READ(INP4)(RCR(3,J),J=1,NREC)
      IF(EOF(INP4).NE.0) GO TO 999

      ICHK=ICLK+1
      PRINT 5000, ICHK

C12
      LRD=LRD+1
      READ(INP4)(RCR(4,J),J=1,NREC)
      IF(EOF(INP4).NE.0) GO TO 999

      ICHK=ICLK+1
      PRINT 5000, ICHK

C13
      LRD=LRD+1
      READ(INP4)(RCR(5,J),J=1,NREC)
      IF(EOF(INP4).NE.0) GO TO 999

      ICHK=ICLK+1
      PRINT 5000, ICHK

C14
```

```

      LRD=LRD+1
      READ(1,104)(XCH(4,J),J=1,NREC)
      IF(EOF(104).NE.0) GO TO 199
C13
      ICHK=ICLK+1
      PRINT 5000, ICHK
C13
      LRD=LRD+1
      READ(1,104)(XCH(4,J),J=1,NREC)
      IF(EOF(104).NE.0) GO TO 199
C13
      ICHK=ICLK+1
      PRINT 5000, ICHK
C14
      LRD=LRD+1
C*
      XTAR=EX(1)
C*
C*      FIM = 1.0 HEPE - TO CHANGE PLOT SIZE, CCHANGE FIM VAL
C*
C16
      ICHK=ICLK+1
      PRINT 5000, ICHK
      DO 60 I=1,NREC
      DIST(I)=(EX(I)-XTAR)*FIM
      60 CONTINUE
C17
      ICHK=ICLK+1
      PRINT 5000, ICHK
C*
      DO 70 I=1,NF
      EX(I)=(EX(I)-XTAR)*FIM
      70 CONTINUE
C18
      ICHK=ICLK+1
      PRINT 5000, ICHK
      5000 FORMAT(1H,2X,*,ICLK = *,I5)
C*
      IP=0
      RETURN
C*
      900 CONTINUE
      WRITE(IOUT,530)
      WRITE(IOUT,532) LINE,NCRD,NREC,NF
      IP=1
      RETURN
C*
      995 CONTINUE
      WRITE(IOUT,530)
      WRITE(IOUT,535) IFDC(I),I,EX(I)
      IP=1
      RETURN
C*
      999 CONTINUE
      WRITE(IOUT,540)
      WRITE(IOUT,545) LRD,LINE
      IP=2

```

RETURN

.....INPUT FORMAT STATEMENTS

*10 FORMAT(48,7A10)

.....OUTPUT FORMAT STATEMENTS

*20 FORMAT(1H)

*21 FORMAT(1H,2X,*REVERSED LINE INDICATED-DATA ALSO REVERSED*,217)

*22 FORMAT(1H,2X,*X(1)=*,F10.3,* X(*,14,*)=*,F10.3)

30 FORMAT(1H,2X, UNEXPECTED EOF IN INP2, THE FID FILE*)

*32 FORMAT(1H,2X,*LINE,NGRD,NREC,NFID = *,A8,3(2X,I6))

*33 FORMAT(1H,2X,*ICT,1,FX(1) = *,2(2X,I6),2X,F8.3)

40 FORMAT(1H,2X, UNEXPECTED EOF IN INP4, THE DAT FILE*)

*45 FORMAT(1H,2X,*EOF AT LRD = *,I2,* FOR LINE = *,A8)

C
*1111 CONTINUE

IP=999999

C

RETURN

END

SUBROUTINE SUBSW(IX,XI,NP)

***** SWITCHING ROUTINE FOR VARIABLES IN ARRAYS IX(I) AND XI(I)

TAKES LAST VARIABLE OF ARRAY AND PUTS IN FIRST POSITION
AND FIRST VARIABLE PLACED IN LAST POSITION
DOES SAME THING FOR EACH OF TWO ARRAYS

DIMENSION IX(1),XI(1)

IF LESS THAN TWO POINTS NO SWITCHING OCCURS
IF. HOW THE >>IK:IZ?< CAN YOU SWITCH ONE POINT

IF(NP.LT.2) GO TO 30

HALF NUMBER OF POINTS = M

M=NP/2

NUMBER OF POINTS = J

J=NP

DO 20 I=1,M

ITEMP AND TEMPI ARE TEMPORARY STORAGE LOCATIONS

ITEMP=IX(I)

TEMPI=XI(I)

SWITCH FIRST AND LAST, ETC ETC

IX(I)=IX(J)

XI(I)=XI(J)

REASSIGN VALS TO INPUT ARRAYS

IX(J)=ITEMP

XI(J)=TEMPI

DECREMENT J

J=J-1

20 CONTINUE

30 CONTINUE

RETURN TO MAIN OR CALLING ROUTINE

RETURN

END

SUBROUTINE SUBARI(NF,LCT,LINE,NGRD,MR)

SUBROUTINE TO OUTPUT SELECTED DATA FROM SKYVAN FILES

COMMON IINP,IOUT,ITAP,INP1,INP2,INP3,INP4

COMMON X(1200),Y(1200),PX(1200),ICT(1200)

COMMON CN(4,1200),CR(4,1200),AM(1200),AC(1200)

COMMON FX(1200),FY(1200),A2(1200),A3(1200),A4(1200)

COMMON TITLE(100,7),NP(100),LN(100),IFDC(100)

COMMON IWT1,IWT2,IWT3,IWT4,IWT5

K=LCT

NREC=IP(LCT)

IT=0

II=1

10 CONTINUE

IF(MR.EQ.9) GO TO 40

IF(IT.EQ.1) GO TO 30

NREC=5

WRITE(IOUT,500)

WRITE(IOUT,510) LN(K),(TITLE(K,II),I=1,7)

WRITE(IOUT,520) NP(K)

WRITE(IOUT,525) (ICT(I),I=1,NREC)

NFI=NF

IF(NFI.GT.5) NFI=5

WRITE(IOUT,530) (FX(I),I=1,NFI)

WRITE(IOUT,540) (X(I),I=1,NREC)

WRITE(IOUT,540) (Y(I),I=1,NREC)

WRITE(IOUT,550) (AC(I),I=1,NREC)

WRITE(IOUT,560) (CN(1,I),I=1,NREC)

WRITE(IOUT,565) (CN(2,I),I=1,NREC)

WRITE(IOUT,570) (CN(3,I),I=1,NREC)

WRITE(IOUT,575) (CN(4,I),I=1,NREC)

WRITE(IOUT,590) (CR(1,I),I=1,NREC)

WRITE(IOUT,595) (CR(2,I),I=1,NREC)

WRITE(IOUT,600) (CR(3,I),I=1,NREC)

WRITE(IOUT,605) (CR(4,I),I=1,NREC)

WRITE(IOUT,620) (AM(I),I=1,NREC)

30 CONTINUE

C..... SUMMARY TABLE OUTPUT

L=1

IF(II.-0.0) WRITE(IOUT,500)

WRITE(IOUT,510) LN(K),(TITLE(K,I),I=1,7)

WRITE(IOUT,625) LINE,NGRD,NREC,NF

PRINT 5005, IFDC(1),IFDC(3F)

IF(ICT(1).GT.1CT(2)) WRITE(IOUT,5010)

IF(ICT(1).GT.1CT(2)) CALL SUBSW(IFDC,F,NF)

WRITE(IOUT,530)

DO 40 J=1,NREC

IDIFF=ICT(J)-IFDC(L)

IDIFF=ABS(IDIFF)

IF(IDIFF.LT.1) GO TO 35

GO TO 39

35 CONTINUE

WRITE(IOUT,645) L,IFDC(L),X(J),Y(J),AC(J),((CR(I,J),CN(I,J)),I=1,4
*7),AP(J)

L=L+1

39 CONTINUE

40 CONTINUE

45 CONTINUE

IF(MR.GE.9) WRITE(IOUT,650)

WRITE(IOUT,655) A1(10),A1(5),A1(1),A1(6),A1(2),A1(7),A1(3),A1(8),A
*1(4),A1(9)WRITE(IOUT,656) A2(10),A2(5),A2(1),A2(6),A2(2),A2(7),A2(3),A2(8),A
*2(4),A2(9)WRITE(IOUT,657) A3(10),A3(5),A3(1),A3(6),A3(2),A3(7),A3(3),A3(8),A
*3(4),A3(9)

WRITE(IOUT,670)

500 FORMAT(1H1)

510 FORMAT(1H0,2X,*LINE ID = *,A8,* TITLE = *,7A10)

520 FORMAT(1H ,2X,*NUMBER OF POINTS*,13X,I6)

525 FORMAT(1H ,2X,*COUNTER DATA*,17X,5(10,2X))

530 FORMAT(1H ,2X,*FID PT X CHORDS*,10X,5(2X,F8.2))

540 FORMAT(1H ,2X,*X,Y PLOT DATA - GRID*,5X,5(2X,F8.2))

550 FORMAT(1H ,2X,*ALTITUDE DATA*,12X,5(2X,F8.2))

560 FORMAT(1H ,2X,*TOTAL COUNT CON DATA*,5X,5(2X,F8.2))

565 FORMAT(1H ,2X,*POTASSIUM CON DATA*,7X,5(2X,F8.2))

570 FORMAT(1H ,2X,*URANIUM CON DATA*,9X,5(2X,F8.2))

575 FORMAT(1H ,2X,*THORIUM CON DATA*,9X,5(2X,F8.2))

577 FORMAT(1H ,2X,*TOTAL COUNT RAW DATA*,5X,5(2X,F8.2))

```
545 FORMAT(1H,2X,*POTASSIUM RAW DATA*,7X,5(2X,F8.2))
550 FORMAT(1H,2X,*URANIUM RAW DATA*,9X,5(2X,F8.2))
555 FORMAT(1H,2X,*THORIUM RAW DATA*,9X,5(2X,F8.2))
560 FORMAT(1H,2X,*CALC-MAGNETIC TOTAL FIELD *,5(2X,F8.2))
```

C*
C..... SUMMARY TABLE OUTPUT STMTS
C*

```
625 FORMAT(1H,2X,*LINE FROM FILE = *,A6,/,3X,  
  *FILE GRID LINE = *,I6,/,3X,  
  *NUMBER OF RECS = *,I6,/,3X,  
  *NUMBER OF FIDS = *,I6)
```

C*
630 FORMAT(1H0,* FID COUNTER XCD YCD ALT TCRAW TCURS KR
 AN KPCT URAN UPPM THRAW THPPM MAG)

C*
645 FORMAT(1H,2X,I3,2X,I6,2(F7.3,1X),F5.0,1X,4(F7.2,1X,F6.2,1X),F5.0)

C*
650 FORMAT(1H0,2X,*RECALCULATED VALUES SINCE A NEG OCCURED*,/)

C*
655 FORMAT(1H0,2X,*LINE MAXIMUM VALUES =*,6X,F5.0,1X,4(F7.2,1X,F6.2,1X
 *),F5.0)

C*
656 FORMAT(1H0,2X,*LINE MINIMUM VALUES =*,6X,F5.0,1X,4(F7.2,1X,F6.2,1X
 *),F5.0)

C*
657 FORMAT(1H0,2X,*LINE AVERAGE VALUES =*,6X,F5.0,1X,4(F7.2,1X,F6.2,1X
 *),F5.0)

C*
670 FORMAT(1H0,2X,80(*=*))

C*
5000 FORMAT(1H0,2X,*IFCD1,IFDCNF = *,2(2X,I6),/)

5010 FORMAT(1H,2X,20(*X*),*COUNTERS INDICATE REVERSED LINE*,20(*X*),/)

C*
RETURN
END

SUBROUTINE SUBMM(IARR,MR,L,NQ)

CALCULATES MAX,MIN,AVE FOR SINGLE,DOUBLE ARRAYS

COMMON INP,IOOT,ITAP,INP1,INP2,INP3,INP4
COMMON X(1200),Y(1200),PX(1200),ICT(1200)
COMMON Z(4,1200),I3(4,1200),E1(1200),AC(1200)
COMMON EX(1200),EMAX(1200),EMIN(1200),AVE(1200),A4(1200)
COMMON TITLE(100,7),NP(100),LN(100),IFDC(100)
COMMON IWT1,IWT2,IWT3,IWT4,IWT5

NPTS=NP(L)
IF(NPTS.LE.0) GO TO 999

NQ=NQ+1
SUM=0.

IF(MR.GT.4) LR=MR-4

EMAX(NQ)=-99999.
EMIN(NQ)= 99999.

AVE(NQ)=0.00000

IF(IARR.EQ.1) GO TO 30

IF(MR.GT.4) GO TO 10

DO 5 J=1,NPTS
IF(E2(MR,J).GE.EMAX(NQ)) EMAX(NQ)=E2(MR,J)
IF(E2(MR,J).LE.EMIN(NQ)) EMIN(NQ)=E2(MR,J)
SUM=SUM+E2(MR,J)

5 CONTINUE

GO TO 60

10 CONTINUE

DO 15 J=1,NPTS
IF(E3(LR,J).GE.EMAX(NQ)) EMAX(NQ)=E3(LR,J)
IF(E3(LR,J).LE.EMIN(NQ)) EMIN(NQ)=E3(LR,J)
SUM=SUM+E3(LR,J)

15 CONTINUE

GO TO 60

30 CONTINUE

IF(MR.EQ.1) GO TO 38

NQ=10 ---ALTIMETER CALCULATIONS

NQ=10

DO 35 J=1,NPTS

```
IF (AC(J).GE.EMAX(NQ)) EMAX(NQ)=AC(J)
IF (AC(J).LE.EMIN(NQ)) EMIN(NQ)=AC(J)
SUM=SUM+AC(J)
```

```
35 CONTINUE
```

```
GO TO 60
```

```
38 CONTINUE
```

```
      NQ=9 ----- AERUMAG CALCULATIONS
```

```
      NQ=9
```

```
DO 40 J=1,NPTS
```

```
IF (E1(J).GE.EMAX(NQ)) EMAX(NQ)=E1(J)
```

```
IF (E1(J).LE.EMIN(NQ)) EMIN(NQ)=E1(J)
```

```
SUM=SUM+E1(J)
```

```
40 CONTINUE
```

```
60 CONTINUE
```

```
AVE(NQ)=SUM/NPTS
```

```
IF (NQ.GT.3) NQ=0
```

```
GO TO 999
```

```
998 CONTINUE
```

```
NQ=21
```

```
999 CONTINUE
```

```
RETURN
```

```
END
```

SUBROUTINE SUBZL(IARR,MR,L,NQ)

ADJUSTS ZERO LEVEL TO ZERO IF NEGATIVE VALS

COMMON IINP,IOUT,ITAP,INP1,INP2,INP3,INP4

COMMON X(1200),Y(1200),PX(1200),ICT(1200)

COMMON E2(4,1200),E3(4,1200),E1(1200),AC(1200)

COMMON FX(1200),EMAX(1200),EMIN(1200),AVE(1200),A4(1200)

COMMON TITLE(100,7),NP(100),LN(100),IFDC(100)

COMMON INT1,INT2,INT3,INT4,INT5

SUM=0.

NPTS=NP(L)

IF(NPTS.LE.0) GO TO 993

IF(MR.GT.4) LR=MR-4

ABSV=EMIN(NQ)

ABSV=ABS(ABSV)

IF(IARR.EQ.1) GO TO 50

IF(NQ.GT.4) GO TO 30

DO 20 J=1,NPTS

E2(MR,J)=E2(MR,J)+ABSV

SUM=SUM+E2(MR,J)

20 CONTINUE

GO TO 90

30 CONTINUE

DO 40 J=1,NPTS

E3(LR,J)=E3(LR,J)+ABSV

SUM=SUM+E3(LR,J)

40 CONTINUE

GO TO 70

50 CONTINUE

IF(MR.EQ.10) GO TO 70

DO 60 J=1,NPTS

E1(J)=E1(J)+ABSV

SUM=SUM+E1(J)

60 CONTINUE

GO TO 90

70 CONTINUE

DO 80 J=1,NPTS

AC(J)=AC(J)+ABSV

SUM=SUM+AC(J)

80 CONTINUE

UTL 0000 73/79 OPT=1

FTN 4.8+528

19

00 CONTINUE

AVE (N1) = SUM / NPTS

EMIN(N1) = MIN(N1) + ABSV

EMAX(N1) = MAX(N1) + ABSV

GO TO 000

000 CONTINUE

N1 = 21

000 CONTINUE

C*

RETURN

C*

END

N4=NPTS+1

ZERO (INITIALIZATION) ARRAYS OF RADIOELEMENT DATA

DO 5 I=1,N4

HR(I)=0.0

SR(I)=0.0

FX(I)=0.0

CF(I)=0.0

ONLY NEED TO ZERO MAG AND A VALUE ARRAYS ONCE

IF(N4.GT.1) GO TO 3

HM(I)=0.0

SM(I)=0.0

FXM(I)=0.0

XS(I)=0.0

3 CONTINUE

5 CONTINUE

CALCULATE SLOPE VALUES FOR RADIOELEMENTS AND MAG DATA

DO 20 J=L,NPTS

I=J-1

DX=X(J)-X(I)

IF(DX.LE.0.) WRITE(IOUT,520) (X(NN),NN=1,5)

IF(DX.LE.0.0) GO TO 998

FOR RADIOELEMENT DATA - CONCENTRATION OR RAW DATA

IF(YR.LE.4) DYR=YR(MR,J)-YR(MR,I)

IF(MR.GT.4) DYR=ZR(LR,J)-ZR(LR,I)

SR(I)=DYR/DX

IF(N4.GT.1) GO TO 10

SLOPES FOR MAG DATA CALCULATED

DYM=Y4(J)-Y4(I)

SM(I)=DYM/DX

XS(I)=(X(I)+X(J))/2.

10 CONTINUE

20 CONTINUE

===== ASSIGN VALS TO RADIOMETRIC AND MAGNETIC PEAKS

NS=NPTS-1
 SL(L)=NS

CALCULATE BINARY HISTOGRAM VALUES FOR MAG AND RADIOELEMENT
 DATA - DO MAG CALCS ONLY ONCE - BUT THERE ARE FOUR TO EIGHT
 RADIOELEMENT CALCULATIONS

DO 30 J=L,NS

I=J-1
 K=J+1

FOR RADIOELEMENT DATA

IF(SR(J).GT.SR(I)) HR(J)=0.
 IF(SR(J).LT.SR(I)) HR(J)=1.
 IF(SR(J).EQ.SR(I)) HR(J)=HR(I)

IF(J.EQ.L) HR(I)=HR(J)
 IF(J.EQ.NS) HR(K)=HR(J)

IF(NS.GT.1) GO TO 30

FOR MAG DATA

IF(SM(J).GT.SM(I)) HM(J)=0.
 IF(SM(J).LT.SM(I)) HM(J)=1.
 IF(SM(J).EQ.SM(I)) HM(J)=HM(I)
 IF(J.EQ.L) HM(I)=HM(J)
 IF(J.EQ.NS) HM(K)=HM(J)

30 CONTINUE

35 CONTINUE

***** COMPARE BINARY HISTOGRAM VALUES *****

***** ASSIGN ***CCV*** TO DATA POINTS *****

DO 50 I=1,NPTS

IF(HR(I).EQ.HM(I)) GO TO 40

IF(HR(I).EQ.1.) CF(I)=2.
 IF(HM(I).EQ.1.) CF(I)=1.

GO TO 45

40 CONTINUE

IF(HR(I).EQ.1.) CF(I)=3.
 IF(HR(I).EQ.0.) CF(I)=0.

45 CONTINUE

...: FLEX: FLEX: IN CALC X VALS FOR FLEX PTS

$J = 1.0$

LF (J. J. L. P. T. S.) SL TO 999

$$TFR(JT, Y, H, P) = TFR + I$$

```
IF (XK(I).GE.XR(I)) FXR(IFR)=XS(I)
```

```
IF (N2.GT.1) GO TO 48
```

```
IF (EM(I),VL,EM(I)) IFM=IFM+1
```

$$IF(PM(J).NE.HM(I))FX^M(1,PM)=XS(I)$$

49 CONTINUE-

50 CONTINUE

GO TO 479

998 CONTINUE

NO = 21

999 CONTINGE

~~OUTPUT FORMAT STATS - NO INPUT REQ'D~~

```
520 FORMAT(1H ,2X,*X(2)-X(1),LE.O-DECREASINGX-NO CALCS DONE*,/,3X,*X(I  
1) ARE = *,5F10.3,/)

```

0111111111 END SUBROUTINE/PROGRAM

2. F. T. K.:

FND

SUBROUTINE SUBRK2(LINE,NU,K)

COMMON INP,IOUT,ITAP,INPI,INP2,INP3,INP4
COMMON COMMON A(1200),AB(1200),AD(1200),IAE(1200)
COMMON COMMON B(4,1200),BA(4,1200),BC(1200),BD(1200)
COMMON CF(1200),C(1200),CA(1200),CC(1200),CZ(1200)
COMMON TITL(100,7),NP(100),NSL(100),IFDC(100)
COMMON INT1,INT2,INT3,INT4,INT5

IF(NU.EQ.1) WRITE(IOUT,520)
IF(NU.EQ.2) WRITE(IOUT,525)
IF(NU.EQ.3) WRITE(IOUT,530)
IF(NU.EQ.4) WRITE(IOUT,535)
IF(NU.EQ.5) WRITE(IOUT,540)
IF(NU.EQ.6) WRITE(IOUT,545)
IF(NU.EQ.7) WRITE(IOUT,550)
IF(NU.EQ.8) WRITE(IOUT,555)

NPTS=NP(K)

WRITE(IOUT,590)(CF(I),I=1,NPTS)

WRITE(IOUT,590)

520 FORMAT(1H0,2X,*CORR FOR MAG AND TOTAL COUNT URS*)
525 FORMAT(1H0,2X,*CORR FOR MAG AND POTASSIUM PCT*)
530 FORMAT(1H0,2X,*CORR FOR MAG AND URANIUM PPM*)
535 FORMAT(1H0,2X,*CORR FOR MAG AND THORIUM PPM*)
540 FORMAT(1H0,2X,*CORR FOR MAG AND TOTAL COUNT RAW*)
545 FORMAT(1H0,2X,*CORR FOR MAG AND POTASSIUM RAW*)
550 FORMAT(1H0,2X,*CORR FOR MAG AND URANIUM RAW*)
555 FORMAT(1H0,2X,*CORR FOR MAG AND THORIUM RAW*)
580 FORMAT(1H,2X,30(F3.0,1X))
590 FORMAT(1H0,2X,80(*-*))

RETURN
END

SUBROUTINE SUBMAG(LA, R, MR, L, NO, NMA)

COMMON TNP, TOUT, ITAP, TNP1, TNP2, TNP3, TNP4
 COMMON X(1200), Y(1200), PA(1200), ICT(1200)
 COMMON E2(4, 1200), E3(4, 1200), E1(1200), AC(1200)
 COMMON FX(1200), A1(1200), A2(1200), A3(1200), A4(1200)
 COMMON TITLE(100, 7), NP(100), LN(100), IFDC(100)
 COMMON IAT1, IAT2, IAT3, IAT4, IAT5

IARR=1 --- NO=9 THEN USE LI=AEROMAG
 10 THEN USE AC=ALTIMETER

IARR=2 --- MR=1, 4 THEN USE E2=CN
 5, 8 THEN USE E3=CR

IF(NMA.EQ.0) GO TO 998
 NO=NO+1

IF(NO.GT.8) IARR=1
 IF(MR.GT.4) LR=MR-4

NPTS=NP(L)

K=0

SUM=0.

TEMP1=0.0
 TEMP2=0.0
 TEMP3=0.0
 TEMPA=0.0

LP=NMA-1

10 CONTINUE

LP=LP+1

IF(LP.GT.NPTS) GO TO 80

K=K+1

IF(K.GT.1) GO TO 40

IF(IARR.EQ.1) GO TO 30

DO 20 J=K, LP
 IF(MR.LE.4) SUM=SUM+E2(MR, J)
 IF(MR.GT.4) SUM=SUM+E3(LR, J)

20 CONTINUE

GO TO 50

30 CONTINUE

DO 35 J=K, LP
 IF(NO.EQ.9) SUM=SUM+E1(J)
 IF(NO.EQ.10) SUM=SUM+AC(J)

35 CONTINUE

GO TO 50

40 CONTINUE

IF(IARR.EQ.1) GO TO 45

IF(MR.LE.4) SUM=SUM+E2(MR,LP)-TEMP2

IF(MR.GT.4) SUM=SUM+E3(LR,LP)-TEMP3

GO TO 50

45 CONTINUE

IF(NC.EQ.9) SUM=SUM+E1(LP)-TEMP1

IF(NC.EQ.10) SUM=SUM+AC(LP)-TEMPA

50 CONTINUE

AVE=SUM/NMA

IF(IARR.EQ.1) GO TO 65

IF(MR.LE.4) TEMP2=E2(MR,K)

IF(MR.LE.4) E2(MR,K)=AVE

IF(MR.GT.4) TEMP3=E3(LR,K)

IF(MR.GT.4) E3(LR,K)=AVE

GO TO 10

65 CONTINUE

IF(NC.EQ.9) TEMP1=E1(K)

IF(NC.EQ.9) E1(K)=AVE

IF(NC.EQ.10) TEMPA=AC(K)

IF(NC.EQ.10) AC(K)=AVE

GO TO 10

80 CONTINUE

DO 100 J=1,K

IF(IARR.EQ.1) GO TO 90

IF(MR.LE.4) A1(J)=E2(MR,J)

IF(MR.GT.4) A1(J)=E3(LR,J)

GO TO 95

90 CONTINUE

IF(NC.EQ.9) A1(J)=E1(J)

IF(NC.EQ.10) A1(J)=AC(J)

95 CONTINUE

100 CONTINUE

IX=((NMA/2.)+0.5)

C*

N=1

N=PTS-1

DO 120 J=1,PTS

I=J+1-IX

IF(I<.01) GO TO 110

IF(I>.99) GO TO 105

IF(J<.IX) E2(MR,J)=A1(N)

IF(J>.IX) E2(MR,J)=A1(I)

IF(J&EQ;.IX) E2(MR,J)=A1(K)

GO TO 120

C*

105 CONTINUE

C*

IF(J<.IX) E3(LR,J)=A1(N)

IF(J>.IX) E3(LR,J)=A1(I)

IF(J&EQ;.IX) E3(LR,J)=A1(K)

GO TO 120

C*

110 CONTINUE

C*

IF(N>.10) GO TO 115

IF(J<.IX) E1(J)=A1(N)

IF(J>.IX) E1(J)=A1(I)

IF(J&EQ;.IX) E1(J)=A1(K)

GO TO 120

C*

115 CONTINUE

C*

IF(J<.IX) AC(J)=A1(N)

IF(J>.IX) AC(J)=A1(I)

IF(J&EQ;.IX) AC(J)=A1(K)

C*

120 CONTINUE

130 CONTINUE

C*

GO TO 999

998 CONTINUE

N=21

999 CONTINUE

C*

RETURN

C*

END


```
WRITE(11,2P) (C(J,M),J=1,NREC)
```

```
WRITE(11,2P) (F(J),J=1,N-1)
```

```
PRINT 540, P
```

```
IF(M% 2.0) INT3=INT3+1
```

```
GO TO 555
```

```
555 CONTINUE
```

```
C*      INT3=5 AT THIS POINT - WRITES PHS DATA TO PROFILE TAPE
```

```
C*
```

```
WRITE(11,2P) (CN(3,J),J=1,NREC)
```

```
C*
```

```
INT3=INT3+1
```

```
C*
```

```
C*      INT3=5 AT THIS POINT
```

```
C*
```

```
PRINT 560
```

```
C*
```

```
559 CONTINUE
```

```
C*
```

```
510 FORMAT(1H ,2X,*FIRST DATA TO PROFILE TAPE*)
```

```
520 FORMAT(1H ,2X,*SMOOTHED MAG DATA TO PROFILE TAPE*)
```

```
540 FORMAT(1H ,2X,*SMOOTHED CONC (*,I3,* ) AND CF DATA TO PROF TAPE*)
```

```
560 FORMAT(1H ,2X,*PHS MID-DEPTHS TO PROFILE TAPE*)
```

```
C*
```

```
RETURN
```

```
END
```

SUBROUTINE SUBPHS(L,IFM)

TO CALCULATE DEPTHS TO CAUSATIVE BODIES FROM
AEROMAGNETIC DATA USING PETERS HALF SLOPE METHOD

COMMON IINP,ITOT,ITAP,INP1,INP2,INP3,INP4
COMMON X(1200),SX(1200),HM(1200),ICT(1200)
COMMON PD(4,1200),DE(4,1200),YM(1200),HR(1200)
COMMON CF(1200),FXR(1200),FXI(1200),XS(1200),SM(1200)
COMMON FILE(100,7),NP(100),NSL(100),IAC(100)
COMMON INT1,INT2,INT3,INT4,INT5

NPTS=NP(L)-1

DO 10 J=1,NPTS

HM(J)=SM(J)

DO 3 K=1,4

PD(K,J)=0.0

DE(K,J)=0.0

5 CONTINUE

RECALCULATE SLOPE VALUES HERE

I=J+1

IF(I.GT.NPTS) GO TO 8

DX=X(I)-X(J)

IF(CX.LE.0.) GO TO 998

DY=YM(I)-YM(J)

SM(J)=DY/DX

8 CONTINUE

10 CONTINUE

I=0

J=0

K=0

IFM=0

NSIS" SING SLOPES & NSPS" POS SING SLOPES

NSIS=0

NSPS=0

DMAX1=-99999.

DMAX2=-99999.

DMAX3=-99999.

DMAX4=-99999.

DMIN1=99999.

DMIN2=99999.

DMIN3=99999.

DMIN4=99999.

20 CONTINUE

NPDE= N-UMBER OF P-POINTS IN D-EPth E-STIMATE

NPDE=0

K=K+1

```
      I=1
      IF=0
23 CONTINUE
      I=I+1
      J=I+1
      IF(J.GT.NPTS) GO TO 990
      IF(SM(I).EQ.0.0) GO TO 23
      IF(SM(I).GT.0.0) GO TO 25
      IF(SM(J).LT.0.0) GO TO 26
      IF(SM(J).EQ.0.0) GO TO 23
      NSNS=NSNS+1
      WRITE(IOUT,520) I
      GO TO 23
25 CONTINUE
      IF(SM(J).GT.0.0) GO TO 28
      IF(SM(J).EQ.0.0) GO TO 23
      WRITE(IOUT,530) I
      NSPS=NSPS+1
      GO TO 23
28 CONTINUE
      IF(SM(J).EQ.SM(I)) GO TO 34
      IF(SM(J).GT.SM(I)) GO TO 30
      GO TO 32
30 CONTINUE
      IF(SM(I).LT.0.0) GO TO 36
      GO TO 23
34 CONTINUE
      IEOS=IEOS+1
      IF(IEOS.LE.2) XIF=XS(I)+XS(J)
      IF(IEOS.GT.2) XIF=XIF+XS(J)
      GO TO 23
36 CONTINUE
```

SUBROUTINE SUBPHS 7/7/74 JPT=1

FTN 4.8+528

```
5      I=I+1
      EXT(IPM)=XS(I)
      IF(IEJS.GE.0) EXM(IPM)=XI/IEJS
0      SMAX=SM(I)
      HMAX=HAX/P.
      JT=T
      JK=1
5      C*
      50 CONTINUE
      C*
      JI=JI-1
      C*
      IF(JI.LE.0) WRITE(IQUT,540)
      IF(JI.LE.0) GO TO 23
      C*
      IF(SMAX.LT.0.00) GO TO 53
      C*
      IF(SM(JI).GE.HMAX) GO TO 50
      C*
      GO TO 55
      C*
      53 CONTINUE
      C*
      IF(SM(JI).LE.HMAX) GO TO 50
      C*
      55 CONTINUE
      C*
      JI=JI+1
      C*
      XI=XS(JI)
      C*
      58 CONTINUE
      C*
      JK=JK+1
      C*
      IF(JK.GT.NPTS) WRITE(IQUT,550)
      IF(JK.GT.NPTS) GO TO 990
      C*
      I=I+1
      C*
      IF(SMAX.LT.0.00) GO TO 60
      C*
      IF(SM(JK).GE.HMAX) GO TO 58
      C*
      GO TO 53
      C*
      60 CONTINUE
      C*
      IF(SM(JK).LE.HMAX) GO TO 58
      C*
      63 CONTINUE
      C*
      JK=JK-1
```

DTI 11/11/74 13/74 01=1

FIN 4.8+528

197

72=33(13)

I=I-1

65 CONTINUE

PLEN=X2-X1

PLEN=X3(PL)

IF(PLEN.LE.1.00001) GO TO 70

GO TO 60

70 CONTINUE

WRITE(1001,500)

J1=J1-1

JK=JK+1

X1=X5(J1)

X2=X5(JK)

I=I+1

GO TO 55

50 CONTINUE

NPDE=NO. PTS IN DEPTH ESTIMARE

NPDE=JK-J1

NPDE=IABS(NPDE)

ICT(K)=NPDE

SR(K)=S MAX

MULTIPLY BY PETERS FACTOR/ CONVERT TO GROUND SCALE

DE(1,K)=X2

DE(2,K)=PLEN/1.2

DE(3,K)=PLEN/1.6

DE(4,K)=PLEN/2.0

DE(2,K)=DE(2,K)+4167.

DE(3,K)=DE(3,K)+4167.

DE(4,K)=DE(4,K)+4167.

IF(DE(2,K).GE.DMAX2) DMAX2=DE(2,K)

IF(DE(3,K).GE.DMAX3) DMAX3=DE(3,K)

IF(DE(4,K).GE.DMAX4) DMAX4=DE(4,K)

IF(DE(2,K).LE.DMIN2) DMIN2=DE(2,K)

IF(DE(3,K).LE.DMIN3) DMIN3=DE(3,K)

IF(DE(4,K).LE.DMIN4) DMIN4=DE(4,K)

GO TO 20

900 CONTINUE

SUBROUTINE SUBPMS 73774 DPT=1

FTN 4.8+528

15

WRITE(1001,5/6) NSPS,NSMS
WRITE(1001,5/5)

DO 100 N=1,K

WRITE(1001,5/6) N,(DE(I,N),I=1,4),ICT(N),SR(N)

100 CONTINUE

C* INVERT SCALES FOR PLOTTING

C*

NPTS=NPTS+1

C*

M=0

N=0

ISKP=0

C*

D2=DMAX2+DMIN2

D3=DMAX3+DMIN3

D4=DMAX4+DMIN4

C*

110 CONTINUE

C*

N=N+1

IF(N.GT.K) ISKP=ISKP+1

IF(N.GT.K) GO TO 120

C*

DE2=D2-DE(2,N)

DE3=D3-DE(3,N)

DE4=D4-DE(4,N)

C*

120 CONTINUE

C*

M=M+1

IF(M.GT.NPTS) GO TO 999

C*

PD(1,M)=X(M)-X(1)

PD(2,M)=DE2

PD(3,M)=DE3

PD(4,M)=DE4

C*

IF(X(M).GT.DE(1,N)) GO TO 130

C*

GO TO 120

C*

130 CONTINUE

C*

IF(ISKP.GE.1) GO TO 120

C*

GO TO 110

C*

998 CONTINUE

IFM=9999999

999 CONTINUE

C*

OUTPUT FORMAT STATEMENTS

C*

520 FORMAT(1H,2X,7SING NEG SL/TR/NO DPT-PT NO,*,13)

SUBROUTINE

7/7/74 OPT=1

FTN 4.8+528

19/

100 FORMAT(1H,2X,*SING POS SLP/PT NO,*,13)

110 FORMAT(1H,2X,*ZERO SUBSCRIPT/INVALID/IN SUBPHS-FIRST SLOPE*,/)

120 FORMAT(1H,2X,*SUBSCRIPT .GT. APTS/INVALID/IN SUBPHS-LAST SLP*,/)

130 FORMAT(1H,2X,*PLEN=0-SING SLOPE-ADJUST*,/)

140 FORMAT(1H,2X,*SING POS SLP5=*,13,* SING NEG SLP5=*,13,/)

150 FORMAT(1H,2X,20(*-*),/,8X,*DEPTH X VALUE*,4X,*DYK W = 0 DYK W =
1 20 DYK W = SI NPDE SLOPE*,/)

160 FORMAT(1H,2X,*DX(*,13,*)= *,F10.3,3(2X,E10.4),3X,16,3X,F6.2)

END PROGRAM-RETURN TO MAIN

RETURN

END

CARLETON UNIVERSITY
Faculty of Graduate Studies and Research
Department of Geology

M.Sc. Thesis Examination

2:00 p.m. Thursday, September 16, 1982

Room 337, Tory Building

Candidate:

George W. Cameron
B.Sc. Carleton University

Thesis Title:

A Simple Correlation-Coincidence Value (CCV)
Technique For Use During Routine Computer
Processing Of Aeroradiometric and Aeromagnetic
Data

Examining Board:

D. H. Watkinson, Chairman, Department of Geology
K. Bell, Thesis Supervisor, Department of Geology
J. Blenkinsop, Department of Geology
T.J.S. Cole, Department of Physics
S. F. Wise, Dean of Graduate Studies
G. B. Skippen, Dean of Science

August 23, 1982

David H. Watkinson
Chairman
Department of Geology

END

1	0	1	0	9	1	8	4
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FIN