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GEOPHYSICAL INVESTIGATIONS AT WEIR'S POND, MOUNT SYLVESTER AND SNOWSHOE POND, NEWFOUNDLAND: IMPLICATIONS FOR LITHOLOGIC DISTRIBUTION AND STRUCTURE

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ABSTRACT

Three areas in central Newfoundland were investigated by magnetic and VLF-EM.

A gap in the prominent aeromagnetic anomaly associated with magnetic units within the Gander River Ultrabasic Belt (GRUB) was the target of surveys in the Weir's Pond (2E/1) and Carmanville (2E/8) map areas. The geophysical signatures of rock units mapped in detail in the vicinity of Weir's Pond were used to trace similar units within the Carmanville map area. The absence of a strong aeromagnetic anomaly northeast of Weir's Pond is the result of a predominance of lower Davidsville Group clastic rocks north of an east-west fault. The occurrence of hydrothermally altered equivalents of the GRUB are relatively rare in this northern area. An attempt to trace the boundary between Gander Group and Davidsville Group rocks through this nonmagnetic area using the above geophysical methods proved unsuccessful.

In the Mount Sylvester (2D/6) map area, a northeast-orientated, structural linear, defined by sporadic outcrops of chromite-bearing ultramafic rocks and associated lenticular aeromagnetic anomalies, was investigated by several ground traverses. Results of modelling on the asymmetrical magnetic anomalies indicates that the ultramafic bodies dip to the southeast at angles ranging from 55 to 75°. Spatial relationships of anomalies suggest that the linear in the Mount Sylvester area is defined by several small prismatic ultramafic bodies arranged en echelon *in fault contact with the siliciclastic rocks of the North Steady Pond Formation to the northwest.*

Two shear zones within units of the Victoria Lake Group were investigated by surveys south of Lake Douglas in the Snowshoe Pond (12A/7) map area. The shear zones showed little character in the magnetic or VLF-EM data. However, a north-northeast-oriented zone within deformed clastic rocks showed a strong magnetic and conductive signature on several traverses, suggesting a structural repetition of the unit. A magnetically anomalous zone was also identified within a unit mapped as mafic volcanic rocks. A highly deformed pelitic layer separating mafic volcanic rocks from volcanogenic sediments was traced by its anomalous conductivity. Several other mapped units were also characterized geophyscially.

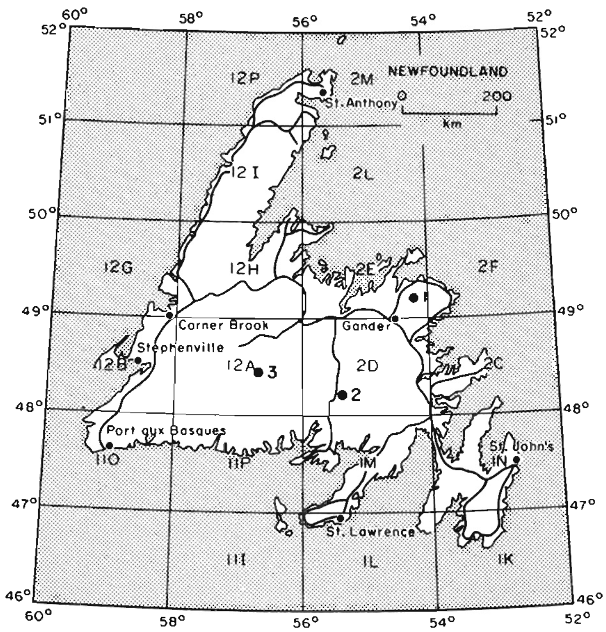
INTRODUCTION

Geophysical surveys were carried out in areas of central Newfoundland during the 1987 field season (Figure 1) to provide a more continuous picture of bedrock geology in regions of little or no bedrock exposure, and to elucidate geological structures. Some of these structures, especially those faults containing ultramafic rocks in the Weir's Pond and Mount Sylvester areas, may be important as loci of gold mineralization (Tuach *et al.*, *this volume;* Tuach, 1987a,b).

Survey Instrumentation and Procedures

Values of the total magnetic field were measured initially by an OMNI IV (EDA Instruments). Measured values were corrected for diurnal variations using a reference of total field values recorded on a 30-second interval by another OMNI IV operating in the base station mode. The inphase and quadrature (out-of-phase) responses of the VLF field were measured by an EM-16 (Geonics) receiver by audibly nulling the received signal by varying the tilt angles and quadrature dial adjustments. The OMNI IV field unit was subsequently replaced by an OMNI Plus instrument, which has capabilities of simultaneous measurement of as many as 3 VLF signals in addition to the magnetic field, and recording both VLF and magnetic readings digitally in internal memory. This allowed the signal from Annapolis, Maryland to be recorded in addition to that from Cutler, Maine. These two transmitters were the only two with sufficient signal strength for surveying in insular Newfoundland. For 10 survey days the survey procedures overlapped: both the EM-16 and OMNI Plus receivers were used for measurement of the local VLF field to facilitate correlation and calibration. Later comparison of the received signals (24.0 kHz) from the two instruments showed an extremely good correlation.

This project is a contribution to the Canada–Newfoundland Mineral Development Agreement, 1984–1989



INDEX MAP

Figure 1. *Study area locations.*

Survey lines were oriented generally at azimuths of 135 to 140°; offsets were introduced to avoid bodies of water or otherwise impassable terrain. A 10-m station spacing was adopted after the first few profiles to obtain the detail necessary for an accurate representation of the VLF field. The southeast profile orientation was chosen to be nearly perpendicular to both the general northeasterly structural trends in the study areas and the incoming VLF signals transmitted from Cutler, Maine (24.0 kHz) and Annapolis, Maryland (21.4 kHz). This arrangement provides optimum inductive coupling to conductors. Traverses were concentrated in areas showing the largest geophysical response.

The data are presented on survey location maps with the magnitude of anomaly plotted vertically above the position along the traverse where the value was recorded. Thus, the location of an anomaly is that point along the traverse vertically beneath the peak, and the magnitude of the anomaly is the scaled offset from profile point to peak. The desired result of this display method is to have the anomalous field appear to stand out of the page in an attempted three dimensionality. A major disadvantage is that, where the anomalous field is large and variable and where profiles are closely spaced, the profiles tend to overlap in nonaesthetic confusion. Contours of a potential field, on the other hand, do not intersect. It is felt that data are better displayed in profile form on these maps, rather than using contours, for the following reasons:

1) averaging and smoothing is introduced by the gridding used to produce contours, therefore much of the high-frequency content used to estimate depth to source is eliminated from contour maps, and

2) since locations, relative magnitudes and shapes of anomalous features are displayed by profile plots, any offset errors present, particularly in magnetic data, become less prominent between adjacent profiles.

Values of the magnetic field are displayed on profile location maps with mapped geology and limited topography included as reference. The VLF—EM field is displayed on similar maps in the form of profiles of the Fraser filtered, inphase response (Fraser, 1969, 1981). The Fraser filter values were chosen for display since the filter provides a limited smoothing and the resultant values represent the digital first derivative of the inphase response (Fraser, 1969). In this way, maximum negative slopes on the inphase profile, which indicate conductivity, result in positive peaks on the Fraser filter profiles. Typical VLF and magnetic profiles or those containing features of interest are also included as side-by-side plots for correlation purposes. It should be noted that the scale of anomaly differs from profile to profile depending on the range of values in each profile.

WEIR'S POND

Objectives

The prime objective in the Weir's Pond (2E/1) map area was to determine the cause for the abrupt northern termination of a large aeromagnetic anomaly associated with Gander River Ultrabasic Belt (GRUB) rocks near the Weir's Pond—Carmanville map area boundary (Geological Survey of Canada, 1969a,b; Rockel, 1973). A secondary objective was to investigate the geophysical signature and orientation of a reported conformable contact (Currie and Pajari, 1977; Currie, *et al.*, 1980a,b) of the Gander and Davidsville groups within the nonmagnetic section of the GRUB northeast of Weir's Pond.

Geology and Previous Work

The principal geologic elements of the area are the Gander Group, GRUB and Davidsville Group; their relationships are described elsewhere (O'Neill, 1987; Blackwood 1980, 1982; Currie and Pajari, 1977). The GRUB succession in the vicinity of Weir's Pond consists of (O'Neill, 1987, 1986a,b):

1) an ultrabasic unit, variably altered to magnesite talc, and serpentinite,

2) gabbroic rocks,

3) mafic volcanic rocks, and

4) trondhjemite

Numerous faults, identified or inferred from geological exposures (O'Neill, 1986a), have structurally repeated the GRUB succession.

Clastic sedimentary rocks of the Davidsville Group, ranging from immature sandstone and conglomerate at the base to largely more mature siltstones and sandstones in the upper parts, are structurally imbricated with the ultrabasic belt and overlie the belt to the northwest. The pelites and semipelites of the Gander Group show increasing metamorphic grade to the east in the Weir's Pond map area. The contact between the ultramafic rocks and the Gander Group is nowhere exposed in the Weir's Pond area. Exposures of ultramafic rocks of the GRUB west of Weir's Pond exhibit varying alteration (O'Neill, 1987).

The Weir's Pond and Carmanville map areas have been covered by an aeromagnetic survey flown at a 300-m altitude and 0.8-km flight line spacing (Geological Survey of Canada, 1969a,b). An airborne electromagnetic- and magnetic-survey was flown over the northern part of the GRUB as reported by Rockel (1973). Several geophysically interesting features identified from these surveys were later followed up on the ground (Zurowski, 1974a,b).

Access and Topography

Access to the northern part of the Weir's Pond area from the Gander Bay highway was provided by a network of logging roads in good condition. Access in the Carmanville map area was also by a system of woods roads, in disrepair, off Route 330 from Carmanville. Temporary field camps were established along woods roads and surveys were conducted within walking distances of overgrown trails. Helicopter support was required on one occasion to provide access to a remote survey location.

Extensive bogs, numerous ponds, wooded, gently rolling hills and small outcrop ridges cover the area. Surface features strongly reflect the northeasterly bedrock trend. Much of the region east of Weir's Pond was burned over and is now heavily vegetated by second-growth thicket, markedly hampering survey progress.

Interpretation of Magnetic and VLF–EM Data

Geophysical traverses were positioned over units of the GRUB with the emphasis on the contact with the Gander Group. Profiles were oriented at 140° where topographic features would permit. Figure 2 shows a profile location plot for traverses north and east of Weir's Pond. The magnetic profiles are total field values with the long wavelength field of the International Geomagnetic Reference Field (IGRF) (Peddie, 1986) removed. In addition, a constant field value of 600 nT was added so that low magnetic background levels, such as the variable field observed in Gander Group sedimentary rocks, would plot near the zero level. Thus the IGRF level is not representative of the background field in the Weir's Pond area. The observed low background levels agree with those recorded at the 300-m altitude, published as 1:1,000,000 scale maps (Geological Survey of Canada, 1984a,b), throughout Newfoundland's Central Mobile Belt. Here, these maps show values lower than the IGRF by 300 to 1000 nT.

Magnetic signatures show a strong correlation with mapped rocks types in the Weir's Pond area (lower portion) of Figure 2. The ultramafic rocks (Unit 2) and the mafic volcanic rocks (Unit 4) are responsible for the largest and most variable anomalies displayed. A low and variable magnetic field was recorded over a large area underlain by gabbroic rocks near the southwest shore of Weir's Pond (near 689E,5454N). A narrow, low magnitude anomalous zone, recorded on the two parallel lines here, provides evidence that the gabbro is bisected. This anomaly may be due to a break between two phases of gabbro emplacement or a structural repetition of gabbro with an intervening stringer of mafic volcanic rocks. The lower Davidsville Group of Unit 6 correlates everywhere with low uniform magnetic fields. On the basis of magnetic signatures, the positioning of lithologic contacts, as mapped by O'Neill (1987) in the vicinity of Weir's Pond, require very little adjustment.

Although modelling of magnetic profiles from Weir's Pond has not been completed, the relative magnitudes of lows associated with the larger magnetic highs suggest a near vertically oriented structure. This is in general agreement with orientation data measured on outcrop.

One of the more prominent and laterally continuous features on Figure 2 is a sharp magnetic anomaly at the contact of the ultrabasic belt of the GRUB with the Gander Group. Correlation of adjacent peaks shows a strong northeasterly trend, but with minor offsets. The peaks should lie vertically above the centres of their causative rock units, whereas locations of the bounding fault should lie 40 to 60 m to the southeast. Apparent offsets in the contact position are thought to be partially the result of offsets along the many faults mapped within the GRUB units and partially due to lateral lithologic changes. The southeasternmost magnetic peak or 'basal anomaly' is caused by ultrabasic rocks (note anomaly magnitudes and profile scale) in the area immediately northeast of Weir's Pond, as evidenced by outcrop on Line 1700. An earlier ground survey reported by Zurowski (1974a,b) also detected offsets in the basal anomaly location. Farther to the northeast, near Cluff's Pond, rocks display increasing alteration, such that the basal magnetic unit here is probably a serpentinite. The prominent basal anomaly detected on Line 2300 is positioned on the northwest flank of a large magnesite outcrop (which has no magnetic signature), suggesting that the actual GRUB–Gander contact is southeast of the basal magnetic anomalies. Thus the most magnetic rocks do not always comprise the basal GRUB outcrops, and their relative positioning may explain many apparent small offsets in the basal anomaly trend.

Many of the magnetic features on Figure 2 reflect the underlying northeast trend of the basal anomaly. Several other features show overprinting of more easterly trends (slightly oblique to the basal anomaly), such as that defined by anomaly alignment on the northwest end of the northernmost profiles. Other northerly oriented trends evident on the anomaly map coincide with faults inferred from map patterns and lineaments (O'Neill, 1986a,b).

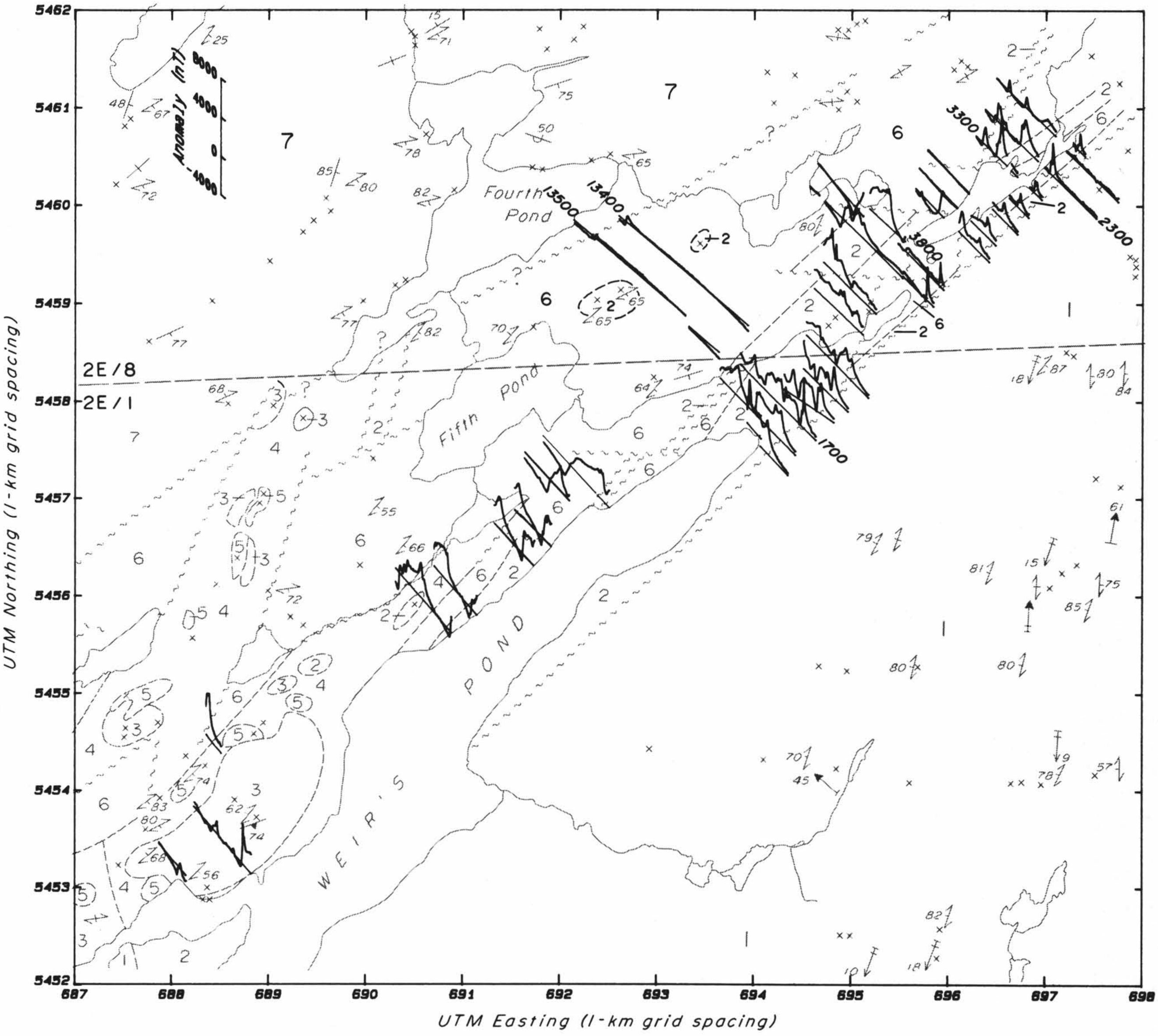


Figure 2. *Locations of total field magnetic profiles in the Weir's Pond (2E/1) and Carmanville (2E/8) map areas. Dashed line trending east-west separates the two map areas. Consult magnetic anomaly scale in the northwest corner of map for magnitude of anomaly relative to position along traverse. Geology from Currie* et al., *(1980b) (for 12E/8) and from O'Neill (1986b) (for 12E/1); a few modifications to geology for both map areas are based on interpretation of geophysical data acquired in this study. All map units, map unit numbers and map unit descriptions from O'Neill (1986b). Coordinates used here and in later figures are Universal Transverse Mercator (UTM) with a 1-km spacing.*

To the northwest, the low uniform magnetic field recorded on Lines 13400 and 13500 (Figure 2) is indicative of clastic rocks of the lower Davidsville Group. The magnetic field measured along Line 13400 is displayed in Figure 3 along with the inphase and quadrature components of the received VLF field. Calculated values of the Fraser filtered inphase response are included to correlate positions of conductive horizons.

Based on lower magnetic levels to the northwest, the small magnetic anomaly on Line 13400 (location -1140 m; Figures 2 and 3) marks the transition from immature siltstones and red shales comprising the lower parts of the Davidsville Group (Unit 6) into black siltstones and shale (Unit 7) of its upper part (Currie *et al.*, 1980b). Although the contact is displayed as a fault on Figure 2, the absence of a corresponding strong conductive anomaly suggests a conformable contact. The black siltstones of Unit 7, although containing clasts of GRUB units (Currie *et al.*, 1980b), are of lower magnetic susceptibility than the underlying red shales and deformed siltstones of Unit 6. The minor anomaly observed is that expected over the northwestern edge of a wide, uniformly magnetized block in these high magnetic latitudes and north-northwest declination.

LEGEND (Figure 2)

MIDDLE ORDOVICIAN

Davidsville Group

7 Upper Member: *grey to grey-green, rarely purple, siltstone; minor thin sandy beds and conglomerate*

6 Lower Member: *interbedded laminated siltstone; immature sandstone—locally crossbedded, fossil-rich sandstone; bioclastic limestone; calcarenite; graphitic black shale and polymictic boulder, cobble and pebble conglomerate*

MIDDLE ORDOVICIAN OR OLDER

5 *Aphanitic to coarse grained trondhjemite*

4 *Mafic volcanic and volcaniclastic rocks*

3 *Gabbro*

2 *Ultramafic rocks*

ORDOVICIAN OR OLDER

Gander Group

1 *Pelite; semipelite; quartzofeldspathic psammite; minor quartz granule sandstone; felsic and mafic sills and/or dykes*

SYMBOLS

Geological boundary (approximate)

Bedding, tops known (inclined, overturned)

Bedding, tops unknown (vertical)

Schistosity (inclined, vertical)

Mineralogical layering in gabbro

Fold axis (F_1, F_2)

Linear fabric (L_2)

Inferred fault (?-uncertain)

Outcrop

Minor variations in magnetic field between locations -1140 and -150 m on Line 13400 can be correlated with positions of conductive peaks in the VLF profile. This region is interpreted as underlain by the red shales of the Davidsville Group. The region from -150 to 480 m shows a smooth southeastward decrease in magnetic field and a corresponding lack of conductivity, and reflects the presence of the deformed black and white siltstones forming the basal unit of the Davidsville Group (Currie *et al.*, 1980b). Parallel Line 13500 shows excellent correspondence of features, particularly in midsection conductivity, indicating that these geophysical signatures are not topographically induced. Magnetic profiles of Lines 13400 and 13500 are subdued in their middle regions, suggesting an absence of a continuous ultramafic body as depicted by Currie *et al.* (1980b).

An anomaly prominent on several traverses near UTM coordinates 695E,5460N (Figure 2) exists over a till-covered, low topographic ridge of uncertain rock type. At the southwestern end of the ridge, ultramafic rock, altered to magnesite and ankerite, is exposed. Magnetic anomalies in profiles across the ridge increase in magnitude to the northeast, indicating increasing magnetic mineral contents, which are due to lenses of serpentinite or other highly magnetic ultramafic rocks in subcrop. These lower GRUB units are flanked to the northwest by lower parts of the Davidsville Group, as shown by a transition to low, smooth magnetic field values. The associated anomaly appears to terminate immediately north of Line 3800 (Figure 2; also Rockel, 1973), perhaps due to an east-southeast-oriented fault.

The several anomalies detected on the northernmost lines are interpreted to be caused by the presence of lenticular serpentinite pods, either in outcrop or shallow subcrop, aligned on fault trends. One such serpentinite body, not previously mapped, is exposed in a bog just north of Line 3300. Extremely variable anomalies, on the order of 1000's of nT, recorded directly over the outcrop, are indicative of anomalously large, probably zoned magnetite concentrations.

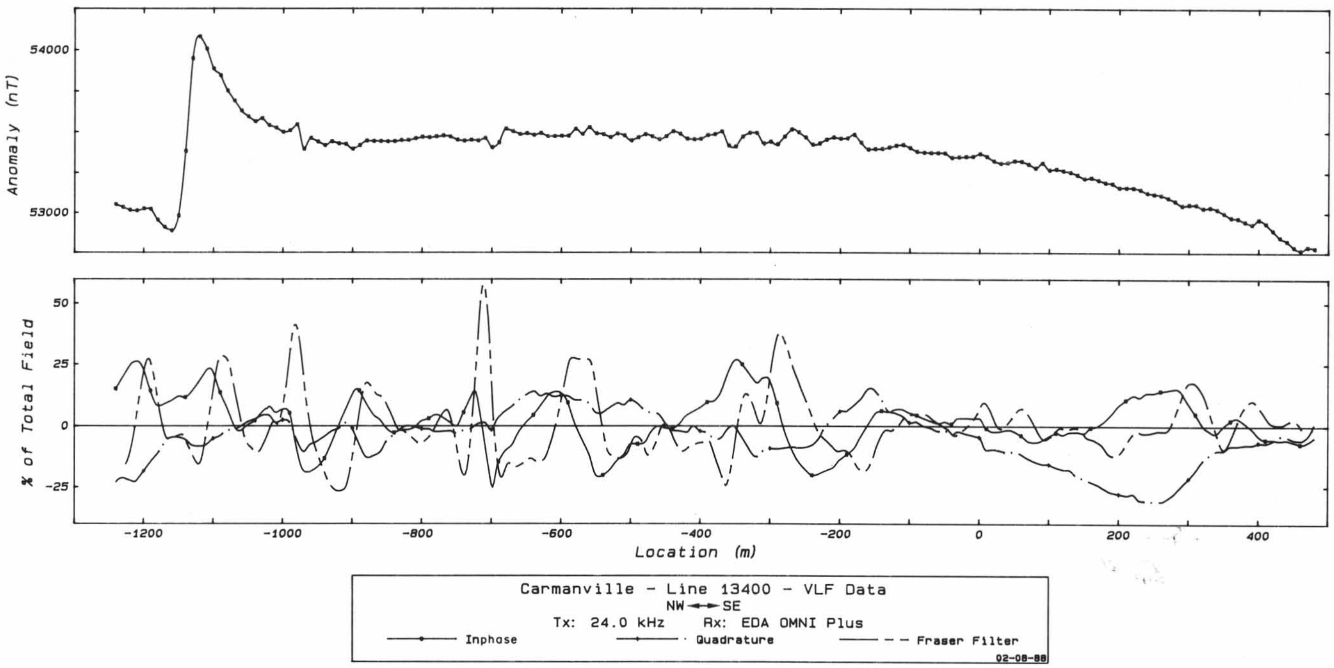


Figure 3. *Magnetic (upper) and VLF–EM (lower) profile data recorded along line 13400, Carmanville map area. See Figure 2 for location.*

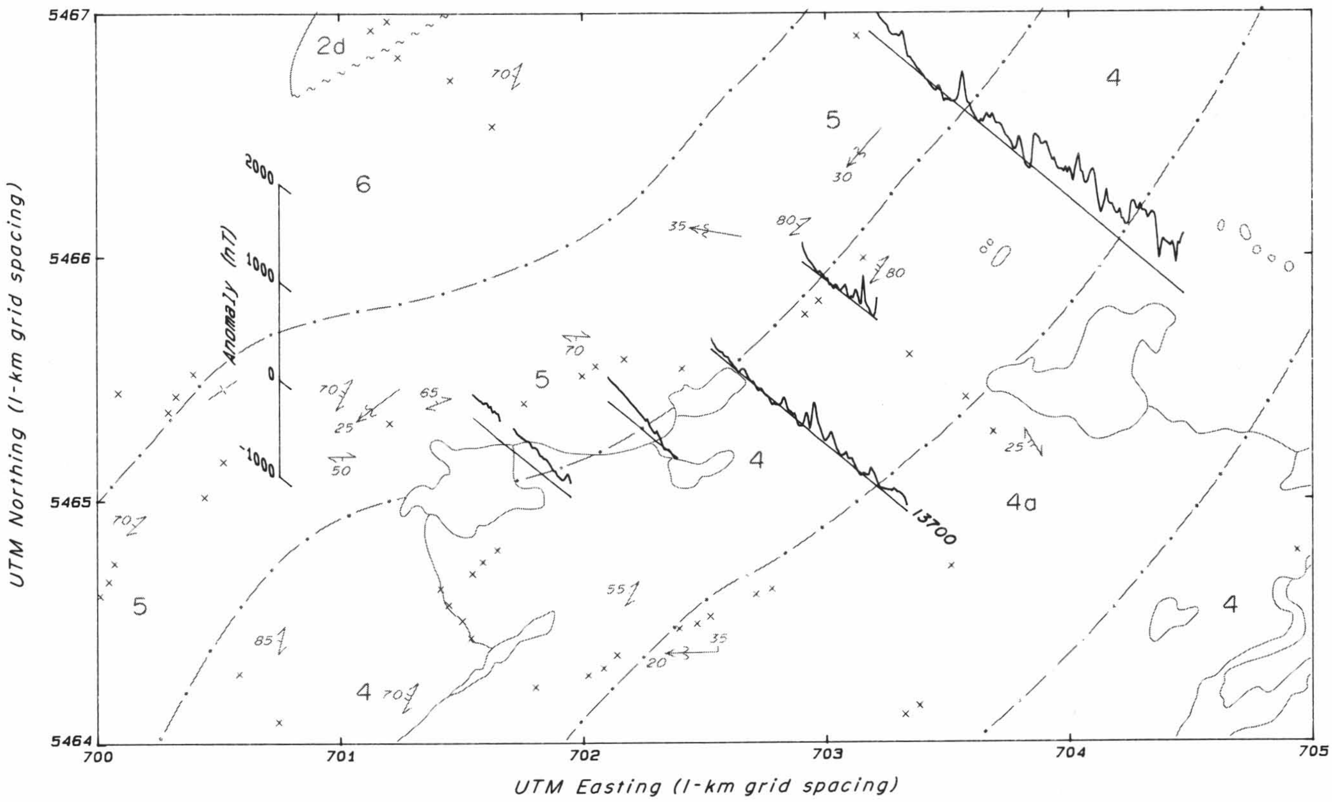
The northwestern margin of anomalous high magnetic values associated with the ultramafic rocks underlying Weir's Pond are detected on the southwest ends of profiles near coordinates 691E,5456N (Figure 2). A graphitic shale is responsible for the low magnetic values recorded between these anomalies and the magnetic highs detected to the northwest. The magnetic anomalies detected on the northwest ends of these lines are due to mafic volcanic rocks as inferred from the several mapped exposures (O'Neill, 1986a). This provides evidence for structural repetition of GRUB units. Structurally interleaved ultrabasic and gabbroic rocks cause the large variable anomalies observed just north of Weir's Pond, an area of extensive bog and till-covered ridges with little outcrop.

The controversial contact between the Davidsville and Gander groups north of Weir's Pond was investigated with several profiles traversing the mapped contact. Figure 4 is a map showing the locations of magnetic profiles. The boundary is not marked in this area by a strongly anomalous magnetic body (cf. anomaly scale with that of Figure 2). Approximate locations of a northwestward increase in magnetic levels follows the curvilinear northeastward trends in mapped lithology (Currie *et al.*, 1980b). Figure 5 shows the magnetic and VLF profiles for Line 13700. The VLF profile shows a strong conductor near the boundary position and a few weak conductors in the contact vicinity, possibly indicating the presence of several minor parallel faults. On adjacent lines, however, only weak conductors were detected. The contact location is not obvious on the basis of magnetic or VLF-EM values recorded from these traverses. Subtle differences in rock properties between the units on either side and a structural interleaving of the units (Piasecki, this volume) near the supposed contact create an environment that is not amenable to solution using these geophysical methods. The above findings concur with a recent megashear description of the contact zone, where deformation encompasses a 1-km- wide zone (Piasecki, *this volume).*

A highly variable magnetic field is observed within the Gander Group on the eastern most profile, Line 13900. The southeast end of Line 13900 approaches a north-trending belt of elevated aeromagnetic anomalies (Geological Survey of Canada, 1970) located entirely within Gander Group units. The northerly strike of this anomalous zone, which contrasts with the northeast strike of the GRUB or Davidsville Group, is parallel to a regional foliation in the Gander Group. The trend of the aeromagnetic anomaly intersects that of the GRUB northeast of the surveyed area. The source of this anomaly is uncertain, but may be related to a second ultrabasic belt as suggested by several exposures of mafic to ultramafic rocks on its eastern edge (recently mapped by O'Neill, *this volume).* The Gander Group magnetic anomaly deserves further geophysical investigations.

Conclusions

GRUB units in the Carmanville area generally possess a lesser magnetic response than units comprising the GRUB in the Weir's Pond map area (Geological Survey of Canada, 1969a,b). This is due to a combination of a northeastward increase in alteration and the fact that mafic and ultramafic rocks of the GRUB are less voluminous north of an interpreted east-west fault in the Carmanville map area. Exposures in the southern Carmanville map area, along strike with strongly magnetic ultramafic rocks north of Weir's Pond, are primarily magnesite–ankerite, serpentinite and deformed clastic rocks of the lower Davidsville Group.



LEGEND

MIDDLE TO UPPER ORDOVICIAN

Davidsville Group

6 *Granule and conglomerate lenses containing volcanic and ultramafic clasts in grey-black siltstone and shale*

5 *Red shale exhibiting local grey-green bleached areas, and local limestone beds; basal sequence of thin-bedded black and white siltstone*

Gander Group

4 *Uniform thin-bedded, grey-green siltstone and quartz wacke; minor pelitic interbeds and conglomerate lenses; 4a, green volcanogenic schist containing amphibolitic layers and dykes*

MIDDLE ORDOVICIAN? AND OLDER

Gander River Ultrabasic Belt

2d *Rubble of volcanic and ultramafic rocks, probably gradational into Unit 6*

SYMBOLS

Vertical bedding

Inclined schistosity

Second-generation, inclined schistosity

Small-scale fold (arrow indicates plunge, inclination of axial plane known, unknown)

Figure 4. *Locations and magnetic results for traverses investigating the boundary between Gander Group (Unit 4 and subunit 4a) and Davidsville Group (Units 5 and 6, subunit 2d) in the Carmanville map area, northeast of Fourth Pond. Note expanded anomaly magnitude scale as compared to Figure 2. Geology and map unit numbers after Currie* et al., *(1980b).*

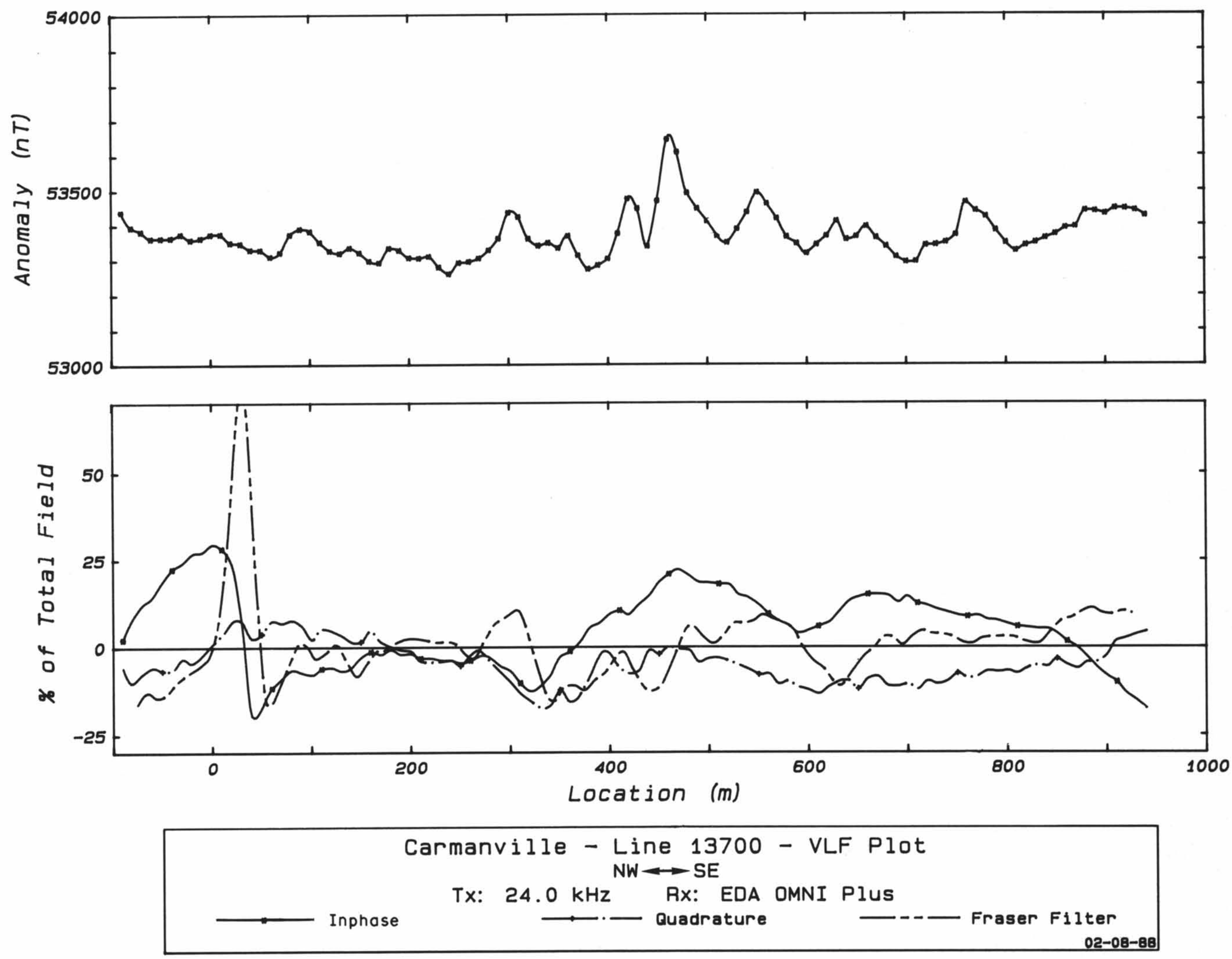


Figure 5. *Magnetic and VLF–EM profile data recorded along line 13700, Carmanville map area. See Figure 4 for location.*

Lack of consistent, correlatable geophysical anomalies near the Davidsville–Gander group boundary, south of Island Pond in the Carmanville area, indicates that mafic or ultramafic rocks of the GRUB are absent in the near surface. Units on either side of the boundary do not show strikingly different magnetic or VLF–EM responses. The presence of a conductor (at 0 m, Figure 5) near the transition could be interpreted as a strike-parallel fault or thrust, in agreement with the observation of Piasecki *(this volume)* that the rocks there are highly strained and locally mylonitic. The geophysical methods employed do not allow further discrimination between a conformable or structural contact.

MOUNT SYLVESTER

Objectives

The feature of interest in the Mount Sylvester map area, targeted for geophysical follow-up, is a series of small outcrops of chromite-bearing ultramafic rocks (Dickson, 1986, 1987). The objective was to determine the areal extent of ultramafic outcrops (or subcrops) and determine their subsurface orientation and relationship to enclosing sedimentary rocks.

Geology and Previous Work

The ultramafic outcrops in the Mount Sylvester map area trend northeastward from east of Conne River Pond to Middle Ridge in the Great Gull Lake map area (Dickson, 1986; Blackwood, 1983). Similar ultramafic rocks have defined linears related to thrust faulting elsewhere in Newfoundland (Colman-Sadd and Swinden, 1984), whereas this linear is described as part of an extensive shear-thrust zone (Dickson, 1987). The ultramafic rocks coincide with a linear magnetic anomaly, which is easily distinguished on aeromagnetic maps (Geological Survey of Canada, 1968a,b; McPhar Geophysics Limited, 1969) by its isolated highs within the relatively nonmagnetic surrounding units of the Baie d'Espoir Group. The surrounding rocks consist of sandstones and siltstones of the North Steady Pond Formation to the northwest, and pyritic and graphitic shales and siltstones of the St. Joseph's Cove Formation to the southeast.

Access and Topography

In the Mount Sylvester map area, geophysical surveys were carried out mainly from fly camps (see Figure 6 for profile locations), but the westernmost profiles were carried out from the Bay d'Espoir highway. The topography consists of large open-bog areas with uniform and gentle southeastward slopes and tree-covered drumlinoids. The entire area was burned over by forest fires in 1984.

Traverses were orientated at 140° to enable good coupling with VLF transmitters and to intersect, perpendicularly, the northeasterly trend of the ultramafic outcrops. Profiles range in length from 0.5 to 4.5 km. Most profiles bracket the ultramafic bodies by extension of traverses well into areas underlain by units to either side of the ultramafic rocks. Traverses were chosen and offsets were introduced where necessary to maximize survey coverage.

Interpretation of Magnetic Data

Figure 6 shows traverse locations with profiles of residual magnetic data (subsequent to IGRF removal) added for correlation between lines. Anomalies of largest amplitude and possessing the highest frequency components are those collected over outcrops of ultramafic rocks. At about UTM position (621E,5340N), where anomalies of high frequency component were observed but no outcrop exists, ultramafic rocks are suspected to occur at shallow depth. The asymmetric nature of the anomalies results from a combination of the high magnetic latitude (magnetic inclination = 70.4°), profile orientation, and the geometry of causative bodies in the subsurface.

To determine subsurface geometry, the magnetic profile for Line 4900 was modelled as a two-dimensional body with the cross-section as depicted in Figure 7. A strike of 045°, roughly that of the ultramafic outcrop trend, was assumed for the body during modelling. Line 4900 was selected for interpretation on the basis of its single, smooth anomaly. The anomaly breadth and degree of smoothness are indicative of a body buried to sufficient depth so that the effect due to any internal variation in magnetic mineral content is smoothed. In modelling the profile, it was observed that the dip angle of the body was tightly constrained (±1°) by anomaly shape. Combinations of other parameters such as body width, magnetic susceptibility and depth could be modelled to produce similar fits with only slightly increased standard deviation. The 'error bars' associated with modelling these parameters are much wider. The model selected is considered to be a realistic representation of true body geometry, but the actual body shape may differ from that depicted in Figure 7 due to the following:

1) the body is modelled as a prism, having uniform thickness and dip, but the actual body would likely be variable in thickness and tend to sole out at depth;

2) a uniform susceptibility is assumed, whereas outcrops show variations and layering of magnetic mineral content (see other profiles on Figure 6); and

3) the magnetic anomaly due to the body is assumed to be entirely induced. The body is assumed not to possess remnant magnetization.

Several other profiles showing more complex or multiple anomalies (Figure 6) would require modelling with structures of increased complexity, particularly for profiles over near-surface subcrop or outcrop. Line 4900 was chosen to avoid such complexity and therefore obtain a realistic estimate of orientation and geometry. Other profiles indicate bodies having varying orientations, but generally dips are toward the southeast. The asymmetry of the profiles is dependent on attitude; strongly asymmetric profiles indicate shallower dips.

The northwest edge of the large magnetic anomalies has been correlated by crossover picks on Figure 6, and is informally called the ultramafic front. This anomalous magnetic front can be observed on all but the southwesternmost traverses, where the front appears to bifurcate and diminish rapidly in magnitude. By correlating adjacent peaks at the ultramafic front, a series of shorter arcuate fronts is defined (see Figure 6). These short fronts are manifested as double peaks on certain profiles and as two separate singular anomalies on others, depending on their mutual proximity. Offsets along the ultramafic front are most apparent where adjacent anomalies are displaced by discernible amounts. The individual ultramafic fronts generally possess a more northward orientation than the regional trend defined by the belt of ultramafic rocks. The ultramafic front is interpreted to be a series of *en echelon* arcuate ultramafic slices, which collectively create the gross appearance of a single thrust front.

A model of the ultramafic rock body and thrust sheet orientations is illustrated in Figure 8 (diagram not to scale). The thrust sheets would not likely be as uniform in thickness or orientation as depicted, but the concept provides an explanation of the sporadic nature of ultramafics along the thrust front. As well, variations in determined orientations of ultramafic bodies within the front from shallow- to steep-southeastward dips can be accommodated by this model. The truncated thrust sheets concept draws further support from the fact that, in general, the ultramafic outcrops are located at the northern termini of individual fronts (see Figure 6).

Near the southwest end of the survey, a similar but weaker front is observed approximately 2 km to the southeast of the ultramafic front, between UTM locations (617.5E,5336.3N) and (620.0E,5338.2N) (Figure 6). This may represent a second, similar imbricate-thrust zone in which ultramafic rocks do not reach the surface.

Interpretation of VLF-EM Data

Attempts to correlate similar trends over large distances between profiles of the Fraser filtered values from the VLF data were less successful due to the coalescing and bifurcating nature of many of the numerous EM anomalies (Figure 9). Several generalizations, however, can be made from the data. Although surface features have added noise to the received

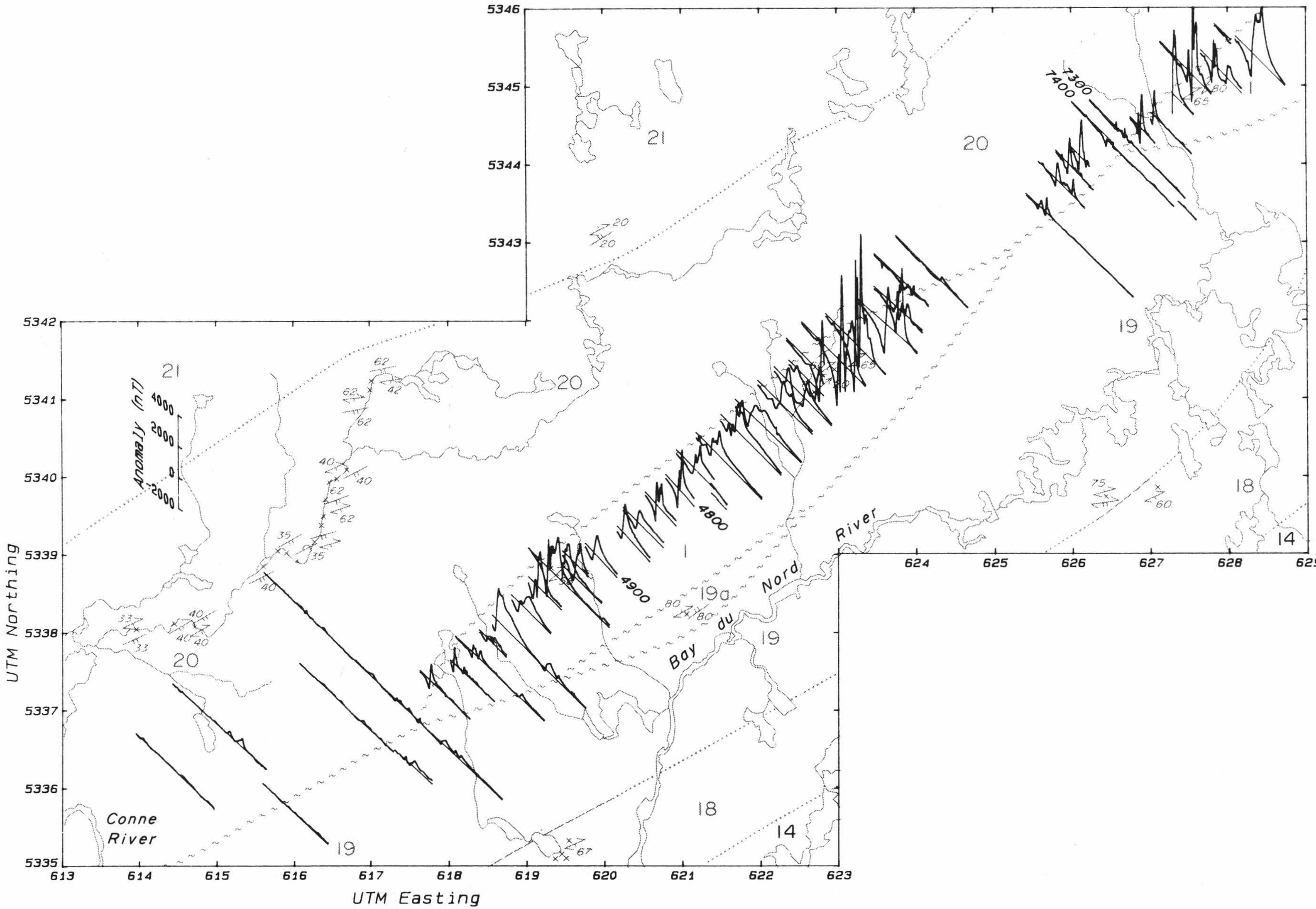


Figure 6. *Total field magnetic data recorded along traverses in the Mount Sylvester (2D/6) map area. Largest and most variable anomalies recorded over outcrop of ultramafic rocks. Note strong asymmetry of anomalies. Geology and map unit numbers after Dickson (1986).*

LEGEND (Figure 6)

MIDDLE ORDOVICIAN AND YOUNGER?

Baie d'Espoir Group

North Steady Pond Formation

21 *Grey, medium-bedded, contact-metamorphosed(?), biotite–muscovite psammite and semipelite; locally highly altered with associated scheelite mineralization*

20 *Grey to buff, thin bedded sandstone with minor siltstone*

St. Joseph's Cove Formation

19 *Thin-bedded, pyritic, black slate and minor, thin, interbedded, coarse grained sandstone and siliceous, graphitic? siltstone;* 19a, *quartz-rich, medium-bedded sandstone*

18 Twillick Brook Member: *very thick bedded, strongly cleaved, coarse grained quartz–feldspar-crystal tuff and quartz-crystal tuff containing minor, interbedded coarse grained sandstone and siltstone, locally highly altered to gossan*

14 *Grey to buff, medium-bedded slate, siltstone and sandstone*

ORDOVICIAN OR OLDER

1 *Cleaved and sheared serpentinized peridotite and dunite; contains disseminated chromite and local talc layers*

SYMBOLS

Geological boundary (approximate, assumed)

Bedding, tops known (overturned)

Bedding, tops unknown (inclined)

Cleavage (first, second generation)

Fault (assumed)

× *Examined outcrop*

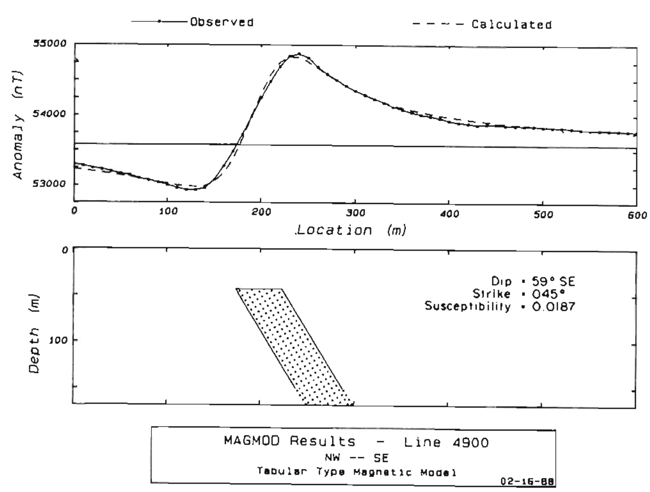


Figure 7. *Results of modelling the magnetic data for profile 4900 (see Figure 6 for location) with background field strength as indicated by solid line at 53,570 nT. A prism-shaped ultramafic body dipping 59° to the southeast and having magnetic susceptibility of 0.0187 cgs. evolves a fit to 0.071 standard deviation. The depth to the modelled body is 43 m and its true thickness is 26m. Magnetic inclination = 70.4°; magnetic declination = -24.5°.*

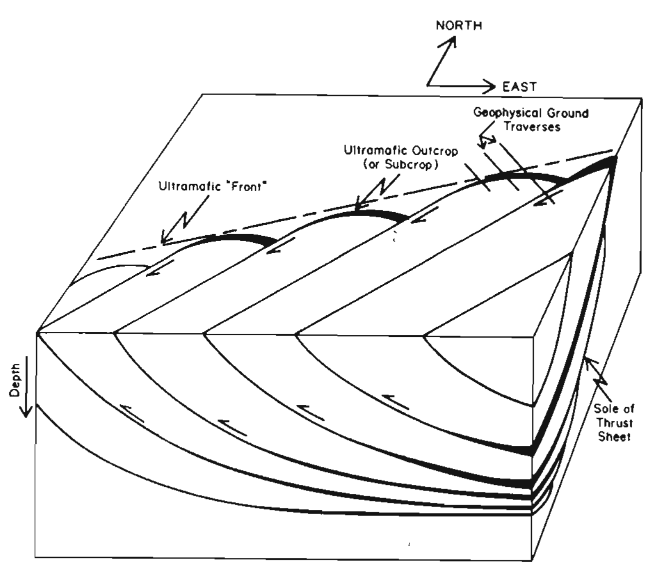


Figure 8. *Block diagram displaying imbricate thrust sheet model proposed to explain the apparent southeastward dip of ultramafic sheets (Figure 7), the observed step-like nature of the ultramafic front, and the sporadic occurrence of ultramafic outcrop with attendant magnetic anomaly. Ground geophysical traverses have relative orientations as illustrated.*

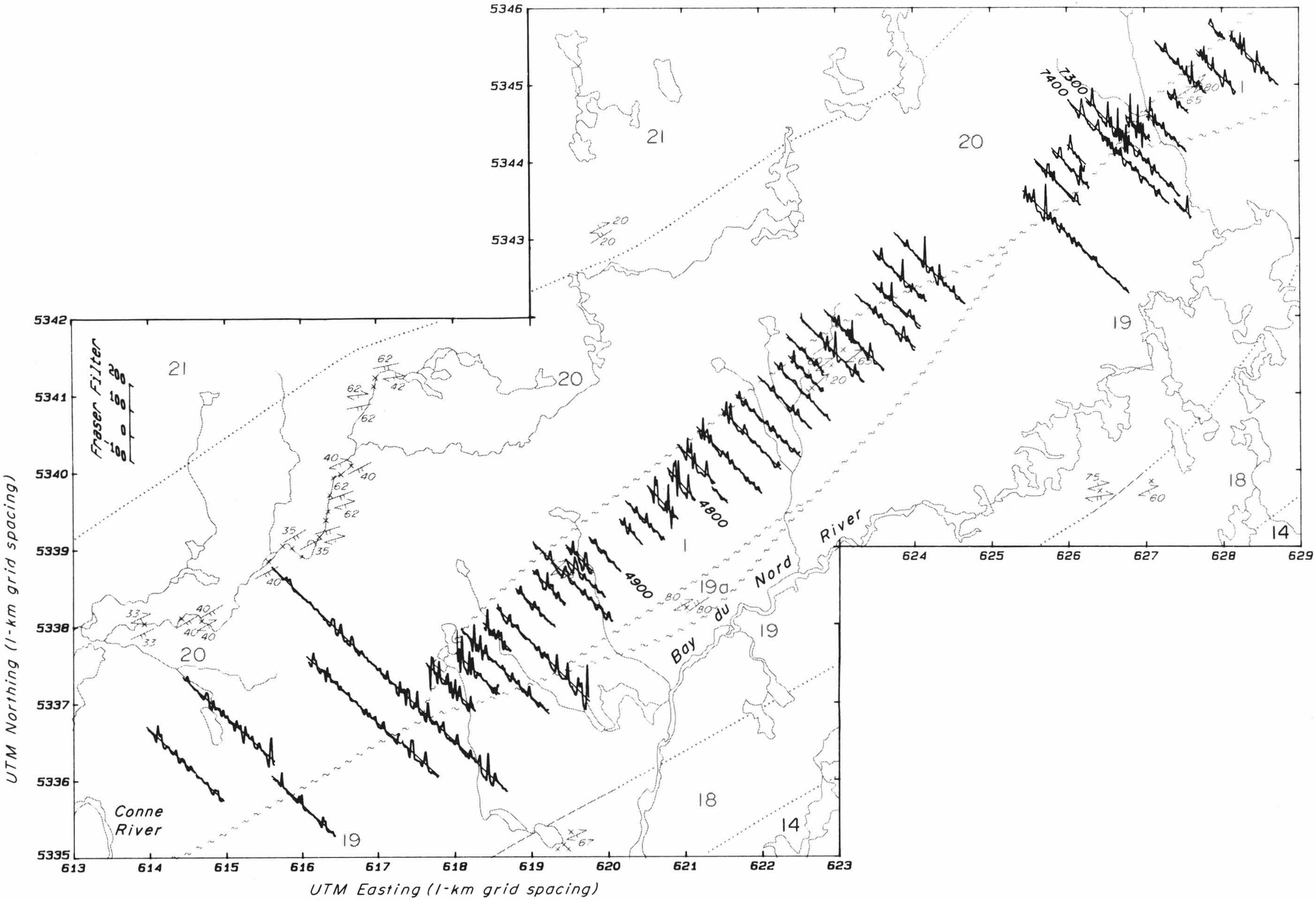


Figure 9. *Fraser filter values of VLF–EM inphase component recorded in the Mount Sylvester map area. Note good correlation of features on lines 7300 and 7400. Geology after Dickson (1986). (See Figure 6 for legend and symbols.)*

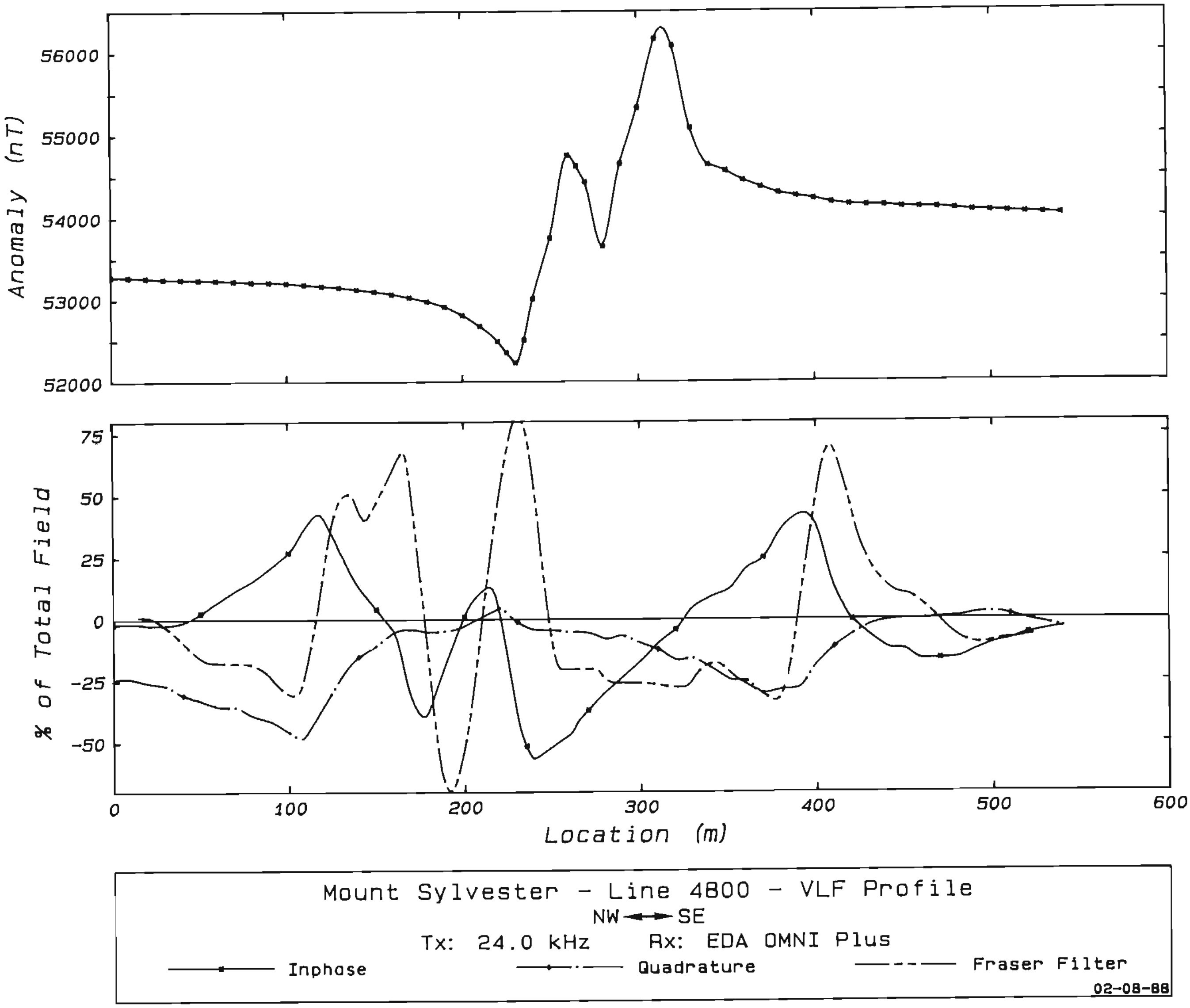


Figure 10. *Magnetic and VLF–EM profile data recorded along line 4800, Mount Sylvester area. See Figures 6 and 9 for location.*

EM field, many of the large-amplitude anomalies can be correlated on several profiles. Trends imposed by anomalies on adjacent traverses are oriented obliquely to the thrust front as are the individual magnetic fronts discussed above and displayed in Figure 6. A good example is illustrated on parallel Lines 7300 and 7400 of Figure 9, where similar topographic features were traversed. On lines of close proximity where peaks could be correlated, the trends coincide with those evident in the magnetic data.

On many profiles, one strong EM anomaly or a pair of anomalies exists to the northwest of the magnetic anomaly at the ultramafic front. The correspondence is readily observed in Figure 10, where a plot of recorded magnetic and VLF data collected along Line 4800 is shown. This northwestern Fraser filter anomaly is interpreted as reflecting the presence of a fault or sheared zone near the magnetic front, in which EM currents are preferentially channeled. Mapping of the EM anomaly associated with the magnetic front might enable mapping of the thrust fault across areas where the fault would be expected to exist but where the magnetic field is featureless.

In general, traverses showing anomalies having largest amplitude and highest frequency are located in areas of outcrop or thin drift (Figure 9). The VLF signature of bedrock becomes masked in regions of extensive conductive overburden. Therefore, in a qualitative sense, the EM field may also be used to estimate relative till thicknesses.

Conclusions

The sporadic occurrence of chromite-bearing ultramafic rocks in the Mount Sylvester map area is conceptually modelled as a series of truncated thrust fronts, several of which have been thrusted sufficiently to expose ultramafics

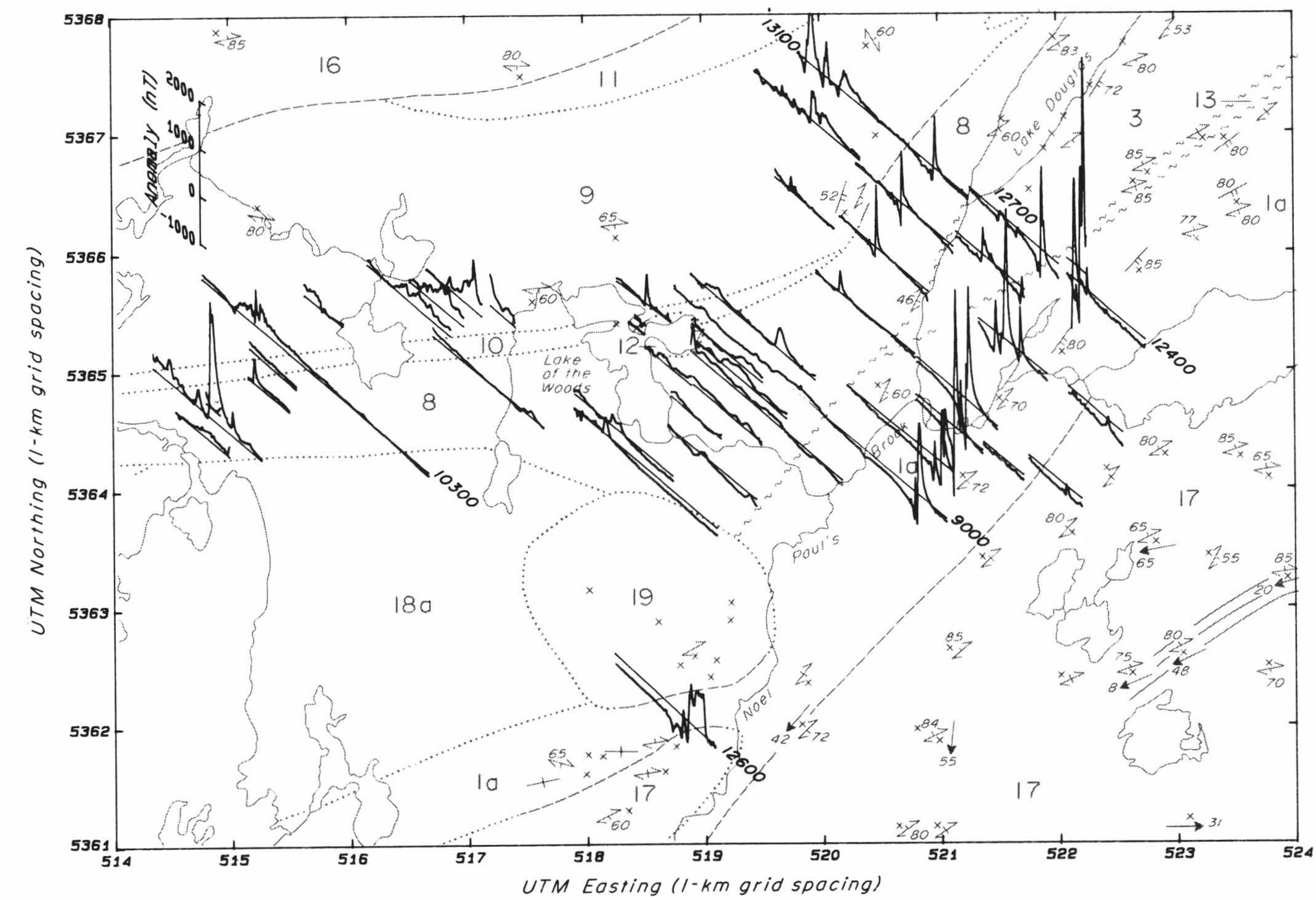


Figure 11. *Total field magnetic data recorded along traverses in the Snowshoe Pond (12A/7) map area. Geology and map unit numbers after Colman-Sadd (1987b).*

at the base of thrust sheets. Magnetic modelling of anomalies coincident with the northeast-trending thrust front indicates a southeastward dip. The present orientation may have evolved from a complex history involving tilting or shearing subsequent to emplacement.

SNOWSHOE POND

Objectives

The geophysical objectives in the Snowshoe Pond (12A/7) map area were to determine the signature of lithologic–structural features, particularly the two major shear zones that merge south of Lake Douglas (Colman-Sadd, 1987a,b, *this volume)*, and to map these features through regions of extensive drift and vegetation cover where the general strike changes from a southwestward to a westward trend.

Geology and Previous Work

The geology of the southern part of the study area consists of Middle Ordovician polydeformed clastic metasedimentary rocks (Figure 11), intruded by several granitoid phases (Colman-Sadd, 1987a,b). Rocks to the northwest comprise sedimentary, volcanic and hyperabyssal intrusive rocks of Early to Middle Ordovician and Silurian ages (Colman-Sadd, 1986, 1987a). The boundary separating rocks from the two areas, known as Noel Paul's Line (Colman-Sadd, 1986), is ill-exposed, lending uncertainty to the structural interrelationships of the two contrasting geological terranes. Noel Paul's Line is interpreted locally as a ductile shear zone (Colman-Sadd, *this volume)*.

Aeromagnetic data coverage consists of a regional survey by the Geological Survey of Canada (1968c,d) complimented by a combined, high-resolution, aeromagnetic and vertical magnetic gradient survey over the west half of the Snowshoe Pond map area and the entire Lake Ambrose (12A/10) map area to the north (Geological Survey of Canada, 1985a,b,e,f). A helicopter-borne, combined magnetic and EM survey (Aerodat Limited, 1983; Fitzpatrick, 1984) covers a gap in the recent high-resolution data for the area around Lake Douglas and overlaps with the recent high-resolution aeromagnetic data of the Geological Survey of Canada (1985a,e) to the north and west.

Access and Topography

Locations of the traverses surveyed in this study are displayed in Figure 11. Access into the surveyed area is

LEGEND (Figure 11)

SILURO-DEVONIAN

19 *Grey and pink, equigranular, medium grained, unfoliated biotite granite*

18a *Grey, moderately foliated, medium grained, porphyritic biotite granite; associated with garnet–muscovite aplite veins at its margins*

17 *Equigranular or locally megacrystic, strongly foliated, medium grained, grey or pink, biotite granite; locally mylonitic*

SILURIAN?

16 ROGERSON LAKE CONGLOMERATE: *Purple, clast-supported, polymictic conglomerate and sandstone*

ORDOVICIAN

13 *Mafic dykes; minor felsic intrusive rocks, and mafic volcanic rocks*

12 *Fine grained, dark-green gabbro*

11 *Lithic and quartz-crystal felsic tuff*

10 *Dark grey and black graphitic pelite with minor green volcanogenic sandstone beds*

9 *Volcanogenic, sedimentary rocks, rich in mafic volcanic clasts; includes laminated and thin-bedded sandstone and shale, thick-bedded sandstone and grit and unbedded conglomerate*

8 Mafic volcanic rocks; includes pillow lava, massive flows and volcanic breccia

3 *Thin-bedded and laminated phyllitic shale, siltstone and sandstone; includes unseparated limestone, graphitic shale and felsic tuff beds*

1 *Interbedded quartzite, psammite, semipelite and pelite, intruded by unseparated mafic dykes;* 1a, *includes black pyritic schist metamorphosed to greenschist and lower amphibolite facies*

SYMBOLS

Geological boundary (approximate, assumed)

Bedding, tops unknown (inclined, vertical)

Cleavage (inclined, vertical)

Lineation (age unspecified)

Exposure

Fault (assumed)

Structural trend (from aerial photographs)

provided by a logging and powerline-access road to Lake Douglas. The topography of the area consists of densely forested ridges separated by extensive bogs in lowlands.

Interpretation of Magnetic Data

The structural trends of lithologies in the study area are readily apparent from the orientations of associated magnetic anomalies on recent aeromagnetic and vertical magnetic gradient maps for the west half of the Snowshoe Pond map area (Geological Survey of Canada, 1985a,b,c,d), but much less so on older aeromagnetic maps (Geological Survey of Canada, 1968c,d). On these maps, a high magnetic ridge associated with the volcanogenic sedimentary rocks (Unit 9) and the Rogerson Lake Conglomerate (Unit 16), in the west half of the area, appears to terminate abruptly just west of Lake Douglas, and is detected again 12 km to the north in the Lake Ambrose (12A/10) map area (Geological Survey of Canada, 1968d, 1985e,f). The Aerodat (1983) survey shows many of the more detailed geophysical features observed on the ground.

The most prominent magnetic anomaly observed on the ground, illustrated along Line 9000, at about 1600 m (Figure 12), is associated with a structure that trends to the northeast. This anomalous zone was detected on several traverses (Figure 11), including Line 12700 at position 800 m (see Figure 13). The large magnitude of the anomaly and its high frequency

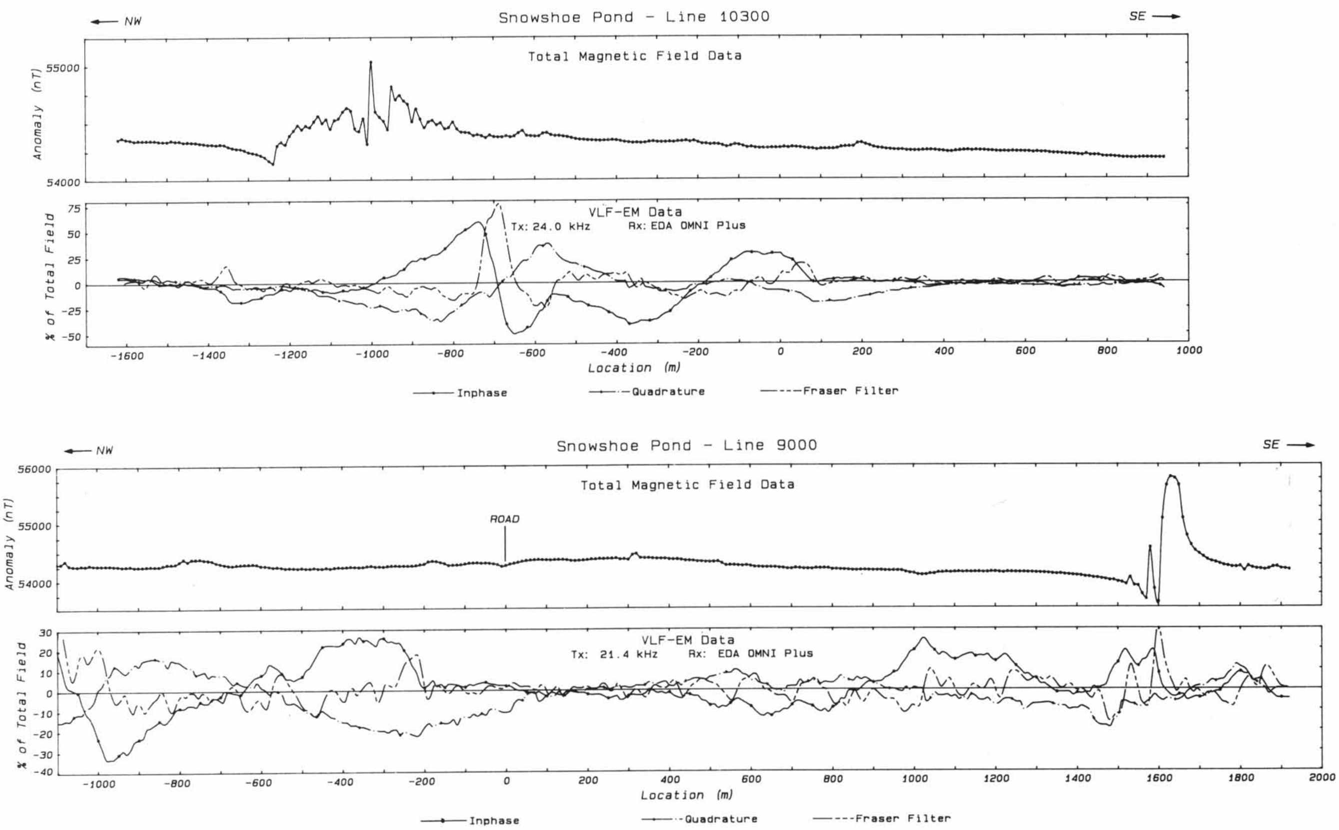


Figure 12. *Magnetic- and VLF–EM-profile data recorded along lines 9000 and 10300, Snowshoe Pond area. See Figures 11 and 14 for locations.*

content suggest the presence of a thrust fault within subunit 1a, bringing a magnetite-rich rock to very near the surface. Although outcrop along this magnetic feature is abundant, no rock types were observed other than highly deformed clastics of subunit 1a. The magnetic susceptibilities of these rocks have not been measured. Magnetic data from a helicopter-borne combined EM and magnetic survey of the Noel Paul's Brook (west) area (Aerodat Limited, 1983) indicate that this strongly magnetic zone trends southwestward to a west-trending, arcuate band of individual anomalies evident on recent high-resolution aeromagnetic maps (Geological Survey of Canada, 1985a,b), as parallel to, and south of Units 8 and 10 (Figure 11). This magnetic-anomaly linear emerges along trend on the southeastern corner of the Noel Paul's Brook map area (Geological Survey of Canada, 1985e,f), and coincides with the mapped position of highly deformed rocks of subunits 1a and 1b of Colman-Sadd (1987b).

Another prominent magnetic feature lies within Unit 8, which runs parallel to and northwest of Noel Paul's Brook (Figure 11). Individual anomalies form a lineament trending to the northeast, parallel to strike. The high-frequency peaks to the northeast suggest a near-surface, narrow magnetic layer. Anomalies defining this lineament broaden and decrease in magnitude to the southwest, such that the feature is barely discernible on Line 9000 (Figure 12). Such characteristics indicate a southward increase in source depth with final termination about 50 m northeast of Line 9000. The anomaly here may be caused by a thin lens of magnetic, cherty iron-formation, representing a depositional break within the massive mafic volcanic rocks of Unit 8. Alternatively, the feature may be caused by a mafic body, emplaced by shear or thrust faulting, as in the Mount Sylvester map area.

The small gabbro outcrops of Unit 12 (Figure 11) are uncharacteristically nonmagnetic. Two short surveys traversing exposed gabbroic rock show little magnetic contrast between the gabbros and their host rocks. Both are relatively nonmagnetic compared with the sedimentary rocks of subunit 1a. The Hungry Hill gabbro, in the Lake Ambrose map area (Kean and Jayasinghe, 1980), is similarly nonmagnetic (Geological Survey of Canada, 1985e,f), particularly in comparison with the strongly magnetic Harpoon Hill gabbro to the south (Kean, personal communication, 1988).

An anomalous magnetic zone was detected within the volcaniclastic sediments of Unit 9 northwest of its contact with Units 8 and 10 (Figure 11). The broad zone consists of several variable anomalies that may be observed on Line 10300 (Figure 12) between -1200 and -800 m and on Line 13100 (Figure 13) between -800 and -350 m. The variablity is thought to be related to alternating, fine grained sedimentary rocks and coarser grained layers rich in mafic volcanic clasts near the southeast contact of this volcanogenic sedimentary unit (Colman-Sadd, 1987b).

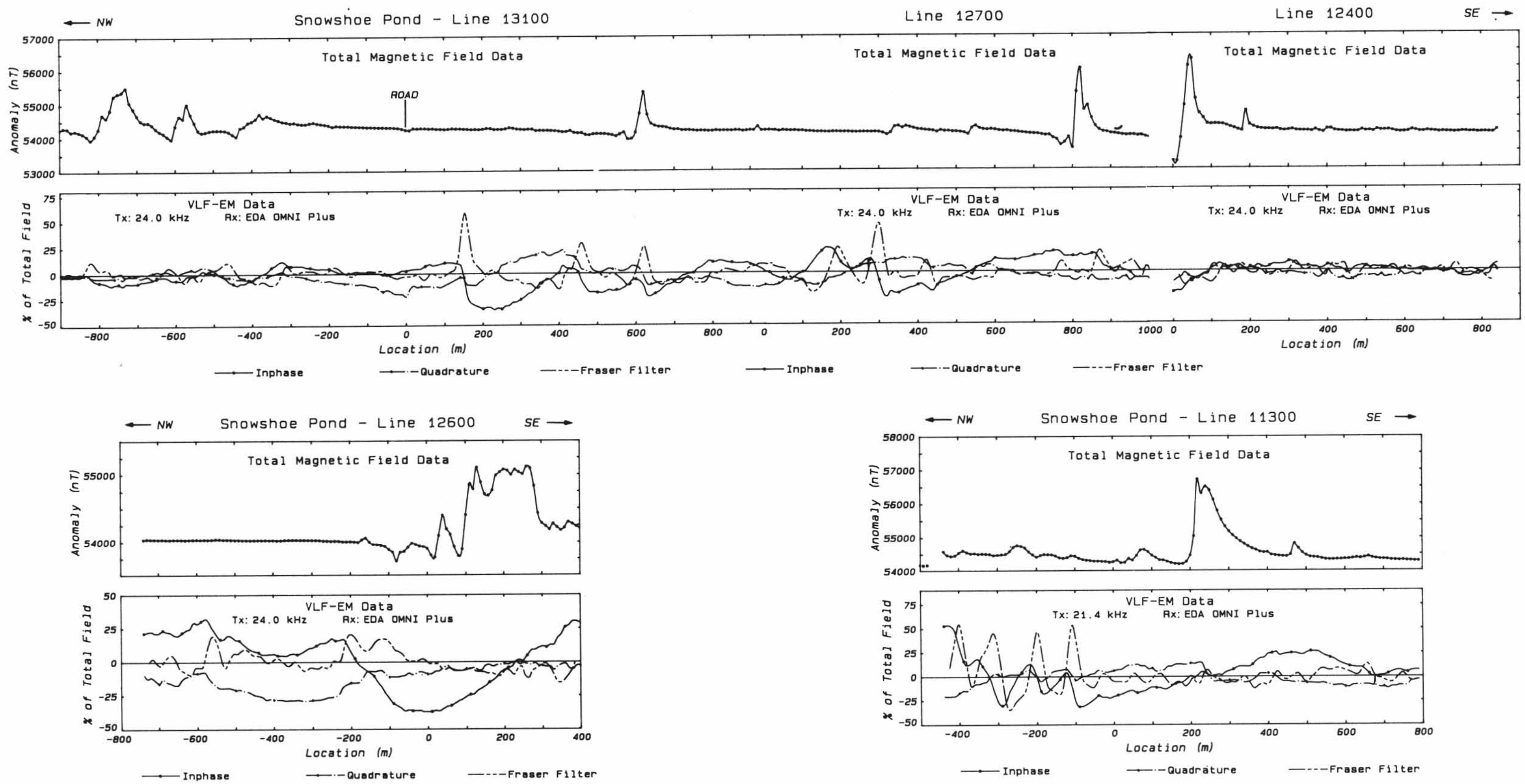


Figure 13. *Magnetic- and VLF–EM-profile data recording along lines 13100, 12700, 12400, 12600 and 11300, Snowshoe Pond area. See Figures 11 and 14 for locations.*

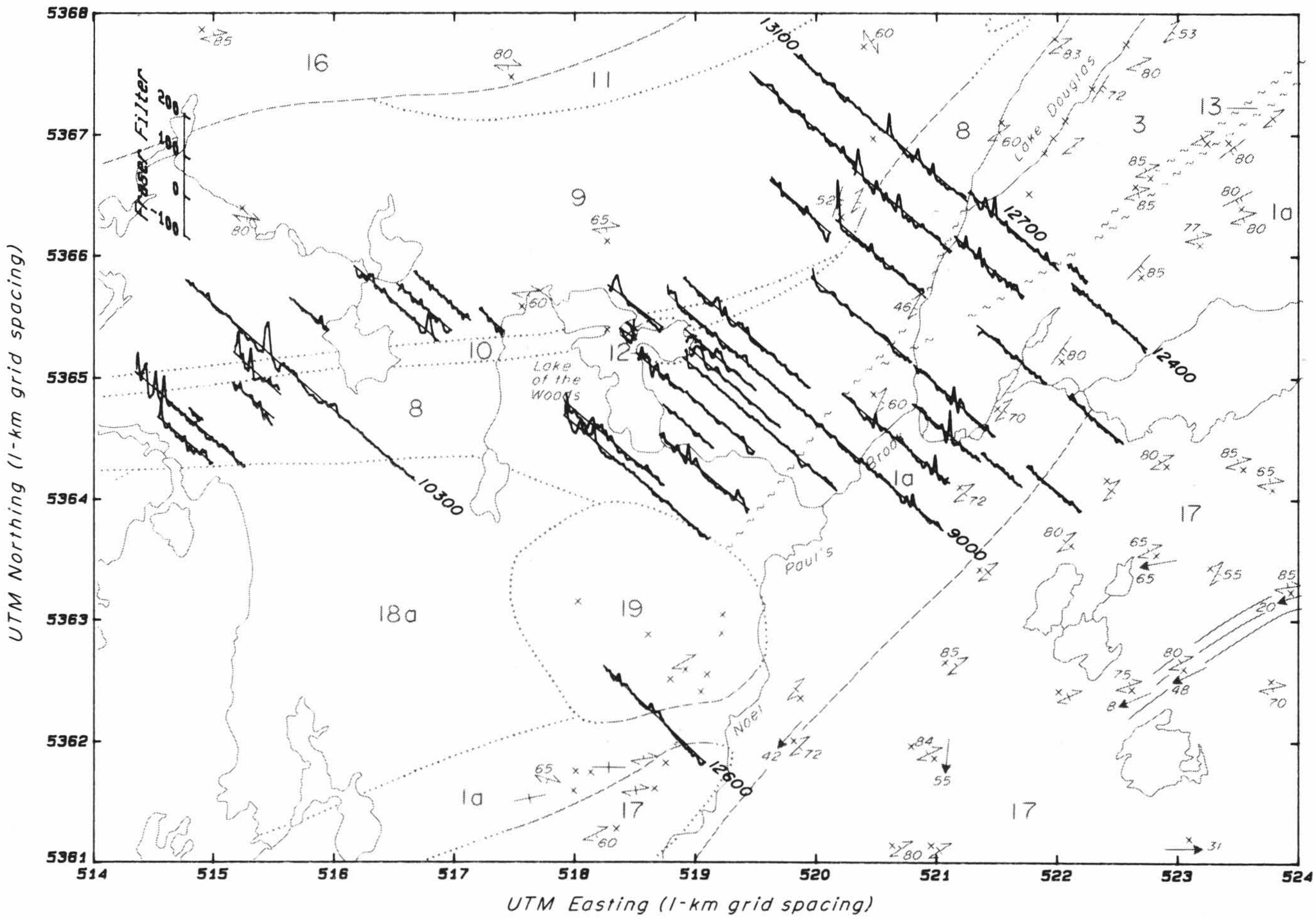


Figure 14. *Location plot of inphase Fraser filter anomalies for profiles in the Snowshoe Pond map area. Geology after Colman-Sadd (1987b). (See Figure 11 for legend and symbols.)*

Interpretation of VLF–EM Data

A major objective of the survey was to attempt to map out the positions of two major shear zones, identified geologically as coalescing in Noel Paul's Brook (Colman-Sadd, 1987a,b), using VLF–EM conductivity and to relate them to the structural geology and spatial distribution of lithologies. Unfortunately, peaks in the plot of Fraser filtered VLF inphase response (Figure 14) could not be correlated with either shear zone. Therefore, the shear is probably distributed through a wide zone, as in the Carmanville map area, and may presently be dry or lacking sufficient conductive mineral concentrations to give an anomalous halo zone.

The largest conductor observed in the surveyed area occurs at about position -700 m on Line 10300, (Figure 12), and coincides with the boundary between Units 8 and 9. This conductor has an associated large quadrature anomaly, indicating the presence of a good conductor. Figure 15 shows a pseudosection result of Karous-Hjelt filtering applied to the inphase anomaly (Karous and Hjelt, 1983). If the conductivity here arises from a fault contact, the symmetrical pseudosection contours suggest a near vertical orientation for the fault. This conductor correlates with that observed at the northwest extremity of Line 9000 (Figure 12). The conductive boundary between Units 8 and 9 can be traced for about 2 km east of Lake of the Woods (Figure 14), at which point it abruptly changes to a north-northeastward trend, and can be observed again near the 150-m mark of Line 13100 (Figure 13). On the basis of the VLF–EM signatures the boundary would be positioned about 70 m to the northwest of its mapped location. This is partly a consequence of the oblique survey orientation relative to the trend of the conductive horizon.

The four conductors on the northwest end of Line 11300 (Figure 13) coincide with the graphitic black shales of Unit 10.

The contact between undeformed granite (Unit 19), and sedimentary rocks of subunit 1a is very evident for both the magnetic and conductivity profiles (Line 12600, Figure 13). The contact is distinguished largely on its variable magnetic signature within the sediments, rather than any difference in magnetic values. On the basis of geophysical signatures, the contact between the units should be located 50 m to the northwest of its currently mapped position. The lack of outcrop near the traverse allows a sufficient degree of

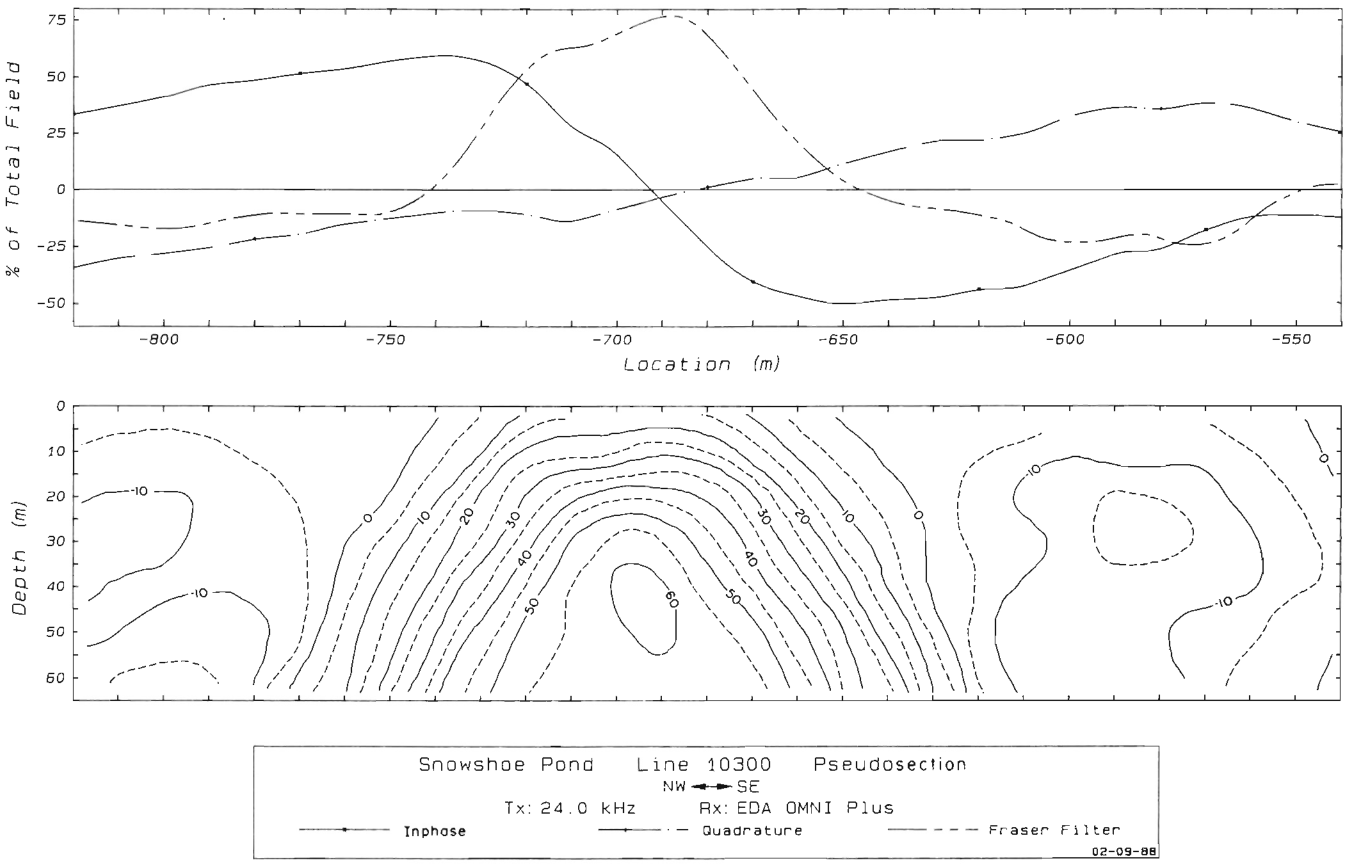


Figure 15. *Karous-Hjelt filtered pseudosection of conductivity underlying the large Fraser filter anomaly on line 10300 (see Figure 12). Symmetry of pseudosection contours indicates vertical orientation of conductor.*

freedom so that the contact position can be mapped geophysically. The southeastern end of this traverse also crosses into deformed granite (Unit 17) near the 270-m station as interpreted on the basis of an abrupt decrease in magnetic field strength. The associated magnetic anomaly appears to correlate, in relative magnitude and trend (Figure 11), with the anomalous magnetic zone detected on Line 9000.

Work has yet to be completed on orientations of contacts. However, in contrast to the asymmetric magnetic anomaly shape observed in the Mount Sylvester area, the symmetry of individual anomalies suggests a near vertical orientation of causative structures. Magnetic anomalies west of Lake of the Woods exhibit greater symmetry than those to the east, indicating that the structures to the east have a southeastward dip component.

Conclusions

1) Magnetic results of a survey conducted in the Lake Douglas area have defined several interesting anomalous zones within mapped lithologies that are otherwise undetected in surface outcrop. One zone, entirely within subunit la, is interpreted to be related to local thrust faulting. Thus, the extensive area mapped as deformed clastics of magnetic subunit la may represent structural repetition(s) of the unit. Subunit la may be repeated elsewhere by similar faults.

2) The mapped northeast-trending shear zones that converge at Noel Paul's Brook show little geophysical expression, particularly in the VLF−EM field, despite strong surficial evidence for their existence. The most plausible explanation is that the shear zones are dry and that units to either side have similar magnetic and conductive properties.

3) The abrupt change in lithologic trends from nearly east to north-northeast, which exists at Lake of the Woods is readily identified by shifts in trends of magnetic and VLF data. Units are probably cut off to the west by a northerly oriented fault.

4) Trends in the VLF Fraser filter plot follow those of the magnetic field, but generally are not as coherent in defining lithologies. Locations of zones defined by magnetic anomalies do not coincide with conductive horizons.

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