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INTERPRETATION OF AEROMAGNETIC DATA FROM THE BEAUFORT SEA - MACKENZIE DELTA REGION
OPEN FILE 2210

BY

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TORONTO, ONTARIO

(DSS FILE 03SG.23294-8-0693-A)

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(at 1:1,000,000 scale)

(Maps #1-7 and RTP Total Field Magnetic Contour Map are in the pocket of Book 2)

Summary

Aeromagnetic data covering the Beaufort Sea - Mackenzie Delta (BSMD) Region (from 68°N to 72°N and from 128°W to 141°W) has been interpreted with regard to regional trend and character analysis, major tectonic elements and depth to magnetic source.

During the course of the interpretation a series of enhanced products were derived from the original data. These maps are presented at a scale of 1:1,000,000 and include colour plots of reduced to pole (RTP) total field magnetics, calculated first and second vertical gradients, and residual/regional component separation. Two grey shadow maps each of residual field and RTP total field magnetic data are included. In excess of 3700 line kilometers of magnetic profile data and a number of individual anomalies were modelled.

The aeromagnetic interpretation identified terrains with two significantly different magnetic signatures: large amplitude, long wavelength responses characteristic of continental crust; and smaller amplitude, shorter wavelength features more representative of crust with an oceanic or mixed oceanic/continental affinity.

Breaks and structural trends within magnetic basement were evident on all of the colour products. These basement trends apparently controled, to a varying degree, the development of younger features.

A number of major tectonic features were recognized on, and outlined from, the enhancement products: tectonic elements directly related to basement structure (Demarcation Basin); features developed in response to, or influenced by, pre-existing basement structure (ELFZ); uplifts of magnetically susceptible units (components of the Aklavik Arch Complex); shallow source features (Sedgewick Granite); and, susceptible intrasedimentary units (volcanics).

Depth to bedrock calculations are questionable given the relatively unconstrained models, a wide range of magnetic basement sources, and ambiguities inherent in the geophysical modelling.

The Beaufort Sea - Mackenzie Delta Region is interpreted to have developed through the generally polewards rifting of a block of continental crust. A spreading centre generated the oceanic crust interpreted to underlie the Beaufort - Mackenzie Basin. Associated with the rifting is the development of an aulocogen extending back into the current continental mass to the west of the Yukon/NWT border. Massive sediment influx from the rifted margin buried both the newly generated oceanic crust and the failed arm. Components of either southwesterly or northeasterly directed compression sealed the rift system; the latter deformed Tertiary sediments along a pattern influenced by the foundered continental elements.

Some circumstantial evidence for the rotation of Alaska away from the Arctic Islands is presented but further work on this theory would require the collection of more aeromagnetic data

from farther offshore.

It is recommended that future aeromagnetic surveys do not use the hyperbolic Decca navigational system to orient flight lines, because it imparts an extremely corrugated texture to the magnetic data set. Additionally, separate survey segments should be merged carefully in order to avoid the edge effects found in this data.

1.0 INTRODUCTION

Urquhart Dvorak Limited of Toronto, Ontario, was contracted in October, 1988, by the Geological Survey of Canada to conduct quantitative interpretation of aeromagnetic data from the Beaufort Sea - Mackenzie Delta Region (DSS File No.03SG.23294-8-0693-A). The data were collected over an area confined between latitudes 68°N to 72°N and longitudes 128°W to 141°W, measuring approximately 450 x 500km (see figure 1).

The purpose of the project was to help advance the knowledge of the deep structure and evolution of the geologically complex Beaufort - Mackenzie Basin. The study provides a series of modelled magnetic profiles, enhanced colour map products, an analysis and interpretation of the nature and structural fabric of the magnetic basement, and calculations of magnetic source/basement depths.

In addition, spurious magnetic features caused by flawed aeromagnetic data, and identified during the course of the project, are plotted on a set of interpretation maps.

Scientific authority for the project was Dr. Randell Stephenson of the Institute of Sedimentary and Petroleum Geology, Calgary. Mr. James R. Dietrich and Dr. Larry S. Lane also provided much helpful information concerning the Beaufort Sea-Mackenzie Delta Region.

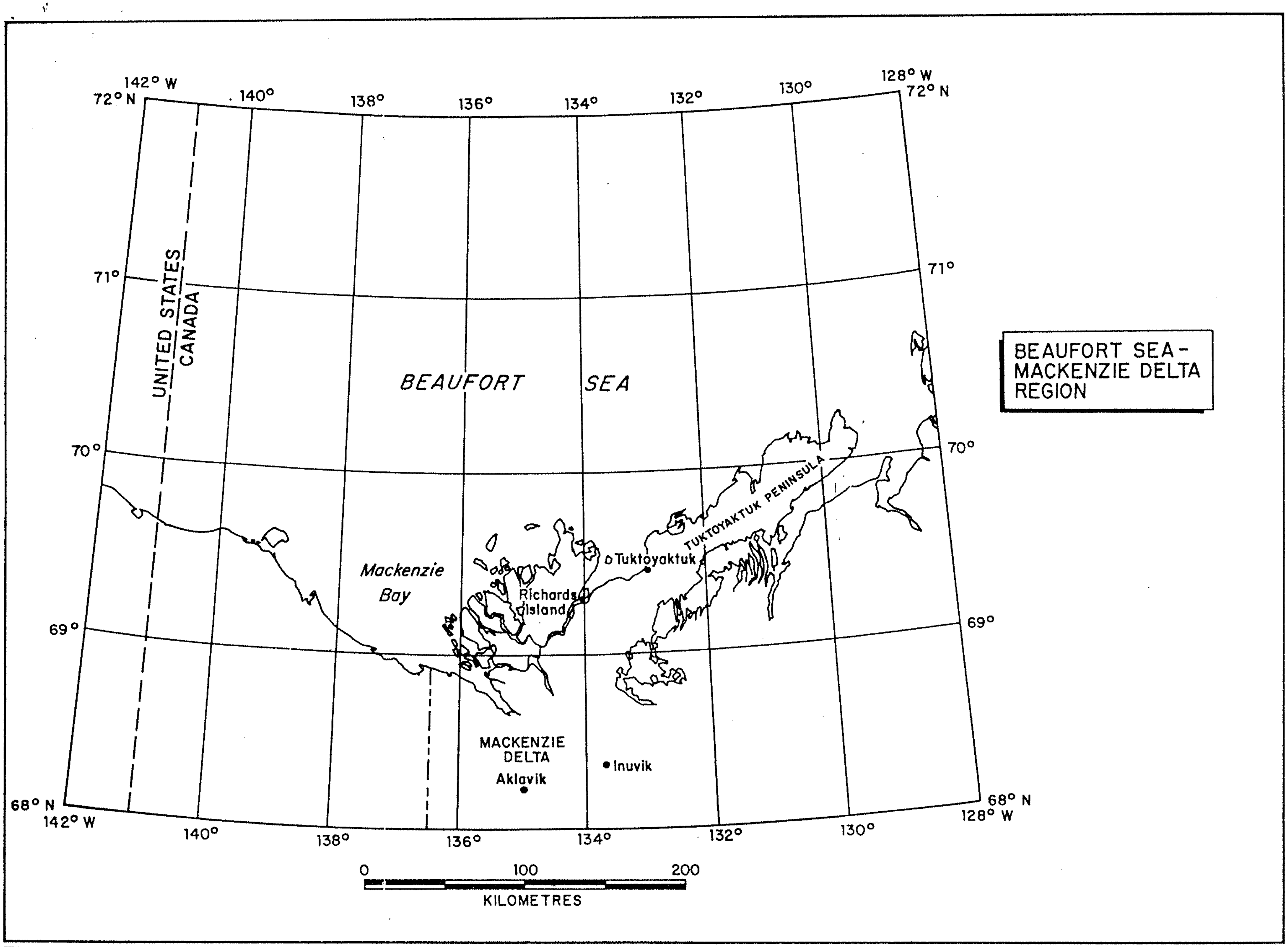

BEAUFORT SEA - MACKENZIE DELTA REGION
142° W
72° N
128° W
72° N
140°
138°
136°
134°
132°
130°
71°
70°
69°
68° N
142° W
68° N
128° W
UNITED STATES
CANADA
BEAUFORT
SEA
Mackenzie Bay
Richards Island
Tuktoyaktuk
TUKTOYAKTUK PENINSULA
MACKENZIE DELTA
Aklavik
Inuvik
0
100
200
KILOMETRES

Figure 1

2.0 BEAUFORT SEA - MACKENZIE DELTA REGION

2.1 Introduction

The Beaufort Sea - Mackenzie Delta region, as defined in the terms of the contract, comprises an area of approximately 450 x 500km, extending from 68°N to 72°N, and from 128°W to 141°W. The majority of the study area is situated offshore although parts of the Northwest Territories (NWT) and Yukon land masses are located in the southeast and southwest corners of the map, respectively. Bathymetric contours indicate depths to the sea floor, in the northwest quadrant, in excess of 2,000m while onshore in the Yukon Territories, less than 40km from the coast, the British Mountains have elevations greater than 1,430m.

The Beaufort Sea - Mackenzie Delta (BSMD) region is a geologically complex, not fully understood, but economically significant region of the Canadian Arctic coastline. Located between the Canadian continental margin and the larger Canada Basin to the north, discoveries of hydrocarbon reserves greatly increased scientific interest in the area.

2.2 Structural and Tectonic Elements

A number of major tectonic features or elements are recognized in the study area. The Beaufort-Mackenzie Basin is perhaps the dominant feature, and certainly of the greatest interest to hydrocarbon exploration. The eastern portion of the area is comprised of the Aklavik Arch Complex, Eskimo Lakes Fault Zone (ELFZ), Kugmallit Trough and the Outer Platform Hinge Line. To the west are the Romanzof and Barn Uplifts, the Old Crow Babbage Depression, and the Demarcation Basin/Herschel High. Between these two general areas, in a central location, are the Blow and Tununuk Highs and the Rapid Depression (also known as the Blow Trough).

Mesozoic to Tertiary sediments fill the Beaufort - Mackenzie Basin, reaching thicknesses in excess of 12km in the vicinity of Richards Island (as calculated from seismic data and gravity modelling - Cook et al., 1987). Recent work by ISPG staff has revised this figure to more than 16km of sediment (J. Dietrich, personal communication, 1989). Total extent of the sedimentary package is unknown although good well control exists for the upper 5km, or so. Tectonically, both the sediments and the basin itself have been overprinted by cordillera deformation, possibly related to the collision and subsequent accretion of foreign terrains along the Pacific Coast, or to the rotation of continent bearing plates. Offshore, in the western portion of the basin, Tertiary sediments have developed curvilinear anticlinal fold axes as a result of this compression. Gravity and seismic work suggests that a thick Paleozoic/Proterozoic sequence underlies the Tertiary material onshore. The nature of the underlying crustal material is unknown and will be addressed in this report.

The Aklavik arch complex is a northeast trending series of uplifts and depressions extending from the Yukon to Banks Island. Composed of deformed Proterozoic and Paleozoic rocks, such as those exposed in the Campbell Uplift southeast of Inuvik and the Cache Creek High, this tectonically complex sequence of thrust sheets developed after the Devonian but prior to the Cretaceous.

An array of northeasterly trending listric normal faults known as the Eskimo Lakes Fault Zone (ELFZ) parallels Proterozoic aged features and defines the southern edge of the Beaufort - Mackenzie Basin. From seismic interpretations, Mesozoic and Tertiary sediments appear to pinch out against the ELFZ and at least one "zero edge" has been identified on land. These faults (part of the larger Richardson fault array extending south along the east flank of the Richardson Mountains) have near vertical dips which flatten to the north at depth and are downthrown on the basin side. The Aklavik arch complex was offset by this fault system sometime during the Cretaceous (Cook et al., 1987).

Subparallel to the northeastern portion of the ELFZ and from 30 to 50km further offshore is the Outer Platform Hinge Line, indicating an abrupt increase in basinward dip and depth of sub-Mesozoic strata. The sub-Mesozoic section thins to the west of this hinge line.

The Romanzof Uplift is a thrust faulted and tectonically thickened succession of Lower Paleozoic and Proterozoic strata intruded by granitic plutons (e.g. Sedgewick Granite) and interbedded with volcanic flows. Extending westward into Alaska from the Babbage River area, the north front of the uplift dips steeply basinward near the present shoreline. Southeast from the Romanzof Uplift are the Barn Mountains, a topographic expression of the ovoid Barn Uplift. This small feature exposes a steeply dipping, north trending and highly deformed Cambrian to Devonian succession (Cecile, 1988).

Offshore and north of the Romanzof Uplift is the Demarcation Basin, an upper Tertiary syncline containing up to 7km of sediments (J. Dietrich, personal communication, 1989).

The Rapid Depression is a major north trending structural trough containing more than 5km of Jurassic and Cretaceous sedimentary infill deformed and folded by early Tertiary orogenesis. Located approximately between the Blow River and Big Fish River, the deep structure and offshore extrapolation of this feature are unknown.

North and northeast of the Rapid Depression, and possibly tectonically overprinted on it, are the Blow River and Tununuk Highs. The Blow River High is part of the arcuate Tertiary cored, anticlinal fold belt, identified through seismic work as extending offshore. The Tununuk High is a north-northeasterly trending single isolated anticlinal structure, roughly parallel to the Kugmallit Trough (another component of the Aklavik Arch Complex).

2.3 Basin Development

The genesis and development of the Beaufort Sea - Mackenzie Delta region is currently the topic of discussion. Rotation of northern Alaska and northwestern Yukon away from the Canadian Arctic Islands during the Mesozoic (Cretaceous?) is one possible interpretation. Other proposals considered for the mode of formation include a major right lateral offset of Alaska along the Kaltag Fault system (Pelletier, 1987), or the capture of a continental crust bearing plate (moved in from the south) by the rotating Alaska/Eurasian plate mosaic (Churkin and Trexler, 1980).

Other alternate hypotheses include:

(i) rift valley formation through the subsidence of a crustal wedge due to normal faulting under tension, followed by thinning to compensate in the lower ductile layer,
(ii) development of a "trough" between two swells in the lithosphere (not fault bounded), followed by thick sediment accumulation due to downwarping and subsequent rifting,
(iii) rifting developed due to the influence of a localized hot spot, similar in scale and magnitude to those identified in the adjacent Slave Province (Coronation and Great Slave hot spots),
(iv) or, subsidence of continental crust under the weight of Mesozoic to Tertiary deltaic sediments, followed by upwelling of the Mohorovicic discontinuity and thinning of the crust.

All of these models of basin development impart structural effects to the basement which may be recognizable in the magnetic signature of the rocks. Additionally, the last four models all require thinning of the continental crust.

These models and hypotheses were used as starting points in the interpretational process, although we tried to maintain an unbiased opinion wherever possible.

3.0 DATA

3.1 Individual Data Sets

The primary data set consists of 85,000 line kilometres of aeromagnetic data collected under contract by Questor Surveys Limited of Mississauga, Ontario, in 1985. Flight lines followed the hyperbolic Decca navigational lattice with line spacing varying from 2 to 5km, and cross (tie) lines at 14 to 50km intervals. Data was supplied to Urquhart Dvorak Limited by the Geophysical Data Processing Section (Geophysics Division) of the GSC. The gridded digital data had previously been checked and adjusted for diurnal variations, navigational problems and other errors according to standard GSC procedures. Older vintage data collected at 2km line spacings southeast of the 1985 survey area had been appended to the more recent data set.

Other information provided for the purpose of interpretation included limited bathymetric/elevation data, two preliminary offshore seismic profile interpretations, several recent publications from the area and an onshore geological map. Presentations by, and discussions with, GSC personnel involved in work in the area (R.Stephenson, J.R.Dietrich and L.S.Lane) complemented the available information.

3.2 Data Quality

The GSC aeromagnetic data set was comprised of three separate and distinct surveys collected at different times and at different elevations;

(i) the main offshore data block flown at a 305m mean terrain clearance (mtc),
(ii) a segment flown at 1,829m above sea level (asl) over the northern Yukon and,
(iii) vintage data from the southeast corner of the study area (onshore N.W.T.), flown at a mean terrain clearance of 305m.

Additionally, inspection of the actual flight line tracks revealed that data from the main offshore block was readily divisible into three separate flight patterns (see figure 2). The aeromagnetic survey data therefore represents five separate data segments merged to form a single data set. Characteristics of the five blocks are summarized in table 1.

The data appears smooth and well joined on the first generation GSC residual map originally prepared to fit, on a national scale, with the digital aeromagnetic data set currently being compiled for the rest of Canada. However, once the gridded

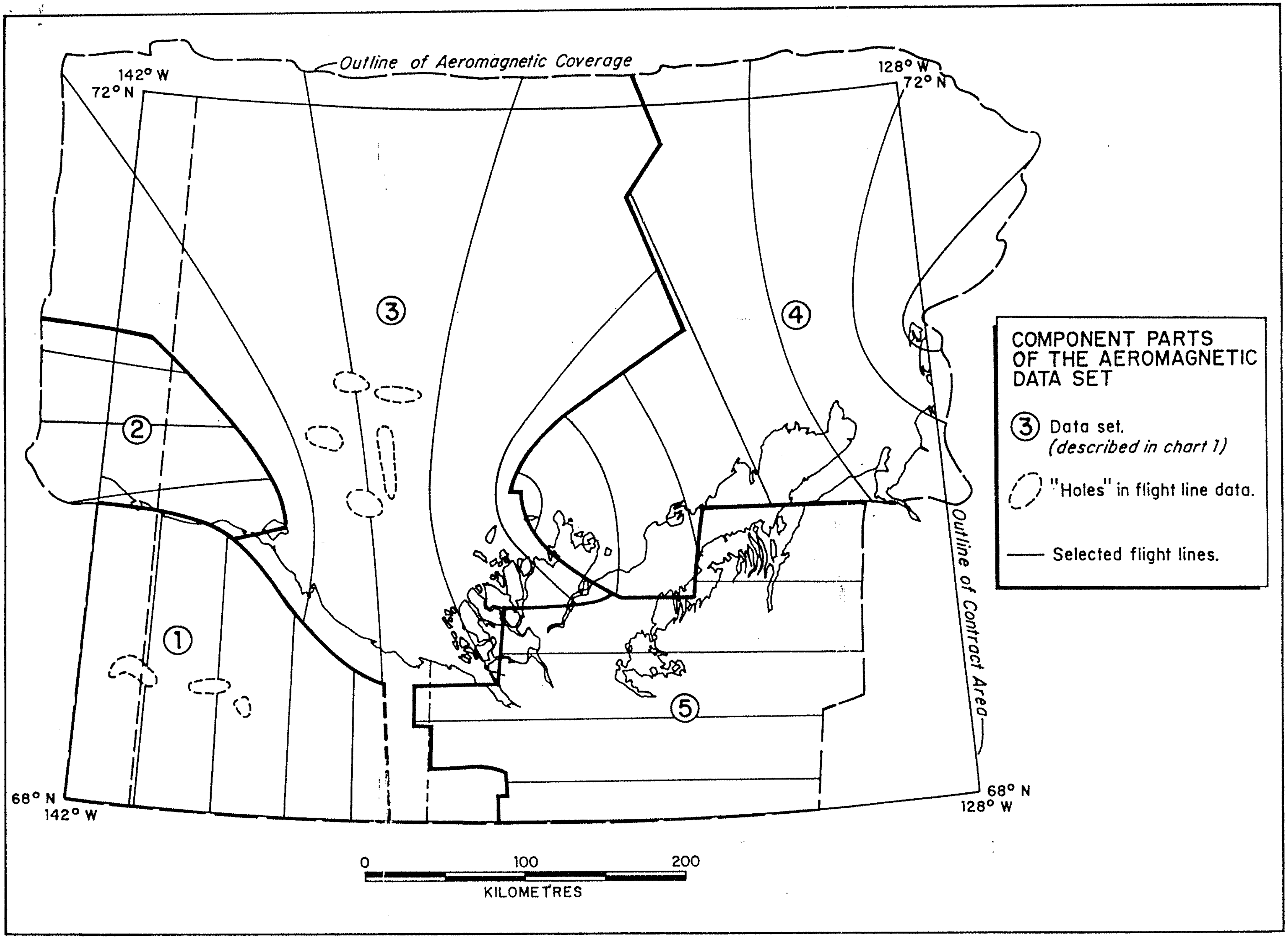

Outline of Aeromagnetic Coverage
142° W
72° N
128° W
72° N
68° N
142° W
68° N
128° W
Outline of Contract Area
1
2
3
4
5
COMPONENT PARTS
OF THE AEROMAGNETIC
DATA SET
3 Data set.
(described in chart 1)
"Holes" in flight line data.
Selected flight lines.
0
100
200
KILOMETRES

Figure 2

DATA SEGMENT	GENERAL LOCATION	FLIGHT ALTITUDE	LINE SPACING	ORIENTATION	DATE	COMMENTS
1	SW corner of main block -onland northern Yukon	1829m (asl)	2km	north-south	1985	-flown over terrain ranging in elevation from 0 to 1430m -numerous gaps in the data set (incomplete lines) -tie lines included with the gridded data -at the east side of the segment (over delta) the data is smoothly merged with Decca lines from segment #3
2	west side of area -nearshore	305m (mtc)	2km	approx. east-west	1985	-sparse line coverage -incomplete flight lines -includes bad tie line from segment #3
3	central portion of area -from delta to offshore	305m (mtc)	2-5km	varies from NW to NS to NE along hyperbolic Decca lines	1985	-scattered gaps along flight lines -strong curvilinear character to the data set -extra infilling lines flown to fill in larger line spacings
4	north-east corner of area -offshore	305m (mtc)	2-5km	varies from NW to NE along hyperbolic Decca lines	1985	-strong curvilinear character to the data set -line spacing decreases in northwest corner -includes bad tie line from segment #3
5	south-east corner -onshore	305m (mtc)	2km	east-west?	? "vintage data"	-well leveled data set; heavily filtered? -not well merged with 1985 data set (edge effects)

TABLE 1

aeromagnetic data was enhanced, the flight line track orientation imparted a strong curvilinear texture to the data. This distorts magnetic features and introduces interpretational prejudice. As data enhancement continued (through calculated first and second vertical gradients) the merged edges of individual data sets became more apparent, as did the flight line effects. Shadow maps brought to light even more flaws in the data set, including several places (e.g. 135°W longitude, north of 71°N) where the original data set had been separated into smaller blocks, leveled, and remerged, creating yet another series of edge effects.

Overlays indicating these artifacts, or pseudo-magnetic features induced by aquisition and processing errors, have been included for the reduced to pole (RTP) total field magnetic map, the calculated first vertical gradient map, and the residual component field map. These artifacts are present on all the colour products because they are inherent in the aeromagnetic data set, but they may or may not appear to be present, depending on the nature and degree of enhancement.

3.3 Data Manipulation

Prior to the derivation of the colour products, minor modifications were made to the original data set. The space around the outside edge of the original GSC grid was filled with reasonably continuous data in order to reduce the effect of transforming and filtering the discontinuity between the edge of real data and the grid default values. This filled space domain grid was then transformed to the frequency domain using a Fast Fourier Transform algorithm. A half-cosine shaped roll off, or Hanning window filter, was applied at the edge of the real data in order to taper any of the discontinuous edges.

All further filter operators, including the reduction to the magnetic pole, first and second vertical derivative (gradient) calculations, and the separation of the data into regional and residual components, were then applied to the frequency domain grid. These other filter operators are discussed in the respective sections dealing with enhancement products.

Grid cell size of the GSC data base was 812.8m and therefore every magnetic feature shown on the final map can be no less than approximately twice the grid cell size. The grid was presented on a Lambert Conformal Projection in a UTM format, with 136°W as the central meridian.

4.0 INTERACTIVE MAGNETIC MODELLING

4.1 Introduction

Profiles of magnetic responses taken from the gridded data set enable the interpreter to view the magnetic field response in detail, provide a means of interpretation as well as a graphical comparison of the sections with other interpretations, such as seismic.

There are three basic methods for the modelling of magnetic data: curve fitting, forward modelling by trial and error, and inversion.

The process of curve fitting involves the use of precalculated models for which characteristic points are measured and compiled as graphs. Comprehensive books of graphs are available for a variety of body shapes. The procedure is useful but time consuming for a large number of anomalies and gives no sense of a "goodness of fit".

In forward modelling, the user calculates the anomalous magnetic field caused by a simple body and matches the derived forward model with the measured anomaly. This process is repeated until an acceptable fit is achieved. The method maintains interpretative restraint and allows geological models to be easily tested.

During direct inversion, multiple forward models are calculated by changing the individual parameters, until a "best fit" is achieved. High speed and "quantized" results are advantages of this method. However, the user has to maintain sufficient control in order to assure that the fitted body parameters are reasonable and geologically meaningful.

Interactive modelling of magnetic profile data was carried out with the assistance of a high performance microVAX II computer. Two separate programs developed by Urquhart Dvorak Limited and our associates were used in order to better evaluate and interpret the data. Program MDI (Interactive Magnetic Data Inversion) models and compares the observed magnetic field with the calculated response from a hypothetical body created by the user. The magnetic modelling program MCPT calculates and compares the response for a number of modelled magnetic bodies with the observed profile data.

4.2 Interactive Magnetic Data Inversion Program (MDI)

Program MDI (Magnetic Data Inversion) combines the interpretational foresight of forward modelling with the power of the inversion method by using the two procedures in a complementary manner. The program allows the user to estimate the final parameters by solving a set of non-linear inversion equations. Estimates of the equation coefficients are obtained by Marquardt's Maximum Likelihood Method (Daniel and Wood, 1980) which combines the Gauss (Taylor series) Method and the Method of Steepest Descent.

The user must select and specify the desired anomaly model to be used for inversion of the selected anomaly or profile. Profiles may be selected, at any orientation and length, from an onscreen overview of the entire data set. Three different model equations were incorporated into MDI:

1) Infinite Dyke: a dipping dyke with rectangular cross section of finite thickness, finite variable depth extent and infinite strike length,
2) Tabular body (Prism): a rectangular shaped dipping body of finite variable depth extent and finite variable thickness, and,
3) Step: a sloping contact of infinite strike length and limited depth extent between two semi-infinite horizontal slabs.

The general flow of the MDI program is as follows;
1) Display of the magnetic contour map of the area of interest on screen for anomaly profile selection. A window of a portion of the contour map may be selected and redrawn for more detailed anomaly selection. Individual anomalies and profiles are selected at this stage.
2) Display of the initial profile and selection of start parameters and/or parameter ranges.
3) Commencement of calculation, production and display of "best fit" parameters and superposition of calculated response profile over original profile. The 95% Student T and normalized Residual Root Mean Square error for the fit are also displayed.
4) An acceptable solution means the user continues on to the next profile. Unacceptable responses may be recalculated by changing start parameters, parameter ranges, or anomaly subroutines.
5) Once a single body has been solved, the calculated response for that body can be removed from the profile in order to simplify modelling of the next anomaly.
6) Finally, in addition to the hard copy of fitted profile results, a plot of anomaly body shapes and relative positions on a plan map can be created.

The MDI magnetic profile modelling can be used to narrow down the parameters which, in turn, are then used as starting values for the MCPT program.

4.3 Magnetic Modelling Program (MCPT)

Individual magnetic anomalies selected from the magnetic profiles, or the entire profile, may be modelled to gain further insight into the nature of the magnetic basement. The modelling program used to assist in this quantitative interpretation is referred to as MCPT. It is an interactive forward modelling gravity and magnetics graphic package. By constructing polygons of varying parameters the user may represent the magnetic conditions postulated to exist in the area and, using the Shuey and Pasquale 2 1/2 D magnetic algorithm (1973), calculate the response of the selected model. The response may be displayed on the screen either alone, or in comparison with the profile of the original observed data. If the fit of the anomaly response is not acceptable, then the polygons are altered interactively using the graphics terminal. The use of individual polygons permits the matching of individual anomalies along the profile. Parameters that can be altered include location, shape and size of the anomalies, susceptibility, and strike length (at right angles to the screen).

4.4 Discussion of Results

The modelling of any geophysical parameter (aeromagnetics, gravity, induced polarization, etc.) involves a large degree of ambiguity. Ambiguities can be reduced through careful attention to parameters and by discarding responses that do not fit into the general framework of the study area.

The more information that is known about an area, the better constrained and more accurate will be the models. Within a relatively unknown area the degree of variability is very wide, and initially attempting to force magnetic profiling to fit preconceived notions may cause the loss of information.

In magnetic modelling similar responses can be obtained from bodies of a vastly different character. Calculated model parameters which match an observed profile may be altered by increasing susceptibility and depth of burial, yet still produce an profile identical to that of the original response curve. The influence of body width and depth extent are also of critical importance in producing the desired profile.

When dealing with magnetic profiles of the scale involved in this survey, modelling of the individual anomalies tends to average or gloss over minor changes within the magnetic information. For example, an anomalous response may be due to several smaller complex features in relatively close proximity to one another, rather than a single simple source body.

4.4.1 Program MDI

Hard copy prints of the anomaly profiling results from MDI modelling are contained, and described, in Appendix A. Thirty-one profiles modelled twenty-eight magnetic anomalies of interest. A summary of calculated anomaly parameters, overlain on a contour plot of total field magnetic data (at 1:1,000,000), has been prepared for discussion and ease of reference (map 1).

Anomalies on this map are referenced by letter designation. Other labelled parameters include: direction and angle of dip, body widths (apparent and true), susceptibilities, depths, and where applicable, depth extent. Depth to the surface of the body has been corrected relative to sea level, and all width/depth measurements are expressed in kilometers rounded to the nearest 100m.

Most of the MDI profiling was conducted using a "dyke-like" body as the model source. This procedure was used due to the limited width of the anomalies as compared to their length. Program MDI was used to obtain initial information about the BSMD Region, and to constrain further magnetic modelling.

The long linear northeasterly trending feature (anomalies AA, AB, AB′, AC, AD, CA2) is a good example of ambiguous responses encountered in parameter calculation. While dip and depth of burial of anomalies AB and AB′ are essentially the same, AB′ has only one-tenth of the width of AB but ten times the susceptibility. Although the degree of fit for AB′ was slightly better than that of AB, the susceptibility value (37,137 x 10-4 emu) would require the source body to be composed of almost pure magnetite, a situation considered extremely unlikely at this scale. Modelled results indicate that the body is deepening from approximately 9km in the northeast to greater than 18km in the southwest. This general deepening effect is reflected in all scenarios.

A discrepancy between adjacent anomaly models along this feature was also noted. Anomaly CA2, located between AA and AB, has a much shallower dip, a greater width and a lower susceptibility value at a slightly shallower depth. This difference may be due to the profile location (between magnetic highs in the body, perhaps a result of faulting or other geologic influences responsible for the break in anomaly pattern), or an expression of the true character of the basement.

The short, roughly circular anomalies BA and BC were investigated with a prismatic body shape to fit the three dimensional magnetic signature and the available geologic information. Anomaly BA appears to be caused by a large feeder stock or plutonic source at depth (approx. 12km) with a smaller, near surface body (ie. Sedgewick Granite) causing the spike on the profile and other similar spot highs in the vicinity.

Modelling of the spike caused by the Sedgewick Granite (BA2) after removal of the response from the deeper plutonic source (BA), yielded a set of parameters different to those of BA' (initial parameters calculated for BA' are midway in between the response of the two separated features). Therefore, it is readily apparent that small, near surface magnetic features effectively mask or obscure the response of deeper bodies.

The response of BC is that of a fairly susceptible body of limited depth extent well below (16km) the surface, again interpreted as an igneous source at depth. In fact, the entire group of bodies along this northeasterly trend within the Yukon/NWT landmass are interpreted to be a result of large masses of susceptible bodies extending to depth (ie. continental crust intruded by, or comprised of, igneous bodies), overprinted by shallower bodies closer to the surface.

Magnetic anomalies in the vicinity of Sitidgi Lake were modelled as both a step (CFs) and a dyke (CFd) feature. The step model was that of a reverse fault dipping to the east - the west side downthrown a distance of 16km relative to the hanging wall. This would be indicative of major basement compression from the west, an observation superficially supported by mapping of thrusts and faults within younger lithologies in the vicinity of the Yukon/NWT border. Responses from both models indicated depth to magnetic basement in the order of 14 to 15km.

The anomalies modelled at CA and CD (as dyke like bodies) are of a broadly similar nature to those of CF; relatively shallow continent-ward dips, moderately high susceptibilities, and at about 20km depth.

The shallowest anomaly (BH2) identified in the offshore MDI profiling is a narrow (800m) dyke-like body of relatively low susceptibility (839 x 10-4 emu) at 2.8km depth. Water depth over this feature is about 1,000m. Therefore the body is very close (approx. 1.8km) to the seafloor, and well within the Tertiary sediments. Alternately, the response may come from a more susceptible, narrower body at a greater depth, hidden because the grid cell size of the data set would preclude the proper magnetic expression of any feature smaller than about 800m. Regardless of whether this depth is entirely accurate, or substantiated by seismic records, the response is still representative of a feature shallower, in a relative sense, than others modelled in the offshore.

This anomaly could not be modelled as a step feature, even though we suspect that one exists here, because emplacement of the dyke along the associated structural weakness masks the magnetic response of the original topography.

The two elongate curvilinear bodies extending from the northwest corner of the map sheet appear, from this stage in the modelling, to be narrow features with moderately high (2-4000 x 10-4 emu) susceptibilities. Dips are dominantly to the west. Models across the east arm show a greater continuity in all respects than responses from the west arm.

A second modelling attempt (DA), using a shallower, wider and much less susceptible body than all the other responses from this paired feature, fit with almost equal statistical accuracy.

While the anomaly body models may not truly represent the insitu parameters, the relative comparison between responses from different "groups" of anomalies should be fairly accurate.

4.4.2 MCPT Magnetic Modelling

Results and a description of the MCPT magnetic modelling are found in Appendix B. Fifteen profiles (Z1-Z6, Z8-Z16) were modelled and the locations are shown in figure 3. A total of 3730 line kilometers of magnetic data were profiled.

Susceptibilities between the ranges of 0.5 and 5.0 emu's are considered to be reasonable for magnetic bodies commonly encountered in the geologic environment. Higher values (e.g. magnetite iron formation) may be found, but it is not likely that they would be present in sufficient quantities to be recognized at the scale of the study area. Modelling was conducted, for the most part, using bodies of limited depth extent (35-45km), because at greater depths, temperature exceeds the Curie Point and magnetism is lost.

Magnetic modelling was at a very coarse scale due to the nature and size of the data set. Individual minor anomalies within a profile could be modelled in great detail, however, they would not necessarily correspond to real bodies or to the complex interaction of deep and shallow magnetic sources. It was therefore decided to model profiles in a broader sense in order to maintain regional compatibility with magnetic responses.

In magnetic modelling it is important to match both the gradient and peak response of the calculated response with the observed profile. Minor discrepancies between the observed and calculated profiles may be adjusted by small changes to the body size and topography that, while aesthetically pleasing, do not affect the overall shape of the model. As previously noted, a slight increase in susceptibility or a decrease in depth of burial have much the same effect on the response profile.

Although many of the models appear simplistic and barren of source bodies it should be noted that adding any number of bodies with a relatively low susceptibility will have little or no effect on the calculated response profile, only on the aesthetics of the model. The level of magnetization adjacent to the larger bodies is so low that in a relative sense its contribution to the profile is effectively zero and therefore no accurate depths can be determined for these areas.

The profiles showed a strong dependency with respect to surface topography of the body. The large effect of basement topographic relief on an uniformly magnetized body noted by Behrendt and Grimm (1985). They invoked 14-15km of basement topography in order to explain some of the structures present along the Atlantic margin.

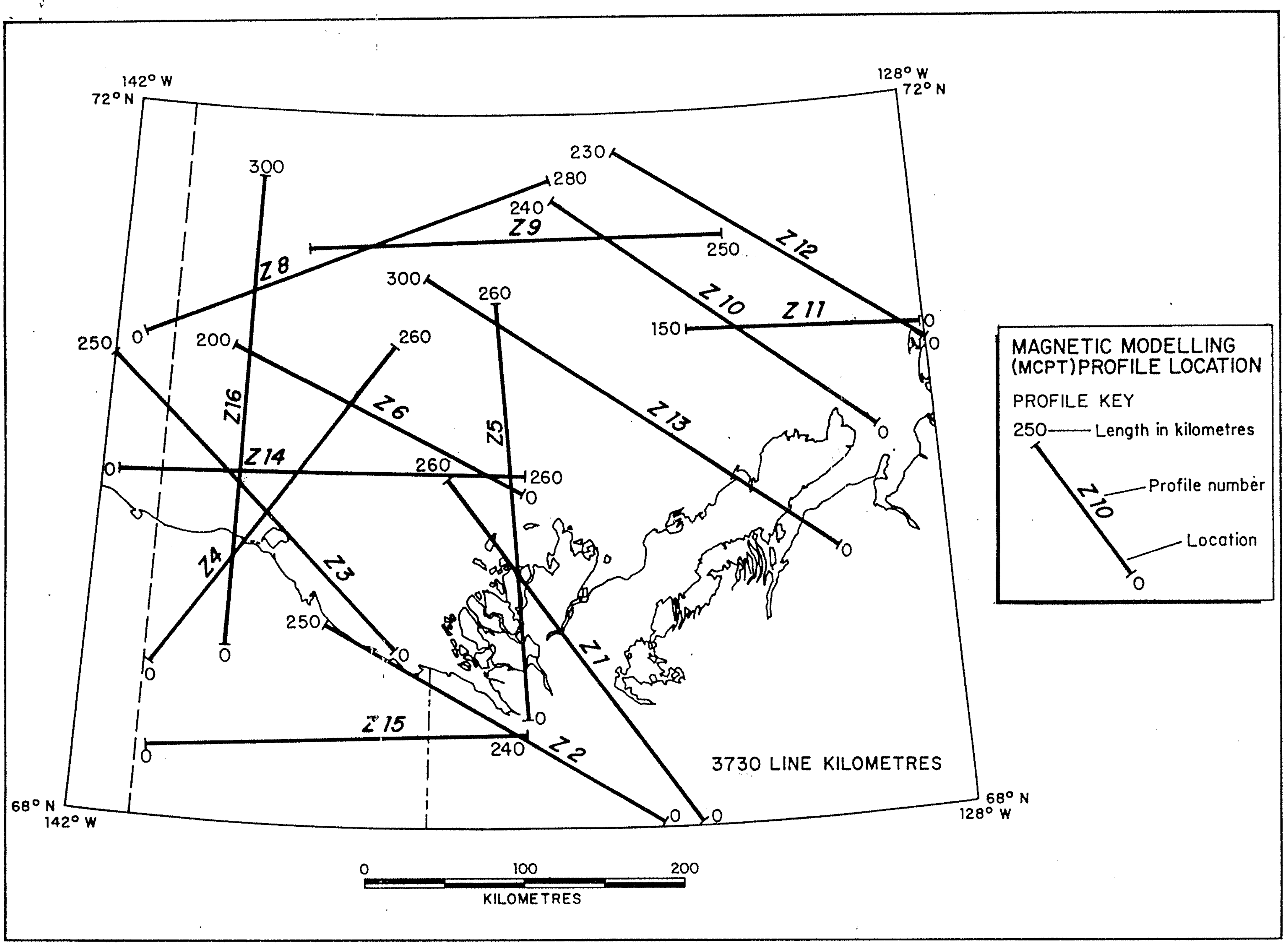
Other information is required in order to constrain the models. Profile Z1B was modelled in layered manner using the interpretation of Cook et al (1987). It required susceptibilities much higher than those used in the unconstrained model (Z1) and included intrasedimentary volcanic units. Profile Z6B, a continuation into the offshore of Z1, was attempted using the same layered approach. However, in order to match profile responses, adjustments to the layered model began to resemble the model originally developed (Z6) using a relatively unconstrained point of view.

The relatively shallow low susceptibility feature of profile Z4 correlates with the uplifted tectonic block of the Barn Mountains and Hoidahl Dome. Uplifts within the Aklavik Arch complex between 1 and 10km depth can be traced along the southeastern ends of profiles Z10-Z13. Shallow features of a higher susceptibility on profiles Z1 and Z2 are related to the Campbell Uplift and intrusive bodies adjacent to Sitidgi Lake.

The arcuate doubly lobed structure noted on the total field map, and areas of high magnetic character in the north, all have a similar susceptibility (in the range of 1-1.2 emu), implying a similar nature. Z6B indicates the presence of an extension at depth (and overlain by a thin less susceptible unit) of the doubly lobed structure.

The long northeasterly orientated anomaly indicated as increasing in depth to the southwest by the MDI anomaly modelling, maintained a relatively horizontal orientation during MCPT work (between 10 and 15km depth).

The models provide a good regional overview and are broadly correct in their shape and style. While providing unconstrained, and therefore somewhat dubious, quantitative information about the BSMD Region, they are extremely useful in the following more qualitative magnetic interpretation.



MAGNETIC MODELLING
(MCPT) PROFILE LOCATION
PROFILE KEY
250 Length in kilometres
Profile number
Location
Z10
0
142° W
72° N
128° W
72° N
68° N
142° W
68° N
128° W
3730 LINE KILOMETRES
0
100
200
KILOMETRES
Z1
Z2
Z3
Z4
Z5
Z6
Z8
Z9
Z10
Z11
Z12
Z13
Z14
Z15
Z16

Figure 3

5.0 DATA ENHANCEMENT

5.1 Introduction

Colour map products were produced by a series of specialized processing steps, performed mostly in the frequency domain. Maps accompanying the report include: reduced to pole (RTP) total field magnetics, first and second calculated vertical gradients, separated residual and regional fields, and four magnetic shadow maps (two each of RTP total field magnetics and residual magnetics). A colour transparent overlay of total field magnetics has been supplied to complement the shadow maps and to present a "three dimensional aspect".

Accompanying the enhanced products are three overlays (for RTP total field magnetics, calculated first vertical gradient and residual field maps) showing spurious magnetic features caused by flaws within the gridded GSC data set.

Although the original contract required the final products to be at 1:500,000 scale, following discussions with Dr. Randell Stephenson (scientific authority for the project) contract revisions updated the scale to 1:1,000,000 in order to reduce the visible flaws and present the enhanced data at the most useful scale possible.

An Iris 2044 Colour Ink Jet Printer was used to plot the high density (240 dots per inch) colour maps. Products have been double laminated with "Satinex", a transparent, matte finish film with a pebbled surface. The purpose of the coating is to screen ultraviolet radiation (that causes colours to fade), seal out moisture, and provide a measure of protection from damage during use. The film covering also allows users to write on the maps with a grease pencil, and to wipe off the marks, as desired, with no damage to the colour products.

The transparent colour overlay was printed on acetate in a reversed image (on the back of the sheet) in order to protect the ink from damage.

The following sections briefly describe the products and technical aspects of data enhancement used to product them.

Significant magnetic features, structural trends and tectonic elements interpreted from the enhancement products are discussed in section 6.0 rather than dealing with them individually.

5.2 Reduced to Pole (RTP) Total Field Magnetics

Regional field magnetic maps delineate large scale structural features, identify major anomalies and permit the generalized subdivision of an area into separate "geologic" units. The superposition of anomalies may obscure smaller features, mask the geologic boundaries, and cause difficulty in obtaining detailed information. A "shadow" version of this map enables the interpreter to recognize subtle structural features and to identify flaws within the data set.

Reduction to the magnetic pole (RTP) transforms the aeromagnetic field data to values as they would be observed if recorded at the magnetic pole. This centres anomalies over their inductively magnetized causative bodies. The Beaufort Sea data was originally measured in the earth's magnetic field at a magnetic inclination of 81.5^{o} (the magnetic pole is 90^{o}) and a magnetic declination of 36^{o} (positive angles east of north). The transformation was the only operator applied to create the Pole Reduced grid.

The RTP total field magnetics colour map was produced from the gridded GSC data set based on a contour interval designed to give an equal area spacing to each colour tone. As a result, the internal resolution of very high, and very low anomalies is reduced in comparison with the median values. A slight modification of the selected colour interval ensures whole number integer representation in the legend instead of fractional intervals. Rather than embedding contours within the colour product, a contour map of the pole reduced total field magnetic data was plotted on mylar. Contour intervals of 20, 100 and 500 gammas (nT) are represented by pens 1,2 and 3 respectively.

Several small problems with the data set have produced a series of magnetic artifacts, or features, on the colour map which are not related to any real magnetic structure. Artifacts evident on the RTP total field magnetics map include linear features due to the inclusion of poor tie line data, an indication of striping as a result of flight line orientation and leveling errors, and the hint of edge effects created by problems with leveling adjacent data sets. Magnetic noise from a drill ship operating during the survey has resulted in a spot magnetic high about 12km offshore of the Yukon/Northwest Territories border. These flaws were already inherent in the gridded GSC data and could not be removed without major modifications to the original data set beyond the scope of the contract. Survey artifacts have been identified on an accompanying overlay at 1:1,000,000 scale (map 2).

The colour map gives a good overview of the regional magnetic character of the Beaufort Sea - Mackenzie Delta (BSMD) Region. Perhaps the most visually striking feature is the 300km by 60km northeasterly trending magnetic low subparallel to the Tuktoyaktuk Peninsula. The southeastern edge of this magnetic trough correlates very approximately with the ELFZ, and its northwestern edge with the axis of the Kugmallit Trough synclinal structure. Within the restraints of the survey area it is not possible to determine wether the magnetic lows in the south central portion and northeastern corner of the map are related to the larger magnetic feature or if they are separate anomalies. A small linear northwesterly trending anomaly along Moose Channel apparently isolates the south central low from the main body.

This magnetically low area is both too large and in the wrong relative location to be caused by the negative shadowing effect of adjacent, more susceptible features. It may represent either material with an anomalously low susceptibility, or rather more likely, the actual background readings of "normal" rocks.

5.3 Calculated First Vertical Gradient

The calculated first vertical gradient, as derived from the total magnetic field data, provides data practically equivalent to a measured vertical gradient. This technique reduces anomaly overlap, improves the spatial resolution of both deep and shallow sources, and aids in the identification of structural breaks and boundaries.

In each case, derivative calculations consisted of reduction to the pole, low pass filter and appropriate derivative operators.

The low and high wave-numbers used for the low pass filter of the calculated first vertical gradient were 0.10 and 0.30 respectively. As the order of the derivative increases (ie. to second and third derivations), so does the enhancement of the higher frequency features. The low pass filter parameters were therefore modified accordingly for the calculated second vertical gradient to 0.05 to 0.20.

Vertical gradient (derivative) operators were used to enhance anomalies with relatively shallow origins, because the operators tend to amplify high frequency features. If the higher frequencies in a data set are dominated by noise, these filters can have disastrous effects unless accompanied by some suppression of the highest frequencies. This was accomplished for the BSMD Region data by applying a Hanning roll-off or low pass filter. The shape of this filter is a half-cosine weighted function between two specified wave numbers. The low wavelength number is the starting point of the filter. All data with a radius equal to, or less than, this frequency will remain unchanged. The high wave-number is the end of the roll-off filter where all data between the low and high frequency are weighted with a cosine Hanning function and all data with a radius greater than the high frequency will equal (0.0,0.0).

The enhancement of total field magnetic data improves not only the anomaly resolution, but also magnifies magnetic noise and artifacts in the data set. Spurious magnetic features identified on the first vertical gradient map are marked on an overlay (map 3). Leveling problems associated with flight line direction are the most difficult flaws to clearly indicate. Identifying all flight line orientations may hide, or cause the observer to ignore, subtle magnetic features.

The most prominent feature on this colour map is indeed the corrugated texture imparted from the curvilinear flight line direction. Secondly, it appears that the flight line spacing has a large effect on the apparent continuity of magnetic anomalies. Aeromagnetic data collected from the northwestern part of the survey has a flight line spacing of 5km or greater and consequently, large wavelength anomalies appear to have a smoother outline than those from areas covered at a closer spacing. However, (despite the interference effects) they are still distinctly different from the shorter wavelength anomalies. The area seems to be composed of two separate magnetic responses: large amplitude, long wavelength anomalies with strong positive and negative responses, and a series of smaller amplitude anomalies.

The apparent preponderance of data quality problems should not obscure useful information that can be obtained from the first vertical derivative. By looking beyond, and through the shortcomings in the data set, useful information can still be extracted.

5.4 Calculated Second Vertical Gradient

The second vertical derivative removes the regional field effects and other long wavelength sources, leading to a better portrayal of geologic boundaries and to more accurate positioning of contacts between units. Anomaly overlap is substantially reduced, but level differences between units of different magnetic properties are maintained. Overall, the second vertical gradient is an aid to the interpretation and classification of individual anomalies and rock formations.

Parameters used in the calculation of the second vertical gradient have been explained in the preceding section.

Flight line and data quality problems are clearly evident and the flaws due to merging of data sets have become even more noticeable, but they retain the same general shape and location as those indicated on the interpretational map accompanying the calculated first vertical magnetic gradient map.

Differences in magnetic character of the region are still pronounced. Similarity between responses in the northwest, southeast and southwest corners is notable; the more broken patterns in the latter are probably due to the relative height differences between the aircraft and terrain elevations encountered during flights over mountainous terrain.

5.5 Residual/Regional Component Separation

5.5.1 Component Separation

In order to separate deep and shallow source data in the BSMD Region, a radially averaged power spectrum was calculated for the input GSC grid (figure 4). From this plot it was determined that the approximate depth to the loci of the shallower sources was 9.5 to 10km, and to regional sources, 30 to 35km. Parameters calculated from the power spectrum, combined with the assumption that the shallower source body types were dipoles, permitted the regional/residual component separation. The component separation also included a reduction of the magnetic data to the pole.

The residual magnetics should be free of all effects from deeper sources, but the regional magnetics may contain some contamination from minor long wavelength components associated with the shallow bodies. A recombination of the two maps would produce an exact duplicate of the RTP total field magnetic map from which they were derived.

5.5.2 Residual Magnetics

Magnetic responses represented on the residual map should be entirely due to the field strength of bodies at depths shallower than about 10km.

As a result, the residual component separation contains all the flight line levelling and orientation errors, edge effects and other flaws previously identified. These spurious features have been noted on an overlay but again, to reduce the risk of inferring that flight line orientation precludes anomaly identification, only the worst effects from this source have been noted (map 4).

Residual magnetic responses seem to decrease in intensity from all edges of the map into the centre, implying an increase in the depth to magnetic basement and the paucity of shallow intrasedimentary magnetically susceptible source features over most of the area.

5.5.3 Regional Magnetics

The regional magnetics map retains the general shape and features of the RTP total field magnetics map. Clearly then, most of the character and shape of the Beaufort-Mackenzie Basin is a direct result of the magnetic basement. With the magnetic response from the upper 10km of material removed, the outline and extent of large basement features become apparent.

5.6 Real Time Imaging (RTI) System

5.6.1 Introduction

Real Time Imaging (RTI) is a state of the art, 256 colour VGA processing package developed by Geopak Systems, the software division of Urquhart-Dvorak Limited, in association with Aerodat Limited. The RTI package provides for improved and comprehensive data interpretation through the use of high speed algorithms and screen drivers run on any AT or 386 computer with extended high resolution VGA capability. Gridded (digital) geophysical data or its derivatives may be manipulated interactively on screen, either singly or in a stacked multiple grid format, by the use of a mouse driven interface.

Colour or grey shadow displays of survey data may be varied according to selected colour tones and contrast. Inclination and declination of the "sun angle" in shadow mapping may be varied in real time (ie. as the cursor moves - driven by the mouse - so does the apparent shadow produced by the "sun"). The onscreen image is a three dimensional visual perspective and gives a pseudo topographic view of the data set. Controlled changes in the "sun angle" greatly enhance structural features, geological contacts and lithologic changes, and assist the interpreter in identifying subtle trends not readily apparent in the hardcopy map products usually associated with geophysical data.

Zooming into and out of the data display allows the user to concentrate on the larger picture or to focus in on significant details. Data collected from several different surveys (for example, magnetics and resistivity, or total field magnetics in conjunction with shadow mapping) may be combined onscreen to produce an unusual and extremely useful image to aid in interpretation.

Output of the view onscreen is easily obtained and provides a hard copy for continued offscreen interpretation. Data sets integrated onscreen may be represented in hard copy as colour transparency overlays, in conjunction with the colour or shadow maps, to recreate the three dimensional effect.

Aeromagnetic data from the BSMD region was treated in just such a fashion. Total field, calculated first and second vertical gradients and residual/regional fields were studied in this manner.

Institute of Sedimentary and Petroleum Geology research scientists Randell Stephenson, James Dietrich and Larry Lane were introduced to the RTI system and selected four shadow maps to be included with this report. Two shadows of the total magnetic field, at "sun angle" inclinations of 40^{o} and 45^{o} and declinations of 330^{o} and 158^{o} respectively, were produced. Shadow maps of the separated residual magnetic field at inclinations of 80^{o} and 54^{o} and declinations of 317^{o} and 146^{o} were also chosen as displaying the most representative features within this data set.

5.6.2 Shadow Map of RTP Total Field Magnetics

Sun angles (inclination and declination) were selected in order to minimize the corrugated effect caused by a hyperbolic flight line orientation and by levelling problems.

Although shadowed magnetic products can resemble pseudo-topographic mapping we are dealing with changes in magnetic character of underlying units (primarily magnetite content), not necessarily a change in topography (although it may be a contributing factor). Examples of this effect are discussed in the following interpretation (section 6.5).

5.6.3 Shadow Map of Residual Field Component

Because the residual field map is comprised of responses within the upper 10km or so of material, the corrugated effects of flight line leveling errors are greatly enhanced, even in areas that previously appeared problem free. Within the larger component parts of the data set are newly identified edge effects related to GSC processing techniques.

Nevertheless, differences in the magnetic character are still clearly evident and many shallow features have been further enhanced or identified for the first time. These map derivations were extremely useful in delineating the extent of several shallow tectonic elements.

6.0 INTERPRETATION

6.1 Introduction

The enhanced colour maps were used to derive a set of interpretation maps (1:1,000,000 scale) showing regional trend and character analysis (map 1), major tectonic elements and the interpreted source of features associated with the magnetic basement (map 2 - aeromagnetic interpretation). An attempt to produce a contoured depth to magnetic basement map (map 3) is included, and, finally, a discussion and integrated interpretation are presented.

6.2 Magnetic Attenuation and Interference

Before discussing the interpretation of colour products, it is important to address concerns about the attenuating effects on, and significance of sediment thickness to, aeromagnetic data.

In the interpretation of magnetic data the wavelength of anomalies is a fundamental result of the depth of burial. Attenuation caused by thicknesses of non-magnetic materials (water, air or sediment) is due almost entirely to the increase in distance between the sensor and the magnetic source.

The rate of magnetic attenuation depends upon both the type of body and the distance from source:

i) dipole source: magnetic response decays as the inverse of the distance cubed (ie. if the distance from source to sensor is doubled, the observed response will be 1/8 of the initial response),
ii) pole source: decay rate is one over the distance squared,
iii) linear source: decays as one over the distance, and,
iv) planar source: no attenuation with distance.

Therefore, the greater the sediment thickness, the more subdued are the anomalies. They become more discrete, broadening and flattening, but their basic magnetic character remains unchanged. Broad long wavelength anomalies cannot be attenuated into a series of low amplitude, short wavelength features although the reverse is possible with very great depths of burial (approaching 100km).

Magnetically susceptible intrasedimentary units (such as volcanic flows) may add to the total field magnetic signature if they are of a substantial volume, of a high susceptibility or at shallow depths.

The generation of epigenetic magnetite from the chemical reduction of iron oxides during hydrocarbon migration may develop local magnetic anomalies within sedimentary rocks of a normally low susceptibility. Donovan et al (1984), using aeromagnetic gradient data collected at 1.6km line spacings at an altitude of 90m along the Alaskan coast, identified shallow anomalies parallel to anticlinal structures thought to result from this source. Total field aeromagnetic data from the BSMD Region, collected at three times the height, on a coarser, irregular grid pattern and with inherent flight line leveling problems and survey noise is far less likely to enable us to recognize such subtle features within the data. If epigenetic magnetite is indeed present, it would probably be confined to the vicinity of short wavelength, complex magnetic responses of the Beaufort-Mackenzie Basin.

Under very special circumstances, (specifically where remnant magnetism developed during a period of reversed polarity and is retained within a large volume of material), magnetic units may actually subtract from the total field response. The existence of this scenario within the BSMD Region is highly speculative and could not be invoked without adequate evidence.

6.3 Regional Character

Five major structural "terrains" (labelled as I,II,III,IV, and V on map 1) have been outlined within the project area. Terrain boundaries were delineated on the basis of a change in magnetic character and a number of other representative features recognized on the colour enhancement products (see table 2). Minor refinements to the terrain boundaries could very easily be made, but would vary slightly depending on the criteria selected for the final delineation. The objective of this section is to indicate gross similarities and differences in magnetic nature, without becoming lost in detail. Although the degree of coverage (line spacing) affects the continuity and appearance of anomalies, their overall character remains constant.

On all enhancement products Terrains I,II,IV and V appear to be of a broadly similar character, a feature shown most clearly by the shadow mapping of total field magnetics. Anomalies are characterized by large amplitude and long wavelength (30km) responses. For the most part, boundaries of Terrains I and II approximate the general morphology of the present coastline. Magnetic response from Terrain V is of a greater intensity than Terrains I,II and IV suggesting that it may be either shallower or composed of a more susceptible material. It is located between, and parallel to, the edges of Terrains I and IV.

On the map of regional character (map 1), Terrain IV has been indicated as having a possible extension at depth - a large doubly lobed structure. The extension apparently deepens to the south as interpreted from decreasing magnetic response and increasing anomaly width noted on the first and second calculated vertical gradient maps and the shadow products. The deepening trend recognized throughout Terrain IV shows progressive down to basin "steps" (#2,3,4 on figure 5) delineating two interpreted fault scarps which coincide with magnetic breaks and lineaments.

The large magnetic features to the east of this double lobed structure on the RTP total field magnetic map are probably of a similar nature and may be offset by two east-northeast trending breaks. The deep continuation of major magnetic anomalies originally noted on the total field map (also see figure 5) is clearly shown on the regional magnetic component map, indicating their relation to deep crustal structure and not merely the to the expression of shallow near surface features. It appears as though the anomalies could be reassembled into a continuous area of constant magnetization in much the same manner as continents on a globe. The doubly lobed structure would move south, fitting into the vicinity of the Blow River High/Rapid Depression. Terrain V (#1 on figure 5) would move into the Mackenzie Delta-Tuktoyaktuk Peninsula, bringing with it the other scattered but regularly spaced anomalies.

These magnetic highs may be similar in nature to the magnetic highs identified within the continental terrains of the Yukon and NWT that apparently correspond to uplifts of Proterozoic/Paleozoic successions.

Magnetic responses obtained over continental crust are typically characterized by strong and broad anomalies (large amplitude, long wavelength), often following regional trends (Montadert et al, 1979). Terrains I,II,IV and V may therefore roughly outline the extent of continental crust.

In contrast, oceanic crust tends to contain anomalies of strong amplitude and short wavelength, often with a pronounced lineation as a result of sea floor spreading.

The oceanic/continental crust boundary may be considered to be a line, or zone, of demarcation between different anomaly types, with the continental side having extensive long-wavelength anomalies following the dominant coastal structure (regional trend). Small anomalies parallel to the boundary, and minor displacement are common at the oceanic/continental transition as is a +/- 100km zone of uncertainty occurring at the termination of the magnetic features (Montadert et al, 1979; Heirtzler, 1985). The nature of the change may vary from one part of the margin to the next.

Anomalies of Terrain III have a generally short wavelength (10km) with significantly reduced (flatter) amplitudes and contain lineations and magnetic striping (best recognized on the

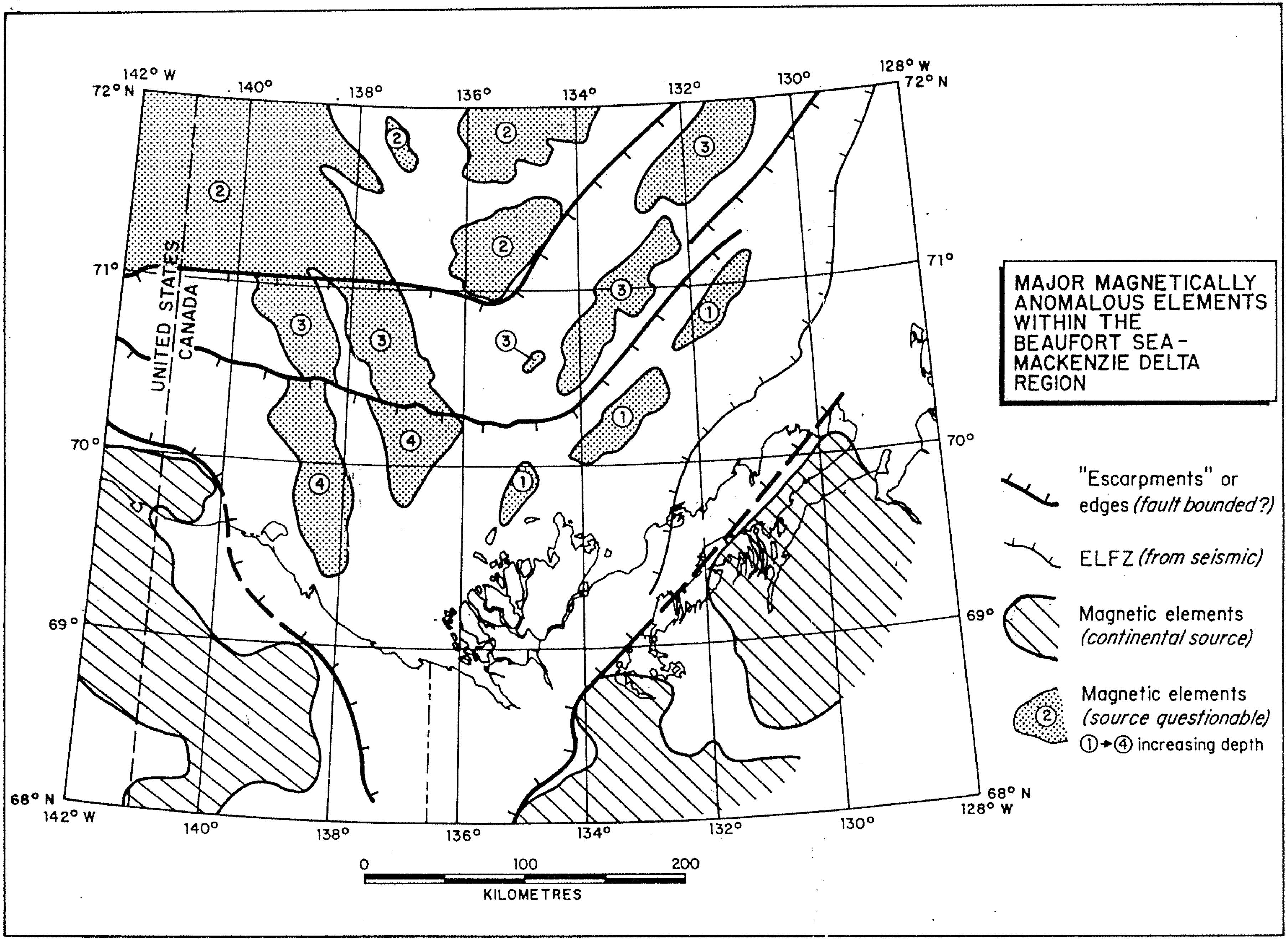

MAJOR MAGNETICALLY ANOMALOUS ELEMENTS WITHIN THE BEAUFORT SEA-MACKENZIE DELTA REGION
"Escarpments" or edges (fault bounded?)
ELFZ (from seismic)
Magnetic elements (continental source)
Magnetic elements (source questionable)
① → ④ increasing depth
72° N
142° W
128° W
68° N
140°
138°
136°
134°
132°
130°
71°
70°
69°
UNITED STATES
CANADA
0
100
200
KILOMETRES

Figure 5

residual or second vertical derivative maps). They may represent oceanic crust buried deeply under clastic sediments.

The outline of Terrain III can be variably represented as having either a "sausage" or a "Y" shape depending on the point of view and the enhancement product selected (see figure 6). On the calculated first vertical derivative map the characteristic responses seem to be confined to a relatively narrow band or belt (100km wide) in the near- to offshore, approximately following the coastline or edge of the Beaufort-Mackenzie basin. A narrow offshoot of a similar magnetic character trends along the Rapid Depression to the south and is also evident on the second vertical gradient map. This zone contains either common intrasedimentary sources or a similar basement structure. RTI imaging is extremely helpful in delineating the corrugated short wavelength anomalies of this terrain.

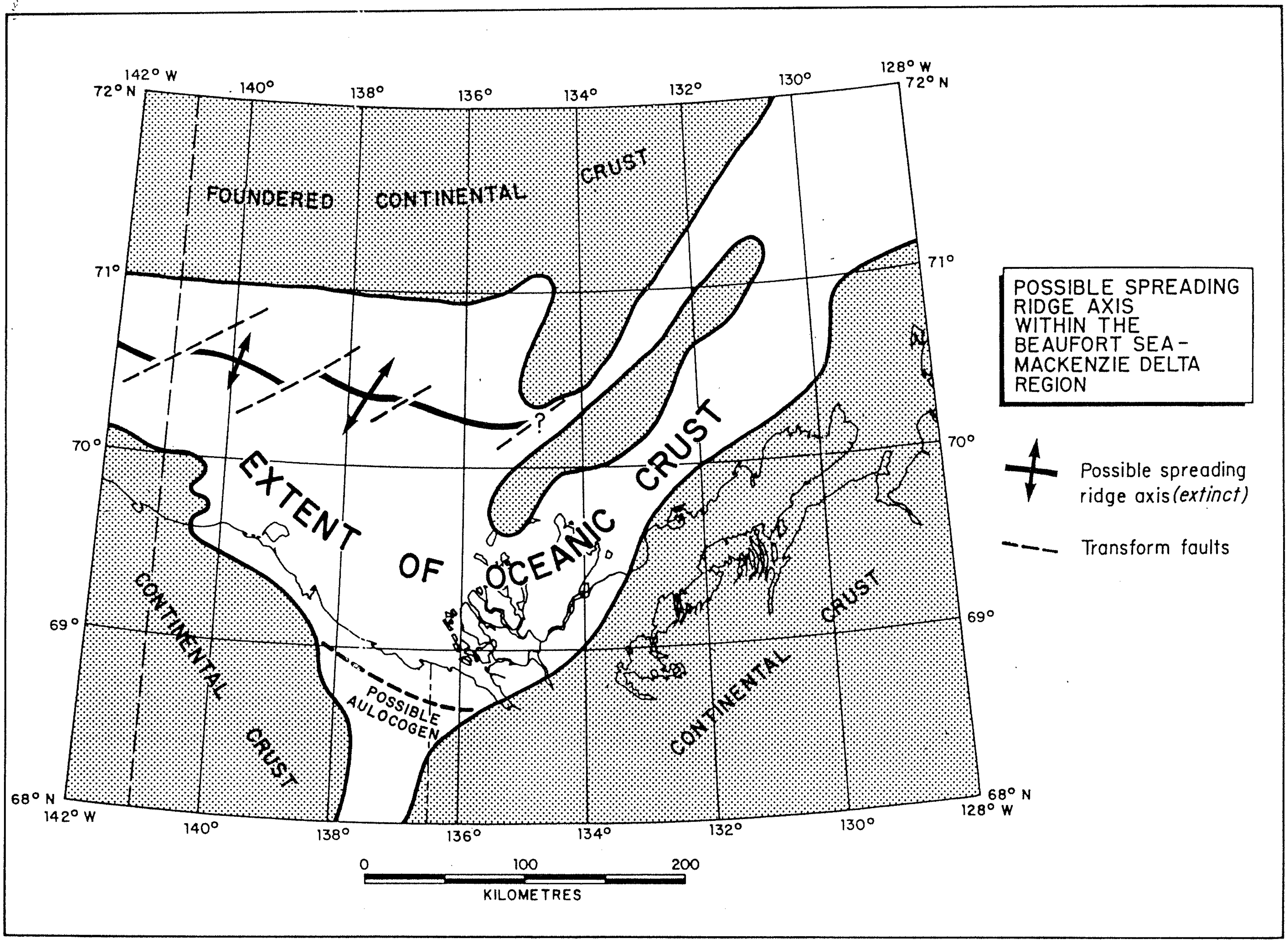
The exact edge of Terrain III is not clear, nor is the nature of its contacts with the broader anomalies around it. Nevertheless, it is distinctly different from adjacent terrains. Flight line orientation and levelling effects, while influencing the overall appearance of the data, do not account for the difference between terrains. The intersection of Terrains III and IV along latitude 71^{o}N clearly indicates this point. Here, the character of the magnetic response changes sharply while the deviation in flight line direction and spacing is, for once, insignificant.

The two magnetic styles become intermixed in places, as though one were overprinted on the other. An example of this occurs in the vicinity, and to the north of, the features labelled as "B" on map 5.

Tertiary fold axes delineated through seismic interpretation appear to be restricted for the most part to Terrain III, although there is some suggestion that they ride up onto Terrain IV in the northwest. This effect may be due to the shallowing of Terrain IV to the north, and the "pinching" of Tertiary strata between Terrains I,II,IV and V during the northeasterly compression that developed anticlinal fold axes identified in the offshore.

6.4 Structural Trends

Interpretation of the aeromagnetic data (predominantly calculated first and second vertical gradient maps) identified a number of regional structural trends. Only the most significant of these have been indicated on the regional trend and character analysis map (#5). In a conscious effort to avoid the influence of flight line orientations and edge effects during the interpretation, real structural trends may have been ignored.


POSSIBLE SPREADING RIDGE AXIS WITHIN THE BEAUFORT SEA-MACKENZIE DELTA REGION
Possible spreading ridge axis (extinct)
Transform faults
FOUNDERED CONTINENTAL CRUST
EXTENT OF OCEANIC CRUST
CONTINENTAL CRUST
CONTINENTAL CRUST
POSSIBLE AULOCOGEN
?
142° W
72° N
128° W
72° N
68° N
142° W
68° N
128° W
140°
138°
136°
134°
132°
130°
71°
70°
69°
0
100
200
KILOMETRES
Figure 6

Structural trends (as interpreted from magnetic lineaments and breaks observed in the enhanced data) reflect, for the most part, features within the magnetic basement. Basement structures probably influenced the development of stratigraphically and lithologically younger features such as the ELFZ.

Large curvilinear structural trends (F) are restricted to Terrains I,II and IV, and more specifically to the areas of higher susceptibility noted on the total field magnetic map. Their absence from Terrain V is probably due to the restricted areal extent of this smaller terrain rather than any fundamental structural difference.

Northwesterly trends noted in Terrain II are thought to reflect the thrusting mapped onland (Norris, 1984). Similar northeasterly trending structures from Terrain I (east of Inuvik) may represent thrusting buried beneath Quaternary cover.

Structural trends associated with the dyke (A) apparently continue to the northeast between the Terrain IV/V boundary. A second parallel structural feature located about 50km to the north of "A" follows the Terrain III/IV boundary before swinging northeast into Terrain IV.

Terrain III, containing predominantly linear structural trends, again appears dissimilar from the other terrains. Trends can be broadly grouped into three clusters of orientations (northeast, northwest and east-west). All clearly cut across flightline directions, and while most are confined to the "corrugated zone" some extend into adjacent terrains.

Northeasterly trends (D) dominate the south and west-central portions of Terrain III. A very faint trace of a parallel trend correlates with the northeastern most extent of the Outer Platform Hinge Line.

Northwesterly trending breaks are present throughout Terrain III but are most common in the northeast arm. One north-northwest break/lineament (C) cuts through the Mackenzie Delta from just southwest of Aklavik, crosses the dyke (A) at one of the apparent offsets, then becomes lost in the flight line chatter about 200km offshore. This feature apparently correlates with the Beaner Fault mapped onshore.

Several east-west breaks are noted, the most significant of them possibly offsetting (right lateral) the southwest segment of Terrain V. The Tarsiut-Amauligak Fault Zone may have developed over this interpreted basement structure. A series of parallel, east-west trending magnetic lineations, or striping (B), are located within Terrain III along its western boundary with Terrain IV.

Along the western contact of Terrains II and III a series of convoluted short wavelength features (E) are interpreted to be related to compression within the basin fill.

6.5 Major Tectonic Elements

6.5.1 Introduction

Major tectonic elements recognized within the BSMD Region have been subdivided into several components: known uplifts and tectonic elements, thrusting, intrusives, volcanics and dykes. Further discussion of Terrain V and the doubly lobed arcuate extension of Terrain IV is also included in this section. Boundaries of known tectonic features have been extended and modified by the aeromagnetic interpretation and new structures identified.

6.5.2 Uplifts and Tectonic Elements

Shadowed total field magnetic data shows a 40 to 60km wide band of broad relatively flat magnetic responses extending northeasterly from west of Aklavik to the Tuktoyaktuk Peninsula, interpreted as outlining the entire Aklavik Arch Complex. Just offshore of the Baillie Islands is an apparent continuation of the complex. The area between the two belts has low amplitude short wavelength anomalies of a similar character to the central portion of the study area (Terrain III) and may be associated with oceanic crust and intrasedimentary sources.

Mapped exposures of the Campbell Uplift are well delineated on shadowed residual field maps and a northeasterly extension of the structure under Sitidgi Lake is inferred. A similar nearsurface uplift of basement rocks is believed to underlie Old Man, Urquhart and Jonas Lakes. Moderate responses noted in the residual magnetics from west and south of Sitidgi Lake may be related to other uplifts along the Aklavik Arch Complex.

The surficial magnetic expression of the ELFZ is clearly recognized as a major zone (40x350km) with a broken and distorted magnetic character (see map 6) on the shadowed residual magnetics. This zone represents the expression of basinward (north) dipping, basement detached, listric faulting developed in shallow lithologies draped over an older basement structure, possibly an escarpment (see figure 5).

The basement feature does not correlate with the location of the ELFZ as mapped from shallow seismic and borehole data, but corresponds approximately with the edge of Terrain I and with a number of very subtle northeasterly trending features noted on the calculated first and second vertical gradient maps.

The interpretation of the Romanzof Uplift (map 6) matches onland exposures of the Paleozoic/Proterozoic succession. This pre-Mesozoic sequence is part of a mapped tectonic block extending further to the southeast then shown here and recognized by a few scattered inliers of pre-Mesozoic material. The Barn Mountains, Hoidahl Dome and other exposures of Cambrian and Ordovician shales (CDr and Osh; Norris, 1984) are part of the same tectonic block as the Romanzof Mountains (L.S. Lane, personal communication, 1989). Magnetic expression of the deeper southeasterly extension is masked by nearby plutonic bodies and depth of burial. The subtle Paleozoic/Proterozoic succession response (lower susceptibility than "true" magnetic basement) requires a lesser degree of burial to attenuate the response.

Within the Old Crow Babbage Depression the second vertical gradient magnetic response, although shown on shadow RTP magnetics as being dominated by intrusive stocks and thrust slices, has a slightly ovoid shape, not caused by flight line orientation effects, that may be related to basement structure.

The Rapid Depression is evident on the shadowed total field map only as a magnetically quiet zone between the faint trace of the Cache Creek High and the Fitton Stock. No delineation between it and the southern edge of the Blow River High is possible.

The Cache Creek High may be associated with the calculated first vertical magnetic gradient response from the vicinity of Big and Little Fish Creeks. Minor magnetic basement activity north of the predicted site of the Tununuk High was also observed on the first vertical gradient map but disappears and degenerates into flight line and edge effects on the second calculated vertical gradient map. No features could be positively attributed to the Tununuk High.

Structural lineament "C" extends northwest from approximately Moose Channel/Shallow Bay through the east edge of the seismically determined Blow River High. Faintly disturbed magnetic patterns on the east side of the Blow River High may be related to the uplift of susceptible intrasedimentary units within the Tertiary strata (interpreted as volcanics) due to the influence of basement structure related to the expression of "C".

The Herschel High/Demarcation Basin area, while not following exactly the tectonic outline predicted from seismic interpretation, shows a distinctly different second vertical gradient character than that of the surrounding Beaufort-Mackenzie Basin. The Demarcation Basin also correlates well with a smooth, magnetically quiet zone interpreted from the shadowed total field magnetics. This feature is thought to represent a deeper continuation of continental material from Terrain II onto which younger sediments were deposited. During northeasterly compression, the Demarcation Basin basement block and its overlying sediments moved as a stable platform, around which adjacent sediments were deformed and tectonically uplifted to create the Herschel High. The distorted magnetic pattern (E) is a result of disturbed intrasedimentary source material within the Herschel High.

RTI total field magnetic shadow signatures of the Arctic Platform and the Demarcation Basin/Herschel High are of a grossly similar nature, despite linearity induced by flight line direction, and may signify a similar genesis or basement structure.

6.5.3 Thrust Tectonics

The correlation of certain structural trends with mapped thrusting has already been discussed.

Elongate magnetic responses along the Old Crow River are evident on the vertical gradient and residual maps. The shape, orientation and sharply defined boundaries of this rectangular anomaly are not characteristic of a plutonic body unless it is under very strong structural control, especially along the south boundary. Overthrusting is interpreted to be responsible for this anomaly.

The inferred thrust slice is buried beneath Quaternary cover. The interpretation of an approximately west trending long axis, while differing from most of the other structural trends in the vicinity, is supported by the exposed Proterozoic anticline immediately to the north. Although interpreted as a thrust slice, the magnetic response may be mapping a second shallow Proterozoic uplift with a greater susceptibility than that outlined in the Romanzof Uplift.

In the vicinity of the Firth River (within the Romanzof Uplift) the broad magnetic response noted on the first vertical derivative map may also be caused by thrust repetition although the edges are poorly defined and the shape more characteristic of interbedded volcanics or a deeper source body.

6.5.4 Large Intrusive Bodies

Areas of strong magnetic character in the onshore are coincident with exposures of Proterozoic rocks (Campbell Uplift) and mapped intrusives (Sedgewick Granite, Fitton Stock). The areal extent of total field magnetic anomalies suggests that the recognized and exposed rocks represent only a small fraction of a much larger subsurface intrusive structure. The large regional magnetic high under the Trail and Babbage Rivers is thought to represent a common deep plutonic source for the numerous intrusive stocks in the area.

Exposed (and interpreted) intrusive rocks within and adjacent to the Romanzof and Barn Uplifts are clearly outlined by the calculated first and second vertical gradient and shadowed total field data. A curvilinear shape to the bodies and the suggestion of a deeper source body are also noted. Emplacement of the bodies may be related to a structural weakness associated with the uplift.

Residual magnetics and shadow manipulation of the residual data clearly delineate the Sedgewick Granite, Fitton Stock and exposed Cambrian volcanics (the strong magnetic responses a result of their surface exposure). Within a 20km radius of these bodies, at least five other shallow intrusive bodies are inferred. Curvilinear responses of the Sedgewick Granite exposures are mimicked by the bodies interpreted to lie immediately southeast of them. Responses from these granites are apparently confined within a northwest trending, wedge shaped zone whose apex is about 25km southeast of the Fitton Stock. Similar responses from the southeast corner and east central edge of the map area are probably caused by near- or subsurface bodies within the Interior and Arctic Platforms. The shadow mapping of total field magnetics reveals another large (30km) suspected intrusive body just north of Aklavik.

6.5.5 Intrasedimentary Volcanics

Possible intrasedimentary volcanic units are clearly recognized only on the shadow map of RTP total field magnetics. Aeromagnetic signatures of the relatively small intrasedimentary sources do not show clearly on the residual component separation due to the amount of noise present in the data set. Magnetic signatures of these "speckled" zones compare very favorably with the response of mapped Cambrian volcanics and it is largely on this basis that the zones have been delineated.

In the vicinity of Tuktoyaktuk, a zone of short wavelength irregular magnetic highs clearly cuts across the edge effects of adjacent survey blocks indicating that it is a real feature. This zone probably represents the outline of extensive relatively shallow intrasedimentary volcanics.

Minor anomalies on the eastern edge of the Blow River High may correlate to additional intrasedimentary volcanics, deformed and uplifted by the compression that aligned offshore Tertiary anticlinal fold axes (and probably related to thrusting at "C").

6.5.6 Dykes

Two major dyke like bodies have been identified during the course of the project. The first, located onshore, south of the

Eskimo Lakes is a north-south trending feature identified on both the residual component separation and shadow map. This 100km long shallow (<10km) linear anomaly is associated with minor parallel structures some of which are reflected in topography and drainage patterns. Offset in several places by structural breaks, the magnetic response is too broad to be caused by a single flight line flaw.

Trending approximately east-west is the axial trace of a second, apparently continuous, dyke (A) with a strike length in the order of 200km. This very narrow linear feature, while evident on the total field magnetic map, has been better defined by enhancement procedures. A minimum strike length of 260km can be measured from the first vertical gradient map. Three apparent left lateral offsets (15 to 20km displacement) are also noted. Offsets may correspond to splay features (A'). Extension of the dyke to the east beyond 135°W is not possible although it may swing northeasterly, parallel to a structural lineament.

Traces of dyke parallel magnetic features (B), trending across flight line directions, have been identified up to 100km north of the linear body. The magnetic lineations or striping are clearly shown on the vertical gradient and shadowed residual field maps. They are definitely not caused by data quality problems and represent true magnetic responses.

With the second vertical gradient calculation the dyke has a much less continuous nature, appearing to be offset by a number of small fractures. The major sinistral offsets identified in the calculated first vertical gradient are still evident, however, some small scale right lateral displacement or minor rotations of body segments are noticed. These may be due to leveling errors between flight lines or to the effect of topography on a dipping body. At or about longitude 137°W, the magnetic signature bifurcates; part swings northeasterly (A'), following a structural break. The trace of the "main" dyke continues eastward along the zone of structural weakness for another 60km where it begins to trend more to the east-northeast, becoming obscured by other features.

Residual component separation contains most of the magnetic response from the dyke indicating that it is indeed a very shallow feature, but between 139°W and 142°W a deeper basement component is retained on the regional magnetics map.

6.5.7 Terrain V

The linear magnetic high of Terrain V on the total field magnetics parallels the major magnetic low and possibly separates it from a second trough to the northeast. This feature seems to be comprised of discrete bodies (see figure 5 or map 1) which may indicate either a single linear body offset by structural breaks, or merely wider or more susceptible portions (shallower?) of the same body. The apparent spatial relation of the Outer Platform Hinge Line and this feature may be coincidental although it will be considered in the following interpretation.

Terrain V seems to be at a shallower depth than source bodies previously inferred as being of a similar nature. It is comprised of four segments, whose depth may be increasing to the southwest, from approximately 9 to 18km.

With the calculation of first and second vertical gradient maps the anomaly has been refined and it appears that the northwestern edge is much straighter than the opposite side (and therefore probably fault bounded). The portion of the source body at the southwestern end seems to be offset from the main trend in either a sinistral sense along a northeasterly trending break, or dextrally along an east west or northwesterly feature. In the former, offset would be in the order of 70km, and in the latter approximately 30km.

Terrain V is considered to represent an element of major tectonic uplift in that overlying sediments would have been affected by its basement structure. This control may be associated with oil and gas fields lying adjacent to, and over the feature

6.5.8 Arcuate Doubly Lobed Structure

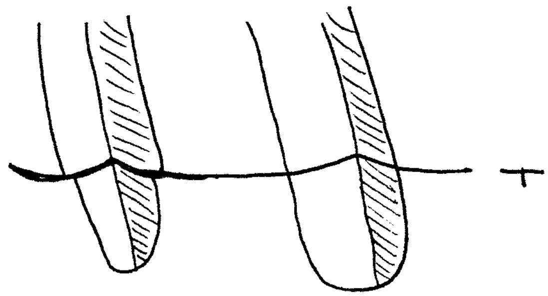
In the offshore, total field magnetics are dominated by a large arcuate doubly lobed structure extending from the northwest some 300km into the basin (extension of Terrain IV). This structure appears to have relatively straight sharp boundaries (faulted?) in four locations. The larger "eastern lobe" is defined on the east side by a sharp 170km south-southeast trending contact which, at the end of the body, swings to the southwest and continues for another 60km. The western lobe has sharply defined boundaries extending along the 71^{o}N latitude line for 80km, then trending south-southeasterly for 60km. This linearity is not a result of flight line orientation. The second, smaller, more westerly lobe closely follows the 100m bathymetric contour but the significance of this observation is unclear. The remaining edges of the body are curvilinear and less clearly defined.

The doubly lobed structure is apparently becoming deeper as we move southward; the magnetic response broadens and decreases in intensity at least twice on the vertical gradient maps, once south of the Terrain III/IV boundary and again south of the east-west dyke (figure 5).

The central portion of the area, within the Beaufort-

Mackenzie Basin, is magnetically subdued although the extension of the doubly lobed structure can be traced right up to the plotted location of the Blow River High and may have had some control on the development of the north west part of the uplift.

At one point during the RTI modelling it appeared as though the dyke crossing from west to east through the lobes had a southerly dip with the previously identified left lateral offsets accounted for entirely by topographic effects. However, we are dealing with aeromagnetic data and no matter how closely the imaged data resembles pseudo-topography the response is still due entirely to changes of magnetic susceptibility (primarily magnetite content) within the features.



Southward from the dyke, the depth of the lobed structure appears to increase significantly, implying that the dyke has intruded along a previously active structural feature which controled the development of the arcuate lobed structure.

The limit of strong deformation within the Tertiary strata (from a 1:1,000,000 scale structural map supplied by J. Dietrich, 1989) is restricted to the area south of the Terrain III/IV boundary (the northern "escarpment", figure 5). Weaker deformation is found over the more northerly extent of the arcuate structure (#2 on figure 5). The deformation front may be riding up onto the generally shallowing surface of Terrain IV (as suggested by visual interpretation and MCPT depth calculations). Since the deformation is known to be related to northwesterly compression (Cook et al, 1987), it would appear as though the older basement structure of Terrain IV controlled the development of the compressional Tertiary anticlinal fold axes. Fold axes are oriented parallel to the Terrain II/IV boundary (east-west) in the west, but towards the central portion of the BSMD Region swing to the southeast, perpendicular to the compression (and the faulted north boundary of Terrain V), where they were unconstrained by any basement structure.

Lineaments (B) parallel the edge of Terrains III and IV and may represent magnetically susceptible intrasedimentary units within the folded anticlinal axes. This interpretation could explain the discontinuous nature of these anomalies north of the terrain boundary where only weakly deformed strata are present.

The eastern limit of deformed strata clearly cuts across the boundary of Terrain III with the lobes of IV but the strata do not seem to be present over Terrain V. It appears that depths of Terrain III and the arcuate doubly lobed structure are large enough to have no influence on sediment deformation. The more northerly part of Terrain IV (and Terrain V) are shallow enough to confine the strata, and therefore are probably within the sediments of the Beaufort - Mackenzie Basin and should be recognizable within seismic records.

In the BSMD Region the presence of a hot spot could offer an alternate interpretation for the genesis of the southern arcuate extension of Terrain IV. As a magnetic body migrates overtop of a hotspot, heating above the Curie Point destroys magnetite and other magnetic minerals responsible for the magnetic character of rocks. As the body passes beyond the sphere of influence of the hot spot, cooling allows the redevelopment of magnetite and the return of magnetism to the body. As distance from the hot spot increases, the progressive cooling increases the level of magnetization, causing an apparent shallowing.

Consequently the arcuate doubly lobed structure would represent the magnetic trace recorded on crustal material as it moved across a hot spot located approximately at the southerly end of the feature. The body of Terrain IV (to the north) would be comprised of continental material while the extension of Terrain IV represents the hot spot track on oceanic crustal material. A small component of rotation towards the northwest of the plate would therefore be indicated by this scenario.

6.6 Depth to Magnetic Basement

The identification of magnetic basement varies with the magnetite content of the rocks. Within an area the size of the BSMD Region it can be reasonably assumed that there will be several different magnetic basement sources present. Sources may vary from true crustal material to uplifted rocks (with a slightly greater susceptibility than adjacent or overlying units) to intrusive stocks, dykes, and volcanic flows, or other intrasedimentary magnetic bodies. The depth of burial of these features and their spatial relation to one another will affect the calculations. Layered situations will tend to show only the dominant source rock, but where it is not present, a weaker structure will still indicate a magnetic basement. Depth to magnetic basement calculations therefore do not necessarily indicate depth to a single consistent feature or unit.

Accurately portraying depth to magnetic basement in an area as structurally complex and relatively unknown as this one is difficult. Many more profiles would be required and the difficulty in positioning the comparatively low susceptibility features between the higher susceptibility zones remains a problem. Apparent magnetic basement shallows over identified and interpreted uplifts, intrusives and in onshore regions. These variable sources create an additional problem in maintaining a constant depth/size/susceptibility ratio in the magnetic modelling.

Intrusive bodies and magnetically susceptible intrasedimentary units within the BSMD Region mask depth determinations and affect the calculations which are based for the most part on unconstrained models. Depth to basement apparently deepens in the valleys between the highs but with little constraint on the models, aside from the few seismic lines in the offshore and some "greater than" depths, the interpreted depth to magnetic basement (map 7) is destined to look very much like a combination of the regional character map and the aeromagnetic interpretation map. Any number of natural magnetic occurrences would serve to complicate or confuse the picture, especially in an area whose genesis is relatively questionable.

6.7 Integrated Interpretation

6.7.1 Introduction

This section pertains to the development of the BSMD Region as a passive divergent continental margin. The regional overview comments on the BSMD Region with respect to the magnetic picture of North America and compares it briefly with observations from the northwest Atlantic passive margin. Features associated with rifting are discussed. Evidence pertaining to the existence of a triple junction or hot spot within the region is also presented. The identification of rotational features was restricted to the comparison of large scale magnetic anomalies from the study area with those of the Bay of Biscay.

6.7.2 Regional Overview

In the context of the regional magnetic anomaly map of North America (Hinze et al, 1988) the BSMD Region appears very similar to, and continuous with, the rest of the coastline of Arctic Canada and Alaska. Data collection from further offshore is spotty and restricted to a few aeromagnetic lines flown by the US Navy in the late 1970's (L.S. Lane, personal communication, 1989). Consequently it is difficult to get a true sense of the larger regional picture.

From regional magnetic mapping (Hinze et al, 1988) it appears as though only the coastline underlying the east side of the Mackenzie Delta is of continental nature. Aeromagnetic data from the west side of the BSMD survey block does not fit well with data collected across the border in Alaska. Specifically, the continental style magnetic highs recorded in Alaska are truncated at the border. Aeromagnetic data sets in a similar situation (adjoining across the border) to the south apparently match well. This observation supports concerns regarding the reliability of the original data manipulation.

Gravity data from the area shows the same narrow, nearly continuous positive anomaly that appears to be characteristic of most passive continental margins (Tanner et al, 1988). Offshore of the linear anomaly, the gravity signature seems to compare best with those observed from the thin continental crust of the Caribbean or between Greenland and Labrador, an observation also supported by the regional magnetics.

Coles et al (1976), looking at large scale magnetic anomalies of western Canada and the Arctic, suggested, on the basis of the low magnetic relief, that there was no crystalline continental basement present or that it is of a different nature.

The development of new oceanic crust or thin continental crust in the BSMD area was postulated by Grantz et al (1979) who also speculated on the existence of an early Jurassic spreading axis in the Canada Basin.

Aeromagnetic data from the passive continental margin of the northwestern Atlantic (coast of North America) was interpreted by Behrendt and Grimm (1985). They found that low frequency anomalies defined the major basins but that on a regional scale positive and negative responses occurred over both troughs and basins. A 300 km long linear magnetic anomaly similar to Terrain V was interpreted as a hinge zone, or the edge of continental crust. Anomalously high magnetic responses related to the interpreted oceanic/continental boundary were thought to be associated with edge effects but the authors also invoked more complex structures such as intrusions or an underlying basement ridge to explain the anomalies.

6.7.3 Rifting and Geomagnetic Reversals in the BSMD Region

Generalized development of the BSMD Region involves the rifting, foundering and subsequent offshore movement (generally poleward) of a wedge shaped block of continental material from the present Mackenzie Delta area. A limited amount of oceanic crust is generated, and while it may onlap, or be intermixed with, the continental crust, it is deeply buried under Tertiary sediment.

Thinned continental crust, subsided, fractured and rotated into half grabens by listric faulting has been identified at the Goban Spur and Galicia Bank (Heirtzler, 1985) and may be analogous to the Outer Platform Hinge Line. Terrain I, IV, and V (figure 6) represent portions of thinned stretched continental crust. This thinning is due to the rifting away of Terrain IV which may have lead to the intermixing of continental crust with oceanic crust. This situation has been recognized elsewhere at passive margins when the continental crust was stretched during the initiation of continental breakup and sea floor spreading (Heirtzler, 1985). This intermixing would account not only for the isolated blocks of magnetically anomalous material, but also for the apparent overlapping and interfingering of magnetic lineations and Terrain IV. Intrusion of the dyke (A) and splays (A') along structural weaknesses are also due to this stretching.

Several variations of the rifted continental block theory are possible and are dependant upon ambiguous interpretations of major magnetic features which will be discussed as required in the following sections. Ambiguous interpretations include the dyke (A) apparent magnetic striping (B) that may represent either a spreading centre or intrasedimentary sources within Tertiary anticlinal fold axes adjacent to Terrain IV. The influence of a "hot spot" on the magnetic character of the region is speculative but may have complicated the interpretation.

The east west trending shallow dyke (A) may be the expression of an extinct spreading ridge (see figure 6) originally active as Terrain IV rifted away from Terrain II. The apparent left lateral offsets along magnetic breaks "D" would therefore correlate with transform faulting and the displacement of Terrain IV parallel to V in a right lateral sense. The ridge was sealed off by either northeasterly compression or southwesterly forces associated with the spreading of the Arctic mid-ocean ridge. Looking at the broad terrain outlines, and ignoring for the moment the extension of Terrain IV, a slight component of apparent rotation (figure 6) is accounted for by the transforms.

The addition of further geologic and geophysical information (especially high resolution seismic profiling) would constrain these hypotheses, and reduce the ambiguity associated with the interpretation.

Characteristic large scale magnetic striping associated with oceanic crust is not in evidence on regional magnetic maps of the BSMD Region. Neither is it clearly shown at a regional scale along the passive margin of Atlantic North America (Tanner et al, 1988) in close proximity to the shoreline.

No strong evidence of sea floor spreading is noted in the nearshore of the passive margin along the Atlantic coast because the basement is of Jurassic age, formed during a magnetically quiet period when there were few geomagnetic reversals to be retained in the rock record. Nevertheless, an extinct spreading centre with little or no magnetic expression has been tentatively identified by several authors (see Heirtzler, 1985) in a situation very similar to that of the BSMD Region.

Ages postulated for the initiation of basin development in the BSMD Region range from early Jurassic (Grantz et al, 1979) to late Jurassic/early Cretaceous. This age range fits within the earlier of two widely recognized peaks in world rift formation: 180 to 130 million years ago (mya).

If rifting of the BSMD Region occurred in the early Jurassic, then it would correlate with the magnetically quiet period of 180 to 153 mya and therefore would not be recognizable in the magnetic record. An early to middle Cretaceous aged spreading/rotational event in the BSMD Region would also be unlikely to have significant magnetic expression due to a second magnetically quiet period experienced between approximately 80 and 113 mya (Larson and Hilde, 1975).

On the other hand, if the depositional basin expanded at the beginning of the late Jurassic (Pelletier el al, 1987) or the early Cretaceous, then geomagnetic reversals may be recognized in the data. During this 40 million year period (153 to 113 mya), 38 pairs of magnetic reversals have been identified from chronologically and radiometrically dated oceanic samples (Larson and Hilde, 1975). Although the rate of reversal varies significantly (from less than 100,000 years to 3 my), on an average 1.05 my is the time from peak to peak within the record.

The amplitude of magnetic anomalies at spreading centres is related to the spreading rate (Jackson and Ried, 1983). Along the Arctic mid-ocean ridge reduced basaltic volcanism and the irregular rates at the slow spreading centres resulted in a mixing and rotation of polarities and a low amplitude anomaly along the ridge.

In order to detect subtle magnetic evidence relating to the development of the "Yermak Hot Spot", Feden et al (1979) had to use profiles of residual data to identify and correlate complex sublinear anomalies caused by the spreading centre. This is of particular significance to the BSMD Region given that magnetic striping (B) became apparent only after the calculation of vertical gradient and the residual shadow maps.

Apparent magnetic stripping noted at "B" on the regional trend and character analysis map indicates a distance of approximately 10km between peaks. Using the average rate of geomagnetic reversal given above, the rate of spreading is therefore in the order of 0.95 centimeters per year (cm/y).

This figure compares very favorably with rates of 1 cm/y for the Reykjanes Ridge, 0.5 - 0.8 cm/y elsewhere in the Arctic (Feden et al, 1979) and 0.4 to 0.5 cm/y in the Venezuelan Basin (Ghosh et al, 1984). Spreading rates calculated from the East Pacific rise (4.4 cm/y) and Juan de Fuca Ridge (2.9 cm/y) are higher but of the same order of magnitude.

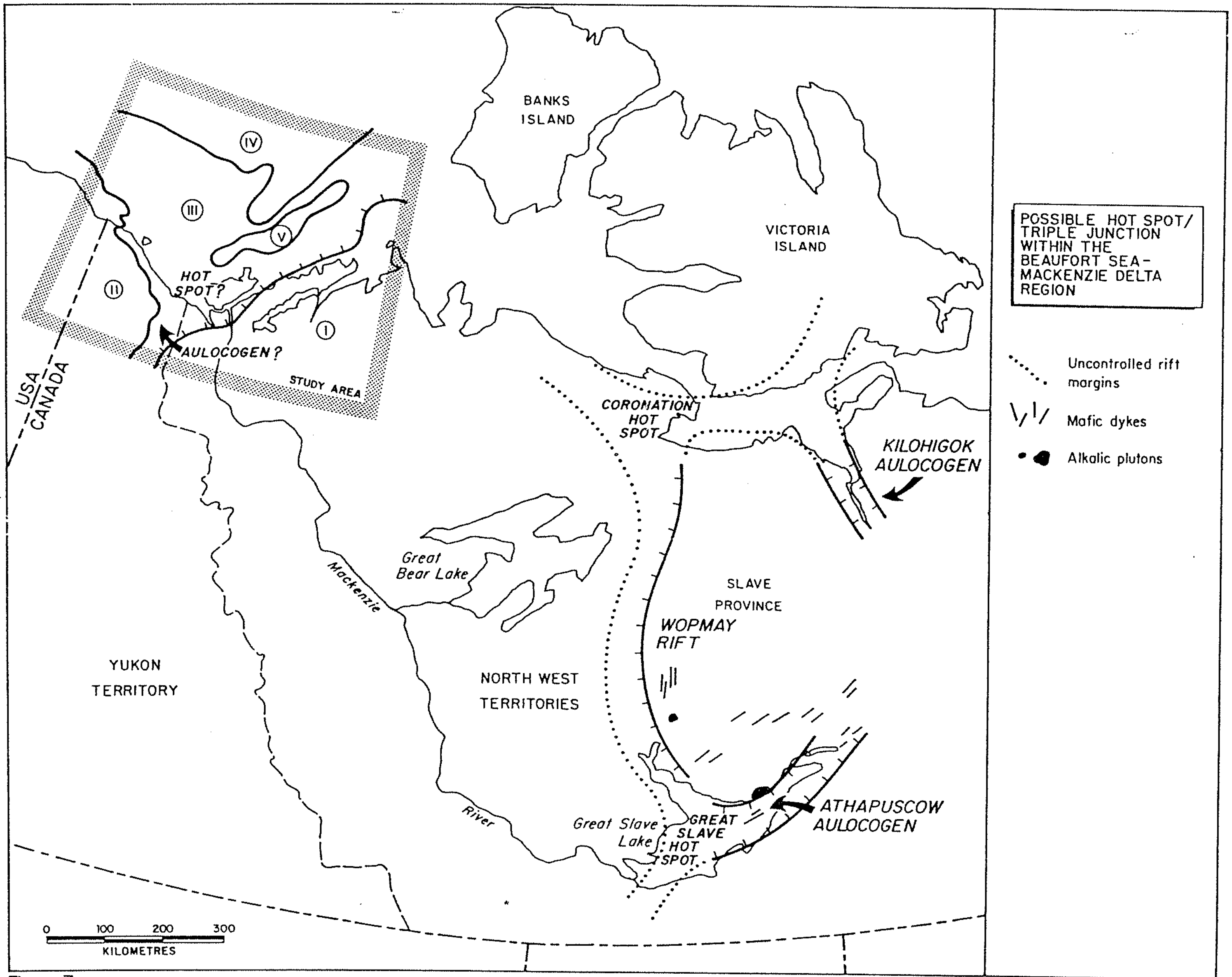
Although the spreading rate for the BSMD Region is only an approximation of the roughest nature, it nevertheless supports the interpretation of these features (B) as magnetic striping and re-enforces the hypothesis of Late Jurassic/Early Cretaceous rifting in a northerly direction.

The seismic trace of the Mohorovicic discontinuity is known to disappear near a ridge, and this may explain the observations by GSC personnel (L.S. Lane, personnel communication, 1989) that, in places within the Beaufort - Mackenzie Basin, extensive thicknesses of sediment are apparently resting directly on the mantle. Heirtzler (1985) also noted a loss of the oceanic basement reflector near the boundary with continental crust.

The presence of a triple junction/hot spot in the vicinity of the BSMD Region (as proposed in section 6.5.8) is supported by a number of superficial observations, perhaps insignificant individually, but suggestive when viewed as a whole. The characteristic 120^{o} structure of a triple junction is shown not only by the outline of Terrain III but also by the isopach maps of sediment thickness in the onshore were three is sufficient information to accurately portray it. The presence of a thick sediment prism is itself one of the characteristics of a triple junction. The scale of the postulated triple junction is comparable to ones identified in the Slave province to the east (figure 7).

The aulocogen, or failed arm, of the triple junction extends back into the craton, in the vicinity of the Yukon/NWT border, coinciding approximately with the northernmost end of the Kaltag Fault system. The aulocogen formed by downfaulting of the rift system and development of a graben. Sedimentation during the downfaulting would infill the graben and normal fault extensional features would be common. The negative Bouguer gravity anomaly (Tanner et al, 1988) extending along the interpreted arm of the aulocogen, and under Richards Island, is atypical of oceanic crust and supports the hypothesis that this feature is due to laterally continuous, large scale structural disturbances, such as rifting or block faulting, within the continental crust.

Tensional features such as listric faults (ELFZ?) and monoclinal flexures (Kugmallit Trough?) would exist in both the basement rocks and the younger infilling sediments of the BSMD Region. These extensional features would thin and rotate the continental crust, developing a series of half graben structures like those identified in the seismic records across the Outer Platform Hinge Line. Calc-alkalic arc volcanism, a carbonate shelf environment, volcanic wedges and turbidite sequences would be expected.


POSSIBLE HOT SPOT/ TRIPLE JUNCTION WITHIN THE BEAUFORT SEA-MACKENZIE DELTA REGION
Uncontrolled rift margins
Mafic dykes
Alkalic plutons
BANKS ISLAND
VICTORIA ISLAND
IV
III
V
II
I
HOT SPOT?
AULOCOGEN?
STUDY AREA
USA
CANADA
CORONATION HOT SPOT
KILOHIGOK AULOCOGEN
SLAVE PROVINCE
WOPMAY RIFT
Great Bear Lake
Mackenzie
YUKON TERRITORY
NORTH WEST TERRITORIES
River
Great Slave Lake
GREAT SLAVE HOT SPOT
ATHAPUSCOW AULOCOGEN
0
100
200
300
KILOMETRES
Figure 7

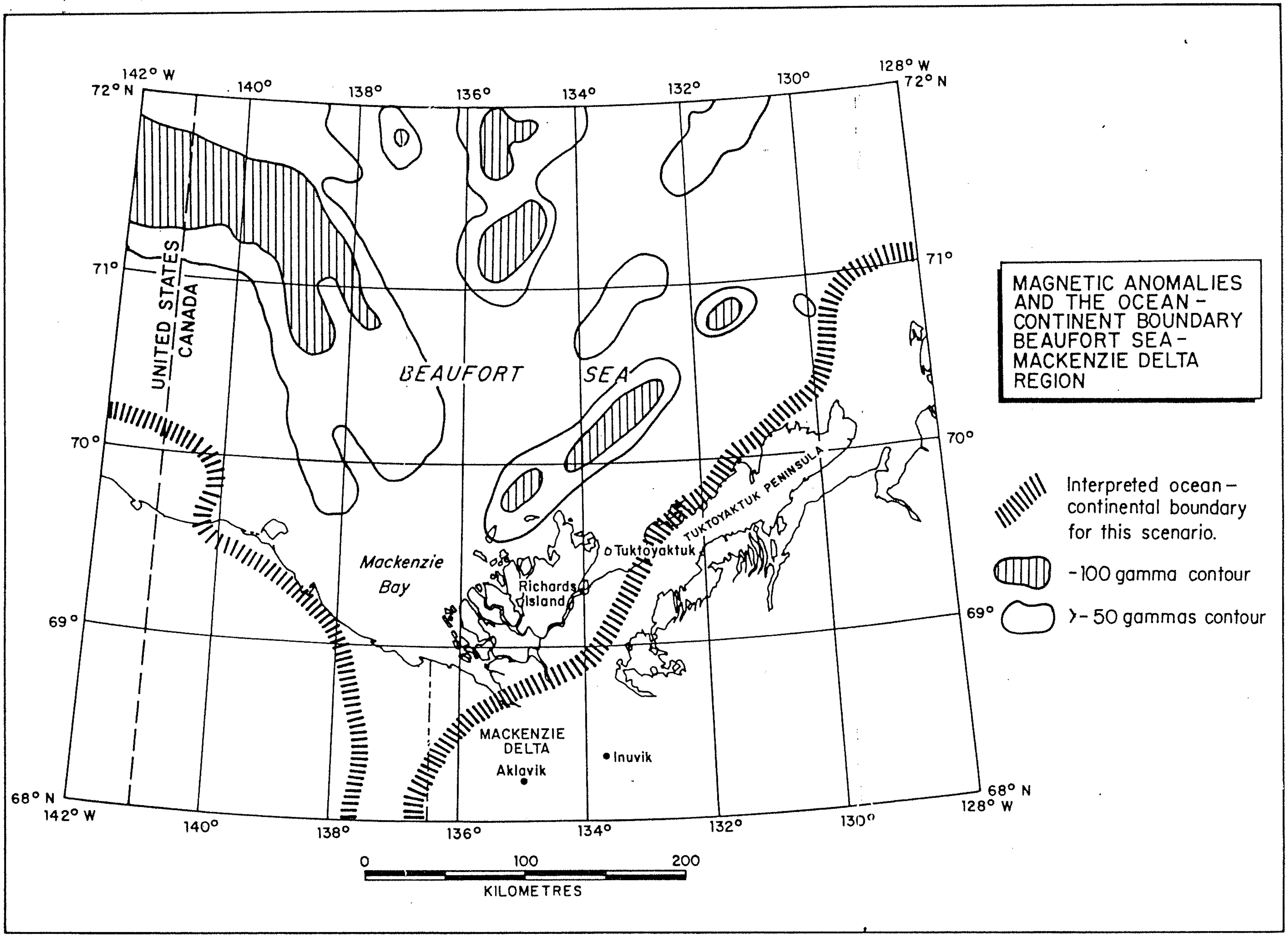
6.7.4 Rotation in the BSMD Region

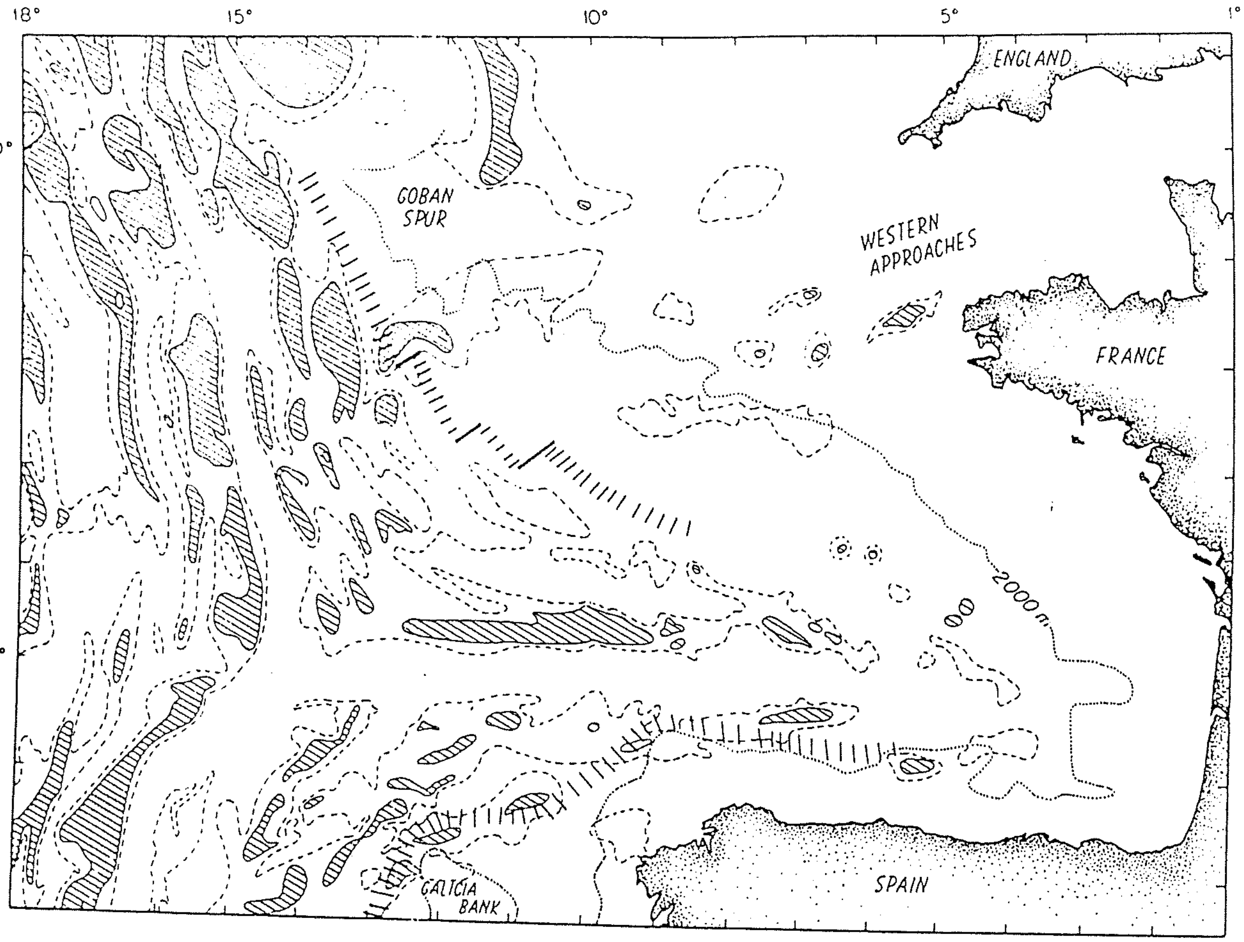
One proposed genesis of the BSMD Region involves the rotation of Alaska away from the Arctic Islands with the continental crust being present only under the current land mass, and the remainder of the area comprised of newly generated crust of oceanic or near continental affinity. Support for this hypothesis within the context of this report, is based primarily on the comparison (on a broad scale) of the magnetic features from the BSMD Region with those of the Bay of Biscay (northeast Atlantic coast) where a rotational component has been suggested by a number of workers.

Observations in the Bay of Biscay (Heirtzler, 1985) have suggested that large scale (250x60km), westerly orientated magnetic features extending oceanward from the apex of the bay were produced when the Iberian Peninsula rotated away from France. These features meet the characteristic north-south oceanic stripping at right angles just beyond the most westerly expanse of land (figure 8).

The westerly orientated features may be comparable to that of the southerly trending arcuate lobed structure. In fact, if we correlate the large scale, poorly defined, roughly east-west trending anomalies of Terrain IV with the north-south anomalies of the same magnitude from the bay of Biscay (by rotating the former 90 degrees in a counterclockwise manner) then it appears as though this environment could support the rotational notion postulated by some scientists (figure 9). This of course assumes that the hypothesis of rotation concerning the Bay of Biscay (Roberts and Montadert, 1979) is correct. It has been noted that if Alaska were rotated back to the Arctic Islands, adjacent sedimentary units would be of a different age and provenance, and paleocurrent measurements would imply opposing source directions (Churkin and Trexler, 1980).

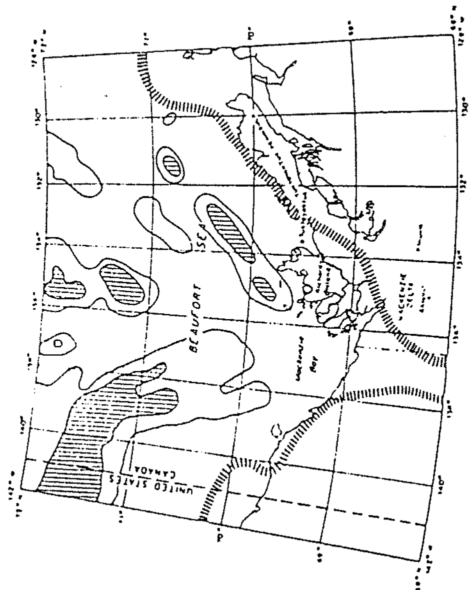
Further aeromagnetic data collected north of the current survey block, and subjected to the same enhancement techniques may show the northern portion of Terrain IV to be composed of large east west trending magnetic anomalies of the same order of magnitude as those offshore of the Bay of Biscay. In this case, the nature of IV would be more closely related to oceanic crust. The sausage shape of Terrain III would therefore outline the basin margins as related to a zone of major crustal deformation.


MAGNETIC ANOMALIES AND THE OCEAN - CONTINENT BOUNDARY BEAUFORT SEA - MACKENZIE DELTA REGION
Interpreted ocean - continental boundary for this scenario.
-100 gamma contour
≻-50 gammas contour
BEAUFORT SEA
Mackenzie Bay
Richards Island
Tuktoyaktuk
TUKTOYAKTUK PENINSULA
MACKENZIE DELTA
Aklavik
Inuvik
UNITED STATES
CANADA
142° W 72° N
128° W 72° N
68° N 142° W
68° N 128° W
140°
138°
136°
134°
132°
130°
71°
70°
69°
0
100
200
KILOMETRES
Figure 8



a) Bay of Biscay
(Northeast Atlantic)

(from Heirtzler, 1985)



b) BSMD Region

Interpreted ocean–continental boundary for this scenario.

-100 gamma contour

>-50 gammas contour

MAGNETIC ANOMALIES AND THE OCEAN–CONTINENT BOUNDARY

Figure 9

7.0 CONCLUSIONS AND RECOMMENDATIONS

A number of significant conclusions may be drawn from the interpreted aeromagnetic data.

Character and shape of the BSMD Region is a direct result of magnetic basement, sediment infill and associated structures.

Regional magnetic component separation indicates that major anomalies on the total field map are due to source bodies at depths greater than 10km. Magnetic responses from bodies within the upper 10km of the data (residual magnetics) outlined two shallow dykes, a number of igneous intrusives, and several areas of potential intrasedimentary volcanics.

Basement rocks within the Beaufort Sea-Mackenzie Delta Region can be divided into two major groups: those with large amplitude, long wavelength responses characteristic of continental crust, and those with smaller amplitude, shorter wavelength responses more characteristic of crust with an oceanic or a mixed continental/oceanic affinity. These magnetic groups have been subdivided, on the basis of magnetic signatures, into five structural "terrains", four of which are considered to be continental in nature. Terrain III is distinctly different from the other four terrains and outlines interpreted oceanic crust. Sediment eroded from the continental margins accumulates in the ocean basin, and Terrain III also approximates the extent of these basin fill sediments.

Rocks of continental affinity in the offshore seem to have been rifted apart from the current coastline in a northerly direction, possibly with some very small component of anti-clockwise rotation.

Depth to basement calculations and magnetic modelling confirm the great thicknesses of Tertiary sediment but suggest that the basement topography is not constant throughout the region and that the sediment cover thins over the "uplifts".

Magnetic character of the BSMD Region consists of relatively susceptible material overshadowing adjacent blocks of lower susceptibility. Magnetic modelling at this scale is influenced by the larger units. The insertion of bodies with substantially lower susceptibilities (as is required to match observed and calculated profile data) into the models is, for the most part, a question of aesthetics rather than a reflection of true geological character. Depth to the "continental" masses (both apparent and calculated) increases from the edges of the BSMD Region down into the basin proper but cannot be effectively contoured without more profiling work and additional geological and geophysical information (e.g. seismic profiling) to constrain the models.

The BSMD Region is interpreted to represent a rifted continental margin possibly developed in response to a triple junction/hot spot. An aulocogen extending back into the continent, is delineated by magnetic material within the Rapid Depression/ Blow River High, similar to that associated with Terrain III, and is interpreted to represent a continuation of the main structure.

Major tectonic elements directly related to basement features were more easily recognized than those developed solely within the Tertiary fill. The latter, if noted at all, were identified only by the expression of intrasedimentary sources (volcanics or magnetite rich sediments), difficult to detect amongst survey noise. Fortunately, there is a strong correlation of surficial and shallow structures with basement features (basement control). For example, the surficial trace of the ELFZ recognized in residual magnetic mapping is probably related to sediments draped over the edge of Terrain I.

The collection of additional aeromagnetic information to the north of the current survey block should be considered. This data would provide a much more comprehensive regional picture, especially with respect to the extension of Terrains IV and V. Aeromagnetic data collected along the Arctic Coastline would also greatly enhance the regional context and could change the interpretation included here.

When gridded geophysical data is prepared for release to the public, consideration should be given to developing a data set that will not only generate a map product that looks nice in the original form, but also one that can be enhanced without revealing numerous edge effects. The collection of aeromagnetic data along the hyperbolic Decca navigational network, although it may be rapid and initially cost effective, is not a suitable means of obtaining good quality information due to the strong corrugation induced in the data by flight line orientation and leveling effects.

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