MINERAL RESOURCES BRANCH

Report on high-resolution airborne VLF-EM processing and enhancement, Targeted Geoscience Initiative, Cape Breton, Inverness, Richmond and Victoria Counties (NTS 11F/14, 11K/02, and 11K/03), South-central Cape Breton Island, Nova Scotia[1]

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[1]Contribution to the Natural Resources Canada (Geological Survey of Canada) and Nova Scotia Department of Natural Resources joint project 'Geological Mapping for Mineral Development, South-central Cape Breton Island', a Natural Resources Canada **Targeted Geoscience Initiative 2000-2003.**

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1.0 Introduction

1.1 Background

The geology of western Cape Breton Island consists of isolated Neoproterozoic to Silurian basement blocks within extensive Devonian to Carboniferous sedimentary basin sequences (e.g. Keppie, 2000). Regional structures play a dominant role in the distribution of these basement blocks and the occurrence of economic industrial mineral deposits in the Devonian-Carboniferous units. These structures include polyphase brittle and ductile faults that were active (re-activated?) from the Silurian to Mesozoic (e.g. Pascucci, 2001).

High-resolution airborne geophysical surveys exist for much of western Cape Breton Island and provide a spatially continuous data set to assist in structural and stratigraphic mapping. One particularly useful data set for mapping and exploration programs is Very Low Frequency Electromagnetic (VLF-EM) data. These data respond directly to faults and lithological variations by measuring resistivity contrasts in lithology and/or current gathering along planar features such as faults and contacts. VLF-EM data were collected by the Geological Survey of Canada (GSC) as part of Survey #260, for NTS sheets 11F/14, 11K/02 and 11K/03.

1.2 Project Scope and Objectives

The Island Targeted Geoscience Initiative (TGI) project in South-central Cape Breton Island was designed to increase geological knowledge in the area through new geological and geophysical investigations. Projects included geological mapping, detailed shallow seismic investigations, and reprocessing and enhancement of existing gravity and magnetic data.

The objective of re-processing existing data (e.g. VLF-EM) is to provide geoscientists with regional (e.g. 1:50 000 scale) map products to assist in unraveling geological problems related to

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mapping and exploration issues (e.g. industrial minerals, hydrocarbons). To this end, existing data are re-processed to remove line or other errors common in airborne electromagnetic surveys and to enhance local structural and stratigraphic trends using advanced digital processing techniques. The resulting images are generated in a geo-referenced format for inclusion into the provincial database. These products allow for easy distribution and comparison to complementary data sets.

This project is not designed to interpret VLF-EM data; however, an attempt to familiarize the reader with the VLF-EM method follows this section. In contrast to magnetic data, VLF-EM data commonly contain cultural features (e.g. power lines) and the first step in any interpretation is an evaluation of known culture in a particular area. Other phenomena related to electromagnetic theory affect VLF interpretations and the reader should be aware of these prior to using these data.

1.3 VLF-EM Survey Theory

VLF-EM surveys are commonly carried out for mineral exploration in conjunction with magnetometer or other surveys. The VLF-EM method relies on a series of high-powered radio transmitters located around the world at strategic sites. These transmitters are maintained by national military agencies for radio communication with submarine fleets and they operate over a range of 15-30 kHz (McNeill and Labson, 1991). In practical theory terms these large transmitter arrays can be simplified to a vertical grounded wire and at large distances from the transmitter the primary electromagnetic field may be considered uniform over an area of several square kilometers occurring at right angles to the transmitting station (Telford *et al.* 1988). Therefore, the VLF method is ideally suited to regional investigations where pronounced geological (structural or stratigraphic) fabrics exist.

It is important to recognize that VLF-EM data contain the measured response from two discrete geophysical phenomena (e.g. Scott, 1985). Firstly, the primary VLF-EM field (i.e. transmitter) interacts inductively with a local conductor to produce a secondary electromagnetic field. This would be the response occurring in a zone containing conductive mineral (e.g. pyrrhotite) or where a significant resistivity contrast occurs. Secondly, the primary VLF-EM field may concentrate itself along planar features oriented parallel to the transmitting station. This effect is referred to as current channeling or gathering, and represents the majority of VLF-EM anomalies encountered in nature. Since the strength of the secondary field is directly affected by the orientation of the causative feature with respect to the transmitter, there is a strong directional bias in VLF-EM anomalies. To compensate for this strong directional bias it is commonplace to survey using two transmitters, oriented roughly perpendicular to one another (i.e. Line and orthogonal stations). This has the effect of generating a secondary potential field component in most conductive features in a study area regardless of orientation.

VLF-EM surveys may record the inclination and eccentricity (e.g. inphase and quadrature) of the polarization ellipse (see Telford *et al.,* 1988) or the strength of the total electromagnetic field. The latter is typically measured as a percentage of the undisturbed primary field. Some systems also resolve vertical and horizontal quadrature components of the total field response.

2.0 Survey Parameters

2.1 Flight Specifications

The Geological Society of Canada acquired this data as part of a high-resolution aeromagnetic survey (#260) from the 7th of July to the 14th of August 1994. Sander Geophysics Ltd. acquired data using a helicopter platform flown at a nominal altitude of 150 m. Lines were spaced 300 m apart and oriented 135-315°. A total of 12 573 line km of data were acquired, including control lines.

2.2 VLF-EM Specifications

VLF-EM data were acquired using a Totem-2A receiver recording transmitting stations Cutler, Maine, and Annapolis, Maryland. "Line station" was Cutler oriented roughly parallel to geologic strike and perpendicular to flight line orientation. Unfortunately, "orthogonal station" Annapolis is oriented roughly parallel (~11°) with respect to the line station. Therefore, data for these two stations will highlight essentially the same structural and stratigraphic fabric in the study area. Total field and quadrature component data were recorded for each transmitting station.

3.0 Processing and Enhancement

3.1 Gridding

The VLF-EM data for this project were extracted from the ASCII data file for Survey #260 provided to the contractor by the Nova Scotia Department of Natural Resources and the Geological Survey of Canada for the purposes of the Cape Breton Island Targeted Geoscience Initiative. Data were stored in UTM NAD 27 format and gridded to a standard 70 m cell size, using a minimum curvature method.

3.2 Error Analysis

VLF-EM data are acquired as an ancillary data set in most surveys and, therefore, are not treated with the same quality control measures as magnetic data. In particular, VLF transmitters are shut down according to a regular schedule and this interferes with data acquisition during that period, unless more than one frequency is measured. An airborne survey is not stopped because a VLF transmitter is shut off for scheduled maintenance (e.g. once a week for Cutler, Me). Ideally two transmitting stations oriented orthogonal to one another (i.e. Line and Ortho station), with respect to the survey area and underlying geology (e.g. Keppie 2000), are recorded with the hope of having at least one station recoding at any given time. The results are blanks the data sets when the transmitters were shut down during the survey or low signal strength due to electromagnetic interference occurs. The survey contractor typically dummies out these data points by use of an arbitrary numerical constant, and they are removed prior to processing and enhancement.

VLF-EM data are not typically levelled, as are magnetic data. This manifests as significant line error in the total field data set, which includes multiple components of the electromagnetic field (e.g. cross-line). A similar error is present in the quadrature data but to a much smaller degree due to the measured component being relatively independent of adjacent lines. Line error is removed from the VLF-EM data by applying a directional high pass filter tuned to line orientation and spacing. The data generated from this filter are subtracted from the original data to generate a decorrugated or cleaned data set. Typically this filter can only be applied to the line station; however, in the case of this survey both stations are essentially parallel and generate “line station” data. These filters are applied to gridded total field and quadrature data at different stages in the processing.

3.3 Total Field Data

Table 1 contains the processing and enhancement procedure applied to the VLF-EM total field data. Several steps are required to remove artifacts that are frequently misinterpreted, such as topographic variations. These variations are typically manifested in longer wavelength anomalies and can be quantified by comparing the VLF-EM total field response to the barometric altimeter data. In this case a cut-off of 3000 m removed most of the topographic component while leaving as much geological source as possible. Other steps in the processing have been discussed earlier with the exception of combining the Line and Ortho data. Because these data sets were generated from roughly parallel transmitters they contain very similar geological signals; however, because they are independently recorded they contain independent noise components. Therefore, a summation of the Line and Ortho total field data increases the signal to noise ratio of the final total field image.

The geo-referenced colour/shaded relief image of the total field data contains some line bias, particularly where there were line gaps in one particular component (e.g. Line or Ortho). In any case, signal or features oriented parallel to flight lines (135^{o}) should not be given much interpretational weight.

3.4 Quadrature Data

Table 2 contains the processing and enhancement procedure applied to the VLF-EM quadrature data. This procedure is similar to that applied to the total field data with the exception of the Fraser Filter, to convert crossover data (e.g. di-polar) to peaks (e.g. mono-polar). Also the decorrugation filter was applied to the combined data to remove line noise whereas the total field data (Line and Ortho) were decorrugated individually. This was due to the fact that the line error was very similar in nature for the Line and Ortho quadrature data but fairly different for the Line and Ortho total field data.

3.5 Map Product Description

The final map products consist of one geo-registered total field VLF-EM image and one VLF-EM quadrature image. These images contain some similar information pertaining to lithological contacts; however, there are marked differences inherent in the data and nature of VLF-EM anomalies as discussed in Section 1.3.

The total field image is loosely analogous to a conductivity image of the study area (conductors). In general the positive anomalies (i. e. red-magenta) indicate changes in the electrical properties of the underlying lithology.

Table 1. Processing template for total field VLF-EM data for the Line and Ortho stations.

Step	Description
Extract XYZ	Raw ASCII survey file
Topographic Correction	High-pass filter with a cut-off of roughly 3000 m
Export XYZ	Short wavelength XYZ Line and Ortho data
Remove Dummies	Window XYZ data to remove null value points
Grid	70 m cell size; minimum curvature
Decorrugate	Error Grid = high-pass direction filter Remove error grid from original data
S/N Enhancement	Add Line and Ortho grids
Shaded Relief	Shading from 135° at 35° off the horizon
Geo-referenced Raster	20 m pixel size; 24-bit colour

Table 2. Processing template for the VLF-EM quadrataure data for the Line and Ortho Stations.

Step	Description
Extract XYZ	Raw ASCII survey file
Topographic Correction	High-pass filter with a cut-off of roughly 3000 m
Export XYZ	Short wavelength XYZ Line and Ortho data
Remove Dummies	Window XYZ data to remove null value points
Fraser Filter	Convert crossovers to peaks
Grid	70 m cell size; minimum curvature
S/N Enhancement	Add Line and Ortho grids
Decorrugate	Error Grid = high-pass direction filter Remove error grid from original data
Shaded Relief	Shading from 135° at 35° off the horizon
Geo-referenced Raster	20 m pixel size; 24-bit colour

The quadrature image is more closely associated with VLF-EM response due to current gathering. Therefore, it tends to highlight planar features such as faults and lithological contacts.

4.0 Conclusions and Recommendations

VLF-EM data provide a unique data set that can directly image structure and stratigraphy, which most other data sets cannot. VLF-EM total field and quadrature data image two different geophysical phenomena and Line and Ortho transmitters allow increased noise reduction and some directional enhancement. The data are complimentary and not mutually exclusive in the electrical response that they contain.

VLF-EM data are not commonly used in regional mapping and exploration, although thousands of line kilometers are collected every year. VLF-EM data contain significant geological information and compliment magnetic data interpretation. Several recommendations can be made regarding the utilization of these data:

1. Preliminary interpretations must involve an assessment of all possible culture in a study area.
2. These images are biased by transmitter orientations, which unfortunately in this case are essentially parallel. Therefore, one should not place undue interpretational bias in fabrics or features corresponding to the line orientation.
3. Lithological variations imaged by the total field data may not be apparent in pre-Carboniferous basement; however, electrical variations within Carboniferous strata are well documented (e.g. Telford *et al.,* 1988).

5.0 References

Keppie, J. D. (Compiler) 2000: Geological Map of the Province of Nova Scotia; Nova Scotia Department of Natural Resources, Minerals and Energy Branch, Map ME 2000-1, scale 1:500 000.

McNeill, J. D. and Labson, V. F. 1991: Geological mapping using VLF radio waves; *in* Electromagnetic Methods in Applied Geophysics: Volume 2, Application, Parts A and B, ed. M. N. Nabighian; Society of Exploration Geophysicists, Investigations in Geophysics No. 3, pp. 521-640.

Pascucci, V., Gibling, M. R. and Williamson, M. A. 2000: Late Paleozoic to Cenozoic history of the offshore Sydeny Basin, Atlantic Canada; Canadian Journal of Earth Sciences, v. 37, p. 1143-1165.

Scott, W. J. 1985: VLF-EM surveys at Chalk River, Ontario; Atomic Energy Commission of Canada, Technical Report AECL-9085, Paper No. 14, p. 189-212.

Telford, W. M., Geldart, L. P., Sheriff, R. E. and Keys, D. A. 1988: Applied Geophysics, Cambridge University Press, Cambridge, U.K., 860 p.

6.0 Statement of Qualifications

M. S. (Steve) King, P.Geo.

Registered Geophysicist

Education

2002:	M.Sc. - Acadia University, Wolfville, Nova Scotia
1998:	Certificate of Achievement (Economics) - Edinburgh University, U.K.
1991:	B.Sc. - Memorial University of Newfoundland, St. John's, Newfoundland

Relevant Project Experience

2002:	Consulting Geophysicist - Statia Terminals Canada Inc. - Point Tupper Project
2002:	Consulting Geophysicist - Duke Energy - Nappan Project
2001-2002:	Consulting Geophysicist - NSDNR/NRCan - Cape Breton Island, TGI Project
2000-2001:	Consulting Geophysicist - Northstar Energy Corp. - Nova Scotia Project
1997-1998:	Project Manager - RJZ Mining Inc. - Meguma Gold Project
1996-1997:	Chief Geophysicist - Archean Resources - Voisey Bay Project
1992-1996:	Consulting Geophysicist - NSDNR/NRCan Meguma Mapping Project

Research Activity

Recent research activity has focused on potential field and petrophysical investigations and their applications to mineral/petroleum exploration and regional geophysical interpretations. This work includes more than 30 published geophysical maps; numerous research papers, abstracts, and presentations; and more than 50 government assessment reports and proprietary technical reports.

Professional Memberships

The Association of Professional Engineers and Geoscientists of Newfoundland
The Association of Professional Geoscientists of Nova Scotia
The Prospectors and Developers Association of Canada
The Canadian Institute of Mining Metallurgy and Petroleum
The Atlantic Geoscience Society