MAGNETIC MINERALOGY AND SUSCEPTIBILITY OF MAGNETOSTRATIGRAPHIC / STRATIGRAPHIC SUBDIVISIONS OF THE GOLDENVILLE GROUP, EASTERN SHORE, NOVA SCOTIA

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ABSTRACT

The Meguma Group has traditionally been subdivided into the upper Halifax Formation and lower Goldenville Formation. Locally these formations have been further subdivided, prompting their elevation to Group status. Previously, subdivision in the eastern Meguma Terrane has been restricted to the Halifax Group. However, high-resolution airborne magnetic data reveal patterns that mimic known stratigraphic trends. This data can be grouped into 'magnetostratigraphic units' that suggest discernable stratigraphic packages exist in the Goldenville Group.

Current mapping was designed to evaluate stratigraphic contrasts between magnetostratigraphic units. Results suggest three stratigraphic units within the Goldenville Group. The lowermost unit, the Moose River Formation, consists of thinly interbedded grey to black slates and green metasiltstones and displays moderate magnetic response. The Tangier Formation is dominated by metasandstone cycles with predominantly black slate caps. This unit is characterized by low magnetic response. The uppermost Taylor's Head Formation is also dominated by metasandstone cycles, however fine-grained caps are predominantly green metasiltstones. Magnetic response of this unit is bimodal, characterized by alternating high and low bands.

Magnetic susceptibility data collected in the field support airborne magnetics. Susceptibility data for the Moose River Formation are moderate and uniform. Data for the Tangier Formation are generally low with few isolated higher values. The Taylor's Head Formation has bimodal susceptibility, consistent with airborne patterns. Susceptibility data indicate that the high susceptibility values occur in both metasiltstones and metasandstones. Petrographic evaluation suggests a correlation between magnetic susceptibility and opaque mineral content. The random distribution and crystal habits of opaques support a mainly metamorphic origin. Petrographic and electron microprobe data of opaques indicate magnetic minerals present in the Taylor's Head Formation include magnetite and ilmenite.

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CHAPTER 1 – INTRODUCTION

1.1 – The Meguma Supergroup

The Meguma Supergroup is a sequence of Cambrian to Ordovician aged metasedimentary rocks which were deposited in an offshore deep-sea turbiditic environment (Schenk, 1995). The Meguma Supergroup covers most of central and southern mainland Nova Scotia. Historically, the Meguma Supergroup has been subdivided into the lower metagreywacke to metaquartzite dominated Goldenville Group and the conformably overlying slate and metasiltstone dominated Halifax Group (Fletcher and Faribault, 1912; Keppie, 2000; Figure 1.1). Regional subdivisions at the formation level have been recognized in the Halifax Group. On the Eastern Shore of Nova Scotia, these formations from the structurally lowest are the Beaverbank, Cunard and Glen Brook formations (Horne et al., 2001; Horne and King, 2002). Historically, subdivisions within the Goldenville Group have been less evident however recently produced high resolution aeromagnetic maps have been used to discern three formations within the Goldenville Group. These are the Moose River, Tangier and Taylor's Head formations (Pelley et al., 2007; White et al., 2007).

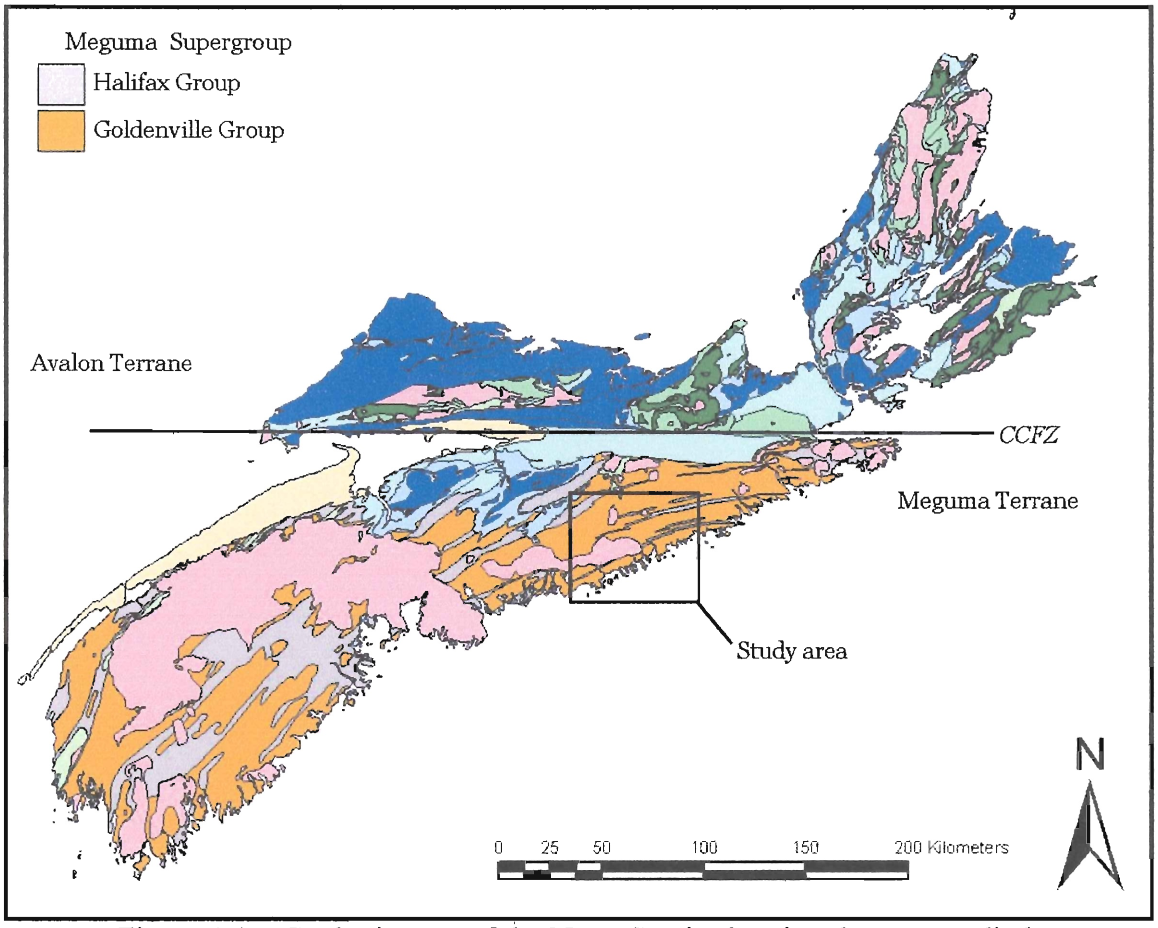

Figure 1.1 – Geologic map of the Nova Scotia showing the area studied.
After Keppie 2000.

1.2 – Magnetostratigraphy

Several generations of airborne magnetic surveys have been carried out on the Meguma Supergroup. Each generation of surveys provided progressively better resolution. The first generation of these surveys was produced by the Geologic Survey of Canada in the 1950s and 1960s. Images produced from these airborne surveys provided enough resolution to distinguish the Halifax and the Goldenville groups due to their vastly different magnetic response.

In the 1970s and 1980s a series of high resolution surveys was carried out by the Geologic Survey of Canada and SeaBright Resources, however it was not until the 1990s when these data were reprocessed to show a significant resolution increase (King and

Loncarevic, 1994). From the newly reprocessed data, linear patterns parallel to regional stratigraphy were evident suggesting that further stratigraphic subdivisions could be made. As a result, clear correlation between magnetic response and subdivisions of the Halifax Group have been well established. Although the magnetic response on the regional maps of King (1997a) does not show obvious subdivision within the Goldenville, many linear patterns extent great distances along strike. Such patterns were used by Lee (2005), who used linear magnetic patterns as stratigraphic markers for the purpose of building cross sections. In addition to the regional maps (King, 1997a) local high resolution helicopter surveys resulted in aeromagnetic maps which show great detail within the Halifax and Goldenville Groups (Anderle, 1988; Hudgins, 1997).

1.3 – Objectives

The Nova Scotia Department of Natural Resources is currently conducting a mapping project on the Eastern Shore. As part of this project packages seen in the high resolution magnetic images will be correlated with known stratigraphic subdivisions in the field. This will be accomplished by using field mapping techniques and a magnetic susceptibility survey. In order to identify the causes for the magnetic variations seen in airborne magnetic images, peterographic and microprobe analyses will be carried out.

CHAPTER 2 – STRATIGRAPHY AND AIRBORNE MAGNETICS

2.1 – Introduction

This past summer (2006), the Nova Scotia Department of Natural Resources conducted a geological mapping project on the Eastern Shore of Nova Scotia (Figure 2.1). As part of this project a transect was carried out between Centre Musquodoboit and Tangier. The primary objective was to establish a stratigraphic and structural cross section which would form the basis for further mapping. This area was chosen because of the high resolution magnetic survey in the Moose River area which showed potential for improvement on known stratigraphic subdivisions. Aeromagnetic images of the study area were used to place gross divisions between units that could then be examined lithologically. As a result, a number of stratigraphic subdivisions were identified based on discrete magnetic/ lithologic packages.

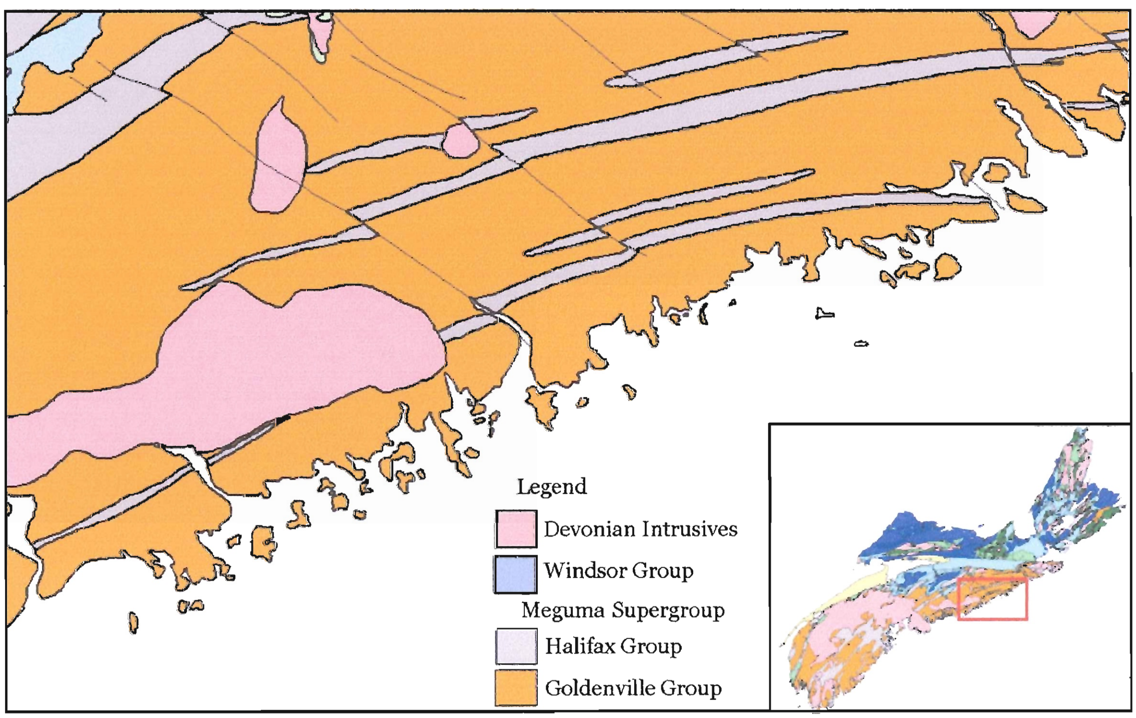

Figure 2.1 – Geologic Map of The Eastern Shore of Nova Scotia. After Keppie 2000.

2.2 – Airborne Magnetics

In Nova Scotia, airborne magnetic surveys have been used as tools to aid in regional geological mapping and in mineral exploration. Images produced from these aeromagnetic surveys cover most of the Eastern Shore of Nova Scotia. Data is collected for these surveys by an airborne magnetometer which measures the total magnetic field produced by the earth. High resolution data used in this study differ from total field data in that they are magnetic vertical gradients. Vertical gradients can be calculated from total field data or measured with a vertical gradient magnetometer. A vertical gradient magnetometer is essentially two magnetometers mounted with a constant vertical separation. The difference between the two outputs is recorded. As a result of measuring the magnetic vertical gradient, the response of magnetic bodies at depth is removed (Hood, 1965). Parallel lines are flown over an area measuring magnetic response at measured increments. A computer controlled process known as 'gridding' breaks down the data collected from flight lines and creates continuous cells of data which covers an area. The size of a data cell in real space is referred to as the resolution of the data. Surveys processed to yield small cell size are said to have high resolution. This continuous data can be contoured and/or displayed using a graduated colour scale in order to produce magnetic maps.

The first generation of magnetic surveys over Nova Scotia was flown by the Geologic Survey of Canada in the 1950s and 1960s. These surveys were flown with wide line spacings and at a high altitude so resolution was at low level relative to more recent surveys. The data from these surveys were used to produce a series of histograms and regional contour images of the total magnetic field over an area (Cameron and Hood, 1975). These histograms and images were used for discerning regional geologic boundaries (example. Halifax – Goldenville boundary).

In the 1980s, second generation total field and magnetic vertical gradient surveys were being flown by the Geologic Survey of Canada and several private mining companies. These surveys were flown over concentrated areas and used both smaller line spacings of 300-400m and lower altitudes to achieve vastly better resolution. However it was not until 1997 that King processed and enhanced the vertical gradient data and produced a series of 1:50 000 scale second vertical derivative maps for the Nova Scotia Department of Natural Resources (Figure 2.2). Methods of enhancement included noise reduction, derivative calculation, and shaded relief presentation (King and Loncarevic, 1994). The detail visible in these new images was vastly superior to that of older versions. These images can aid in detailed mapping, and can be used to distinguish stratigraphic subdivisions within Meguma Supergroup. Horne et al. (2000) examined the differences in the magnetic response of the Cunard and Glen Brook formations in the Wittenburg Mountain area. Also, from these images we can see that within the previously undivided Goldenville, there are zones of high and low magnetic response. White et al. (2006) examined the correlation of aeromagnetic data and subdivisions of the Goldenville Group in southwestern Nova Scotia. Boundaries of intrusive rocks are evident in these images. Structures like folds and faults can also be seen.

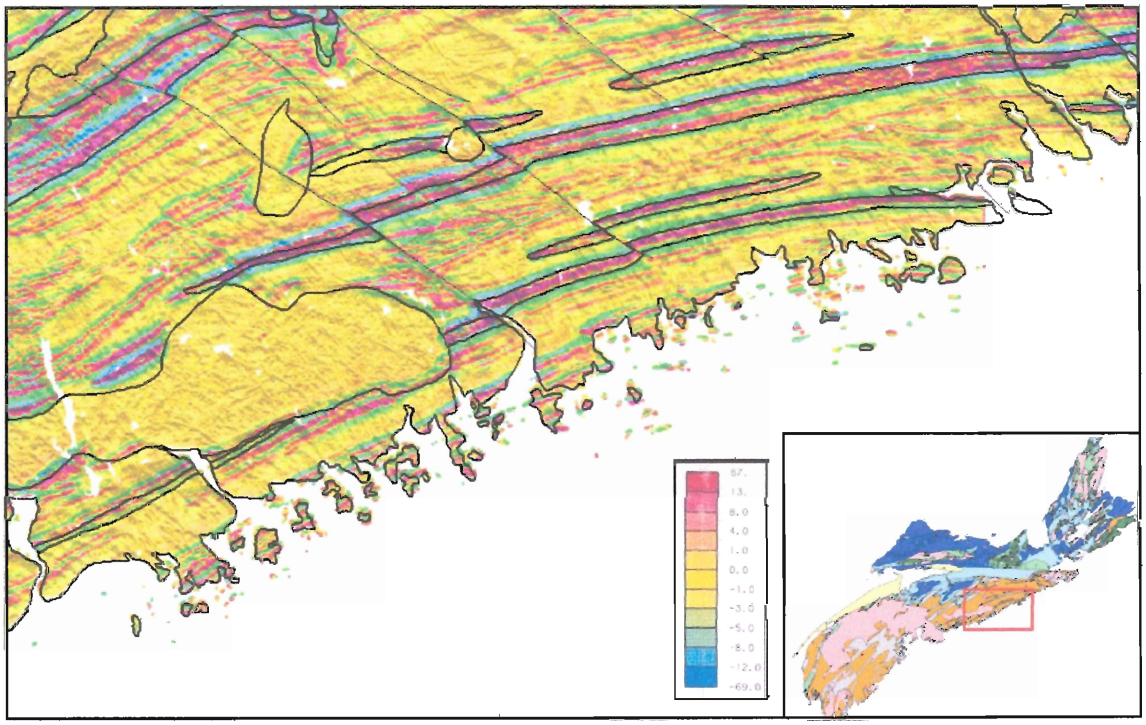

Figure 2.2 – Second vertical derivative aeromagnetic image of the Eastern Shore of Nova Scotia. After King 1997a. Lithologic contacts after Keppie 2000.

In addition to the regional 1:50 000 scale maps, several helicopter and ground magnetic surveys have been conducted within the Meguma Supergroup. Two helicopter surveys within the study area were helpful in that they provided extremely high resolution images over the Meguma Supergroup. The first is a helicopter – borne survey of the Moose River Gold Mines area. The second is a combination helicopter and ground survey of the western section of Caribou Gold Mines.

In 1988 Aerodat Limited was contracted to fly a commercial airborne survey by Wesminster Canada Ltd. as a tool for gold exploration (King, 1997b). The survey covered a concentrated area over the Touquoy zone of the Moose River Gold Mines which is entirely within the Goldenville Group. The survey was flown by helicopter and data was collected at a low altitude with a line spacing of 100m. The data was reprocessed and enhanced by King (1997b). Techniques for enhancement included noise reduction, derivative calculation and shaded relief presentation. From the image produced by King (Figure 2.3), several magnetostratigraphic units could be resolved within the Goldenville Group in this area. Also in 1988, Aerodat carried out a similar survey for Cobequid Resources Ltd. This survey was also used for an exploration tool and was focused over the western area of the Caribou Gold Mines (Figure 2.4). This survey was carried out at an average altitude of 60m and a line spacing of 100m (Anderle, 1988). This survey did collect some data over the Goldenville Group however it was primarily over rocks of the Halifax Group showing high resolution detail of the Cunard and Beaverbank Formations.

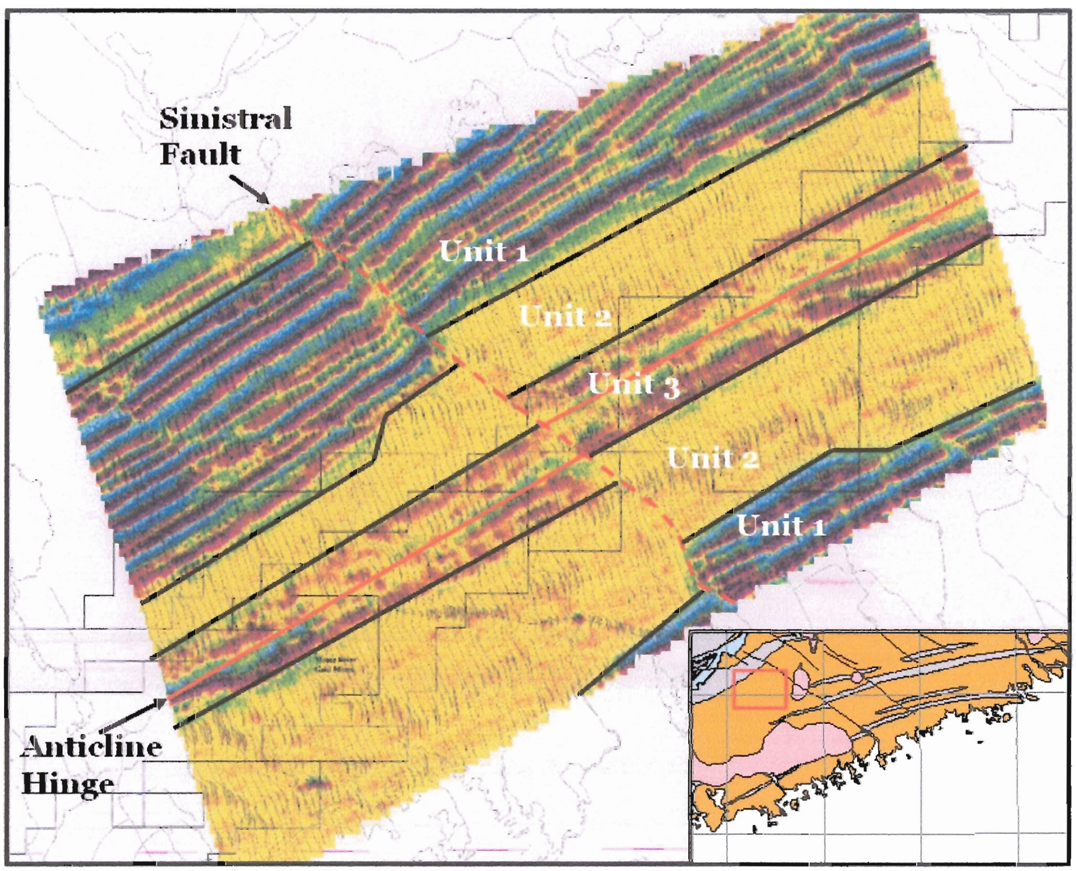

Figure 2.3 – High resolution second derivative aeromagnetic image of the Moose River Gold Mines area produced by King. After Hudgins 1997.

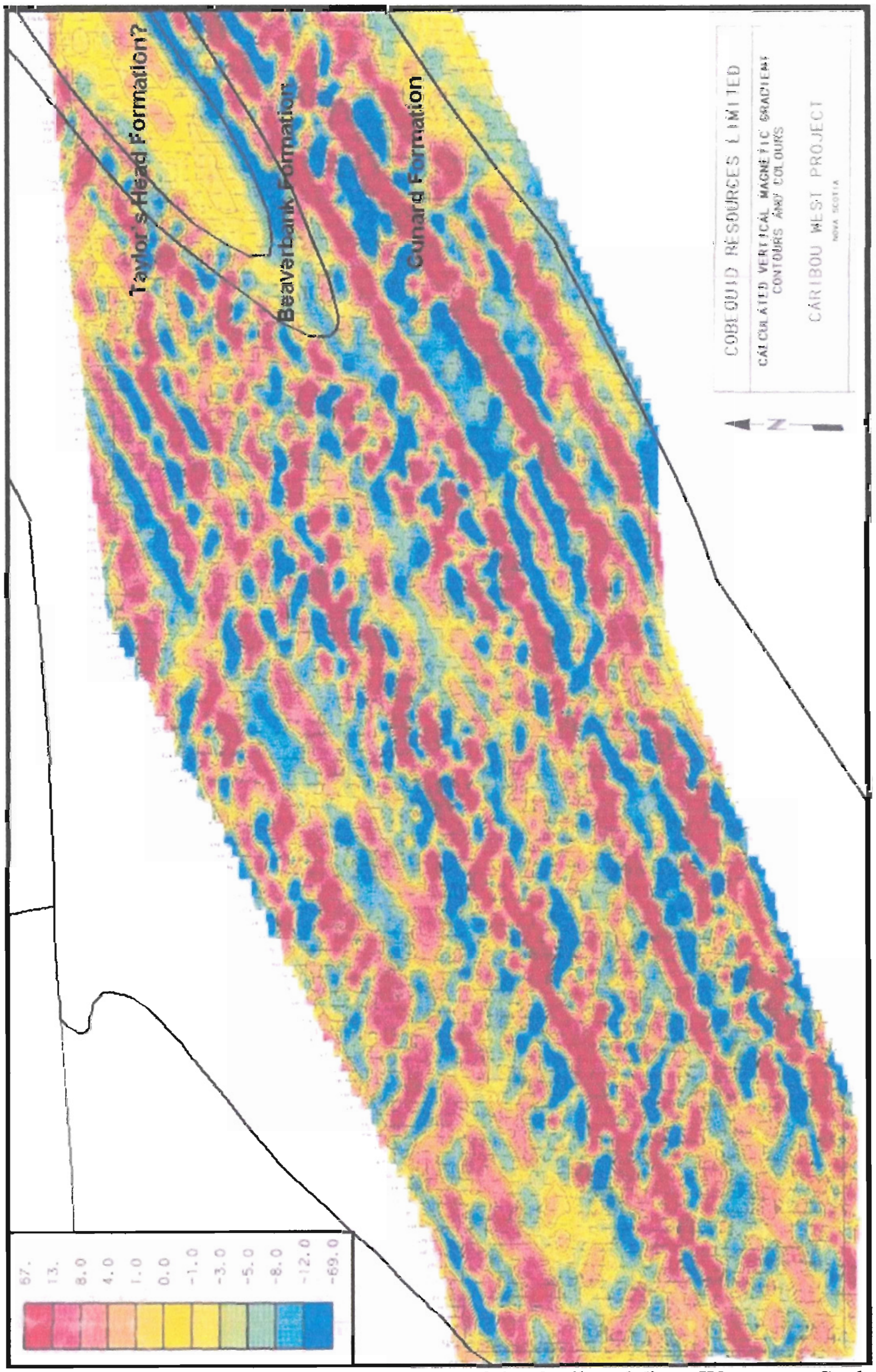

Figure 2.4 – Calculated vertical gradient map of the Caribou Mines West area. Scale in Nanoteslas per meter. After Anderle, 1988. Contacts From Horne 2007.

2.3 – Detailed Stratigraphy

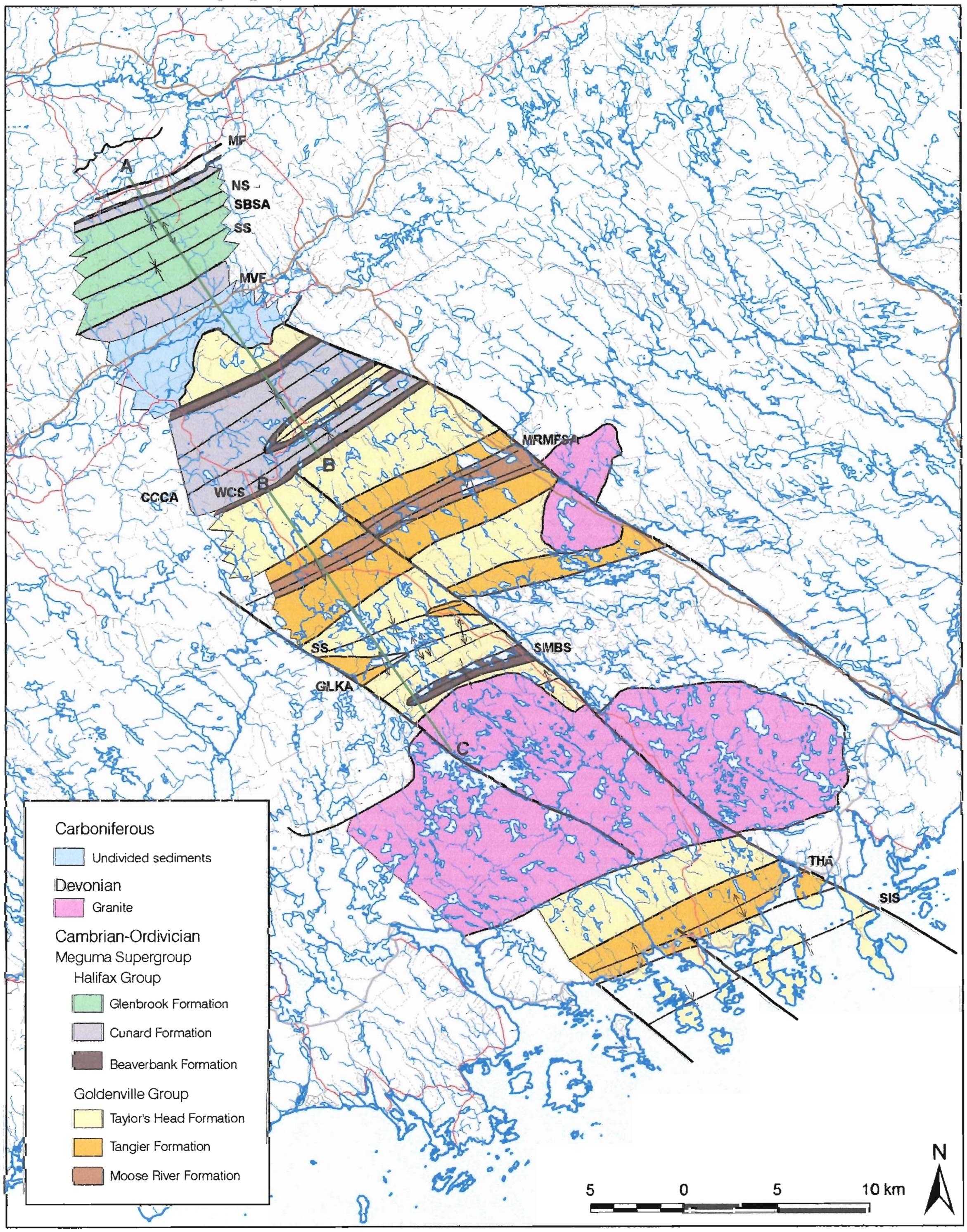

Figure 2.5 – Geological map of Study area including newly defined subdivisions of the Goldenville Group. From Horne 2007.

The Cambrian – Ordovician aged Meguma Supergroup is the dominant rock group within the study area (Figure 2.5). The Halifax Group has been subdivided into the Cunard, and Glen Brook Formations (Horne et al., 2000) within Wittenburg Mountain which is located at the northern margin of the study area. Current mapping indicates the presence of the Beaverbank Formation at the base of the Halifax Group in the Caribou area. The Goldenville Group had not previously been subdivided; however current work (Horne and Pelley, 2006) indicate that within the Goldenville there are three distinct lithologic units: The Moose River Formation, the Tangier Formation and the Taylor's Head Formation.

The Halifax Group

2.3.1 – The Glen Brook Formation

Figure 2.6 – Photograph of the Glen Brook Formation. Photo by R. Horne, 2005.

Stratigraphically, the highest formation in the Halifax Group is the Glen Brook Formation (Figure 2.6). Within the study area the Glen Brook Formation consists of banded green to grey metasiltstones finely interbedded with grey to black slates. Planar laminations and cross laminations are common in this unit. A few isolated metasandstone beds occur. Sulphides are generally absent in this formation. Geographically, the Glen Brook Formation is restricted to Wittenburg Mountain. Magnetically, the Glen Brook Formation is characterized by consistent low response.

2.3.2 – The Cunard Formation

The Cunard Formation which occurs conformably below the Glen Brook Formation was identified in the Wittenburg Mountain area (Horne et al., 2000) in the Caribou Synclinorium and the St Mary's Bay Syncline (Figure 2.5). The Cunard consists of finely laminated black slates interbedded with variable amounts of laminated green to grey metasiltstones and fine metasandstones. Bedding thicknesses in this unit are generally between one centimeter and one decimeter. Throughout the Cunard Formation there was abundant visible secondary pyrrhotite and pyrite. Sulphide minerals were more abundant in the metasiltstone beds. Figure 2.4 shows the magnetic response of the Cunard Formation in the Caribou area. The magnetic response of this unit is elevated relative to the overlying Glen Brook and underlying Beaverbank Formations. Also from figure 2.4 we can see alternating bands of high and low magnetic response (red and blue in color) which run parallel to regional stratigraphy. Ground truthing based on this survey may elude to further subdivision of the Cunard Formation.

2.3.3 – The Beaverbank Formation

The basal unit of the Halifax Group is the Beaverbank Formation. Within the study area the Beaverbank Formation was identified in the Caribou Synclinorium and St Mary's Bay Syncline. This unit consists of grey to black slates interbedded with minor

Figure 2.7 – Photograph of the Beaverbank Formation. Photo by R. Horne 2006.

laminated metasiltstone layers. Locally, thin brown coticule layers are common (Figure 2.7).

Bedding in this formation is on the centimeter to decimeter scale. The magnetic response of the Beaverbank Formation is generally consistent and low relative to the Cunard Formation. Magnetically the Beaverbank unit is elevated relative to the underlying Goldenville Group.

The Goldenville Group

2.3.4 – The Taylor's Head Formation

The Taylor's Head Formation (Figure 2.8) is the stratigraphically highest unit of the Goldenville Group. This unit is well exposed along the coast of Taylor's Head where it was studied in detail by Waldron and Jenson (1985) and in the Scraggy Lake Area. The

Taylor's Head Formation is dominantly comprised of metasandstone cycles. These cycles are comprised of a coarse grained base (metasandstone) and fine grained (green metasiltstone) tops. Thicknesses of these cycles vary significantly from a few centimeters to several meters. Fine conglomerates occur locally at the base of some of these cycles. Other local features observed in this unit include planar laminations, sand volcanoes and ripple marks. Secondary pyrite crystals up to 2cm length are visible throughout this formation. In some locations pyrite crystals were abundant.

Figure 2.8 – Photograph of the Taylor's Head Formation. Photo by R. Horne 2006.

The magnetics of the Taylor's Head Formation are bimodal. Across this formation alternating bands of high and low response are seen at a 100m scale which correlates with magnetic unit one (Figure 2.3).

2.3.5 – The Tangier Formation

The Tangier Formation which occurs below the Taylor's Head Formation is well exposed on the southern section of the Tangier River and on the limbs of the Moose River – Beaverdam – Fifteen Mile River Anticline. With the exception of the Tangier River, this unit is poorly exposed throughout much of the study area. This unit is dominated by thick metasandstone cycles much like the overlying Taylor's Head Formation. These thick cycles consist of massive metasandstones bases with grey to black laminated slates (Figure 2.9). These cycles are on the scale of a few centimeters to several meters in thickness.

Figure 2.9 – Photograph of black slates from the Tangier Formation. Photo by R. Horne 2006.

Magnetically, the Tangier Formation has a consistent low response which contrasts greatly with the overlying Taylor's Head Formation (Figure 2.3).

2.3.6 – The Moose River Formation

The Moose River Formation is the lowest visible stratigraphic unit in the Goldenville Group. The core shown in Figure 2.10 is from the Touquoy zone at the Moose River Gold District, it is however representative of the unit. Within the study area this Formation only occurs in the hinge zone of Moose River – Beaverdam – Fifteen Mile River Anticline. This Formation is host to the Touquoy deposit of the Moose River Gold District which lies within the study area. This unit consists of thick intervals of grey to black slate and grey to green metasiltstone. The scale of bedding thickness is a few centimeter to decimeters in this formation. Disseminated sulphide including pyrrhotite is seen throughout this Formation.

Figure 2.10 – Photograph of drill core from the Moose River Formation. Photo by R. Horne 2006.

Magnetically this unit is characterized by a 'mottled' response which is intermediate in magnitude relative to the rest of the Goldenville Group (Figure 2.3).

2.3.7 - Structure

The structure of the Meguma Supergroup in the study area is dominated by kilometer scale northeast trending box-type anticlinoriums and synclinoriums with steep dipping limbs. Locally second order (100 meter scale) and third order folds are common. Well-developed fine, continuous cleavage in slates and pressure solution cleavage in sandstones is visible throughout the study area. A system of northwest trending oblique (sinistral strike-slip) faults offset rocks within the study area. These faults are easily identified within the regional magnetic maps as offsetting otherwise linear magnetic patterns (Figure 2.2). A series of Devonian aged plutons have intruded the study area placing some of the studied rocks in a contact aureole. Plutons within the study area include the Musquodoboit Batholith and the River Lake Pluton. Plutonic rocks can easily been seen in regional magnetic maps (Figure 2.2). Throughout the study area millimeter to meter scale quartz veins are common particularly in the hinge zones or regional scale folds.

CHAPTER 3 – MAGNETIC SUSCEPTIBILITY

3.1 – Introduction

In conjunction with the current Nova Scotia Department of Natural Resources Eastern Shore geological mapping project, magnetic susceptibility data was acquired at all outcrops. During the 2006 field season 3500 measurements were collected from more than 250 locations within all units of the Halifax and Goldenville groups. These locations fall within NSDNR map sheets 11D10, 11D15, 11E02 and 11E03. The main objective in collecting this type of data is to correlate anomalies from regional scale aeromagnetic surveys with outcrop scale susceptibility measurements.

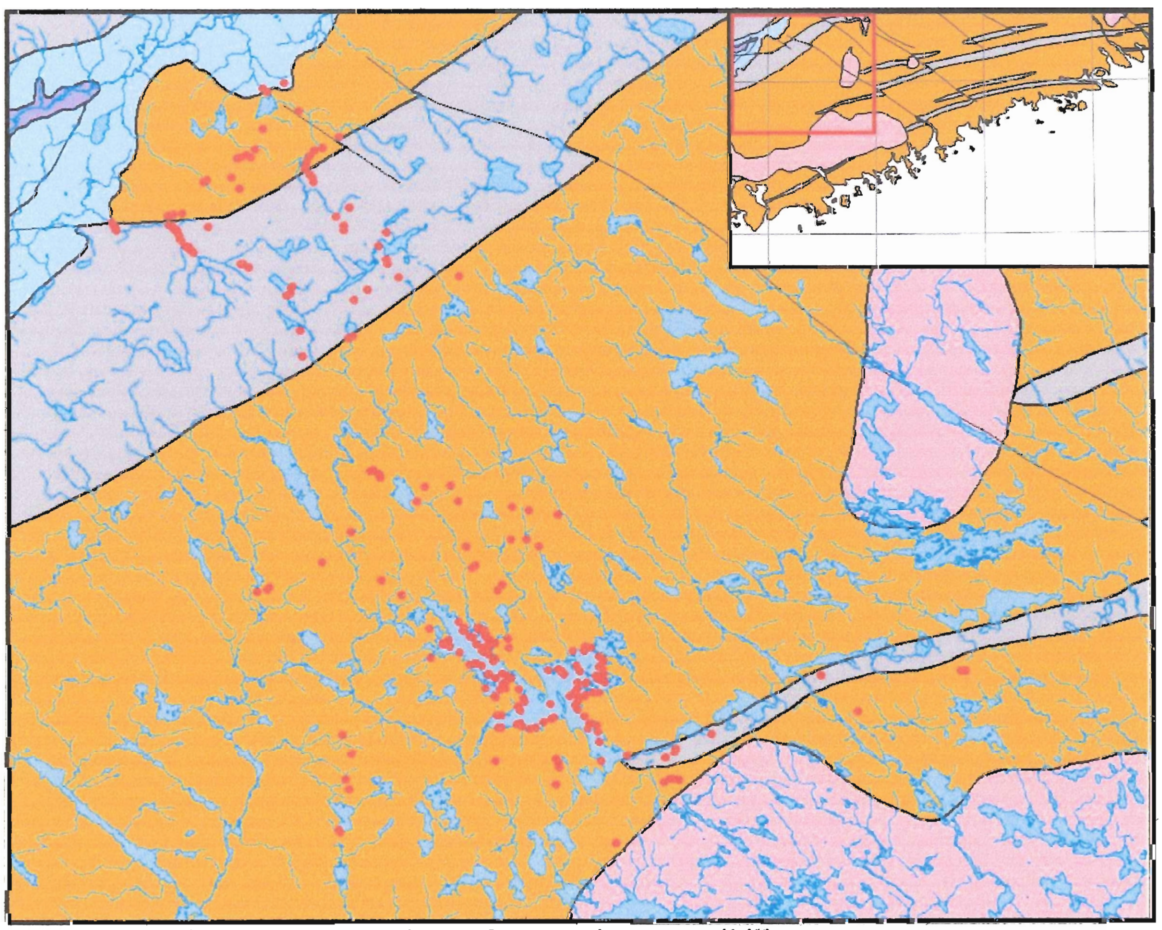

Figure 3.1 – Locations of magnetic susceptibility measurements.

Susceptibility data is commonly used in magnetic modeling, in this case the data was collected as a method to quantify magnetics at the outcrop scale and to evaluatethe magnetic character with respect to stratigraphy at various scales.

Magnetic susceptibility is the property of a material which determines of the magnetic field induced in the presence of an applied magnetic field. It is expressed by:

$$J_I = kH \pm J_R$$

Where J_I is the induced magnetic response, H is an applied magnetizing force; J_R is the intensity of remnant magnetization; and k is magnetic susceptibility or the degree to which a material can be magnetized (Nagata, 1961; King, 1997c). J_I, H and J_R all have units of Amperes per meter (A/m) and thus k is dimensionless (King, 1997c).

Magnetic susceptibility provides a non-intrusive, *in situ* measure of the magnetic mineralogy of an outcrop taking into account the abundance and type of magnetic minerals and the size and orientation of magnetic grains/crystals (King, 1997c). Abundance and size of magnetic minerals increase magnetic susceptibility through increasing the absolute volume of magnetic material in a sample. The types of magnetic minerals present effect susceptibility measurements because each mineral has its own characteristic susceptibility. Orientation of grains/crystals effect susceptibility data because if the magnetic minerals of rock are strongly aligned, an isotropic magnetic fabric can be seen in susceptibility measurements.

3.2 – Data Collection

Magnetic Susceptibility data is collected in the field using a portable hand-held meter. The meter used in this study is the Exploranium KT-9 Kappameter. The KT-9 measures the magnetic susceptibility of a volume of rocks approximately equal to 452 cm^3 which represents a hemisphere with a radius of 6cm about the end of the meter (King, 1997c). The sensitivity of the meter is $1x10^{-5}$ and thus the meter can be used to measure small volumes of magnetic minerals such as magnetite, titanomagnetite, illmenite and pyrrhotite.

Readings were taken by first examining an outcrop and determining the orientation of exposure (with respect to bedding and cleavage). Outcrops were traversed perpendicular to stratigraphy except where exposure was dominantly in the bedding parallel direction. Measurements were taken on average every 10 to 20 cm. Where outcrops were thinly bedded or strongly heterogeneous sample spacing was reduced. The date and weather were recorded followed by the station number (station locations were indicated on airphotos or using GPS co-ordinates). The lithology and stratigraphic formation were also noted. Because of the effect of weathering on susceptibility measurements, the overall weathering of the outcrop was quantified using a scale of 1 to 4 (1: little to no weathering; 4: heavy weathering). The approximate orientation between the KT-9 Kappameter with respect to bedding and/or cleavage was recorded in order to gather consistent data and minimize the observed effects of magnetic isotropy. The orientation of the meter was kept consistent over an outcrop (limited by surface irregularities).

3.3 – Results

Refer to Appendix A for complete data set. Magnetic susceptibility data were sorted on a formation by formation basis. This was done by correlating sample locations with the magnetostratigraphic packages identified in chapter 2. After sorting, statistics for each of the units were calculated including arithmetic mean and standard deviation. The mean for each unit represents the average value of the magnetic susceptibility for that entire lithologic unit. The standard deviation quantifies the variability in the data within each unit.

Group	Formation	No. of Samples	Average (k)	Maximum (k)	Minimum (k)	Standard Deviation
Halifax Group	Cunard Formation	493	0.31	7.01	0.00	0.735
	Beaverbank Formation	131	0.54	1.40	0.07	0.303
Goldenville Group	Taylor's Head Formation	1074	1.91	72.50	0.00	4.735
	Tangier Formation	274	0.06	0.65	0.00	0.101
	Moose River Formation	155	0.21	0.52	0.00	0.117

Table 3.1 – Table displaying magnetic susceptibility statistics for each lithologic unit.

For each of the lithologic units frequency histograms were constructed. Histograms are useful for displaying magnetic susceptibility data because each plot has a unique position and distribution showing the magnetic 'character' of each unit. The x-axis scale in these histograms was chosen to amplify the differences between each formation seen in the highest k values.

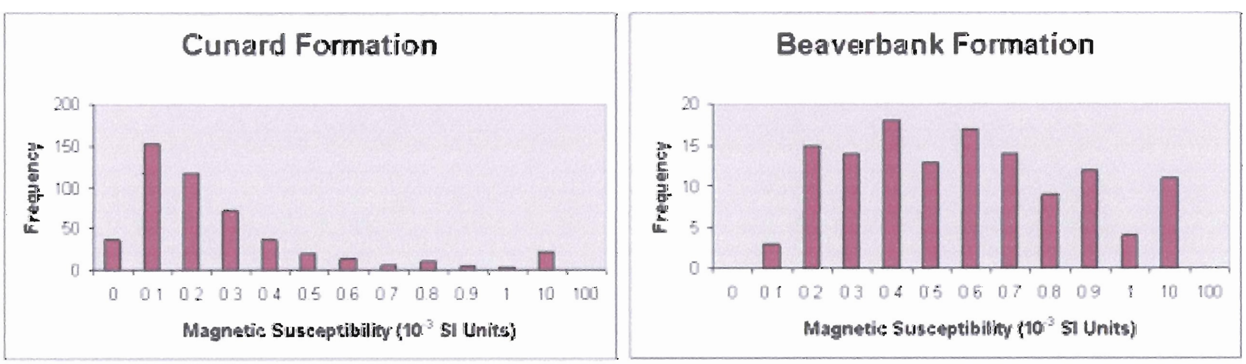

Figure 3.2 – Magnetic Susceptibility histograms for the Cunard and Beaverbank Formations.

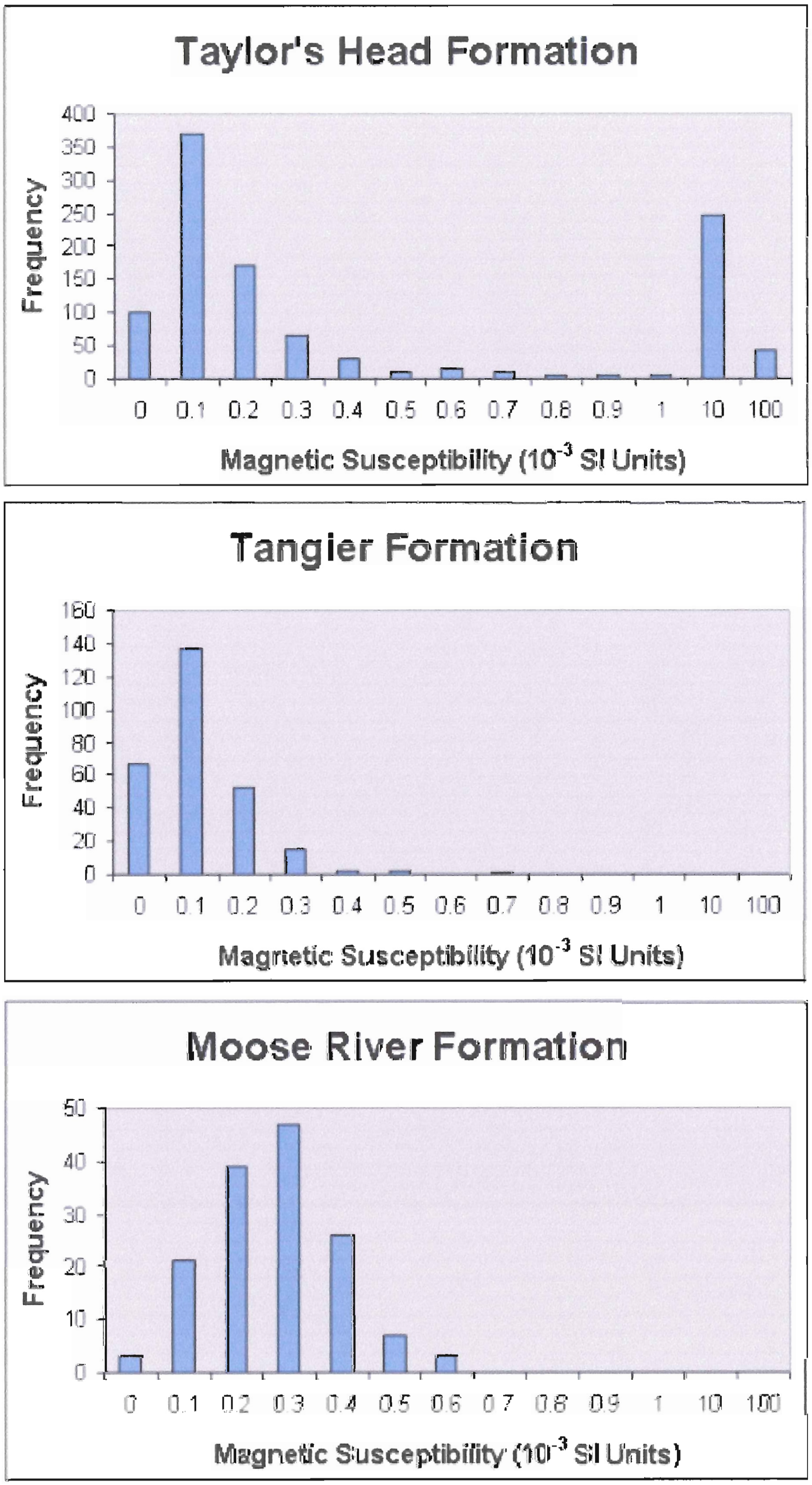

Figure 3.3 – Magnetic susceptibility histograms for each lithologic units of the Goldenville Group.

Histograms of susceptibility data for the Cunard and Beaverbank units are shown for comparison (Figure 3.2). The Cunard Formation is characterized by a broad peak centered on the 0.1 to 0.2 area. The peak decreases in both directions with a slight increase near the 10 to 100 area. The basal Beaverbank Formation has a broad plot with a sharp increase at 0.1 and a sharp decrease at 10. From field observations, variance in the magnetic susceptibility of the Halifax Group is caused by varying amounts of pyrrhotite (Schwarz and McGrath, 1974).

3.3.1 – The Taylor's Head Formation

The susceptibility values of the Taylor's Head Formation are bimodal. There are two distinct peaks; the lower peak is centered about 0.1 (10^{-3} SI Units) and a second, higher peak is centered about 10 (10^{-3} SI Units). There are virtually no intermediate values occurring between the two peaks. Measured susceptibility values from the Taylor's Head Formation were as high as 72.50 (10^{-3} SI Units), two orders of magnitude greater than the highest value from either the Moose River or Tangier formations.

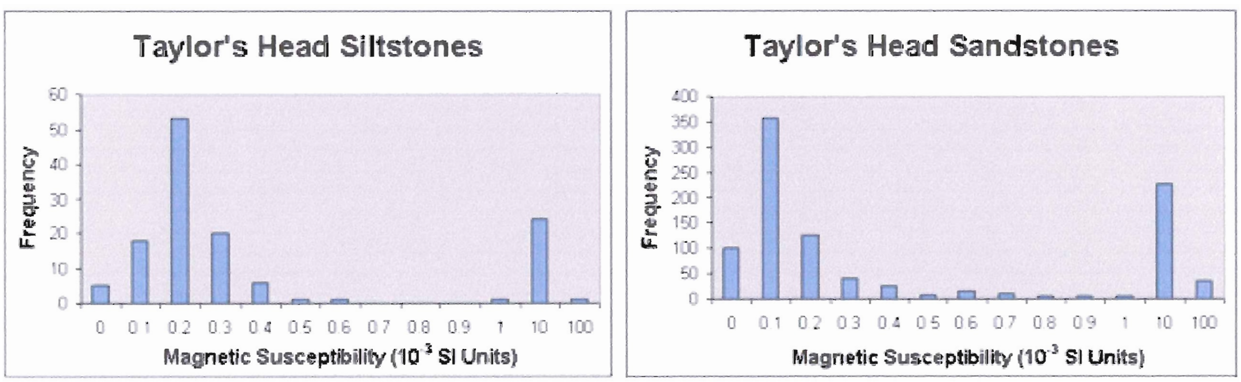

Figure 3.4 – Magnetic susceptibility histograms for siltstones and sandstones for the Taylor's Head Formation.

From field collection of these data it is evident that high and low susceptibility values correspond with bands of high and low magnetic response. Magnetic susceptibility values are affected by both the abundance and grain size of magnetic minerals. Figure 3.4 was prepared to assess whether bands of high and low magnetic character corresponded with changes in grain size. From Figure 3.4 it is clear that high and low susceptibility values occur in both the sandstones and siltstones of the Taylor's Head Formation.

3.3.2 – The Tangier Formation

The Tangier Formation's histogram is characterized by one narrow peak. Susceptibility values for this unit were centered on 0.1 (10^{-3} SI Units). Most of the data collected from this unit fell below 0.4 (10^{-3} SI Units) and higher values were rare.

3.3.2 – The Moose River Formation

The histogram for the Moose River Formation is characterized by a single broad peak. Values in this unit were generally elevated relative to the overlying Tangier and the lowest peak of the Taylor's Head. This peak is centered over the 0.2 to 0.4 (10^{-3} SI Units) area with no values occurring greater than 0.6 (10^{-3} SI Units).

CHAPTER 4 – MAGNETIC MINERALOGY

4.1 – Introduction

The magnetic response of each of the outlined magnetostratigraphic units is due to the presence and/or absence of magnetic minerals. In order to assess the causes of the magnetic response of each unit, detailed petrographic studies were carried out. The studies consisted of sampling each of the units based on lithology and magnetic susceptibility. Thirty two polished thin sections were prepared from rocks samples collected in the field. Each sample was examined in both transmitted and reflected light. Because the majority of common magnetic minerals are opaque, special care was taken to assess the number of opaque phases and the grain size/abundance of each phase. After each opaque phase was characterized, samples were brought to the electron microprobe at Dalhousie University where detailed chemical analysis of each opaque phase was taken.

4.2 – Petrography

Table 4.1 was prepared as an index and initial assessment for each of the polished thin sections. Each slide was examined based on its overall percentage of opaque minerals, the number of opaque phases present and grain size. Each of these factors was compared with the stratigraphic unit to which each sample was collected from. Note that the Taylor's Head formation is heavily favored in number of thin sections. This is because the magnetic response and magnetic susceptibility of the Moose River Formation is caused by variable amounts of pyrrhotite which is seen in the field. Pyrrhotite is common throughout the Moose River Formation. In the field it was noted that the magnetic susceptibility of each sample was approximately proportional to the pyrrhotite content.

Sample #	Rock Unit	Susceptibility	% Opaques	Opaque Phases	Grain Size
D15-045	Taylors Head	42.70	5%	at least 3	Cgl
D15-099a	Taylors Head	30.00	5%	at least 2	Cgl
D15-022	Taylors Head	6.01	2%	3	Coarse sand
D15-016	Taylors Head	1.12	0-1%	2	Fine sand
D15-141	Tangier	0.20	0-1%	2	Fine sand
D15-124	Taylors Head	0.20	0-1%	at least 2	Fine sand
D15-020	Taylors Head	0.07	0-1%	3	Silt
D15-097	Tangier	0.04	1-2%	1 to 2	Sand
D15-105	Tangier	0.03	0-1%	2 to 3	Sand
D15-032	Taylors Head	0.02	1-2%	2	Sand

Table 4.1 – Sample (10 of 32) of index chart for polished thin sections. Susceptibility values are in 10^{-3} SI Units. Full chart in Appendix B.

The Tangier Formation was studied less intensively because of its limited exposure. However both the Taylor's Head and Tangier formations contained metasandstone packages which look quite similar in the field. Because the Taylor's Head formation contained sandstone samples with very low susceptibility, these samples were deemed to contain little to no magnetic minerals. The Tangier Formation had low magnetic susceptibility throughout and thus low susceptibility samples from the Taylor's Head Formation were taken as representative for the Tangier with respect to magnetic mineral content. After indexing each sample, slides were further examined and photographs were taken of significant opaque phase minerals in both transmitted and reflected light.

Initial observations yielded a number of opaque mineral phases. It was noted that some phases which were abundant in high susceptibility samples from the Taylor's Head Formation were absent or present only in trace amount within the Tangier Formation and low susceptibility Taylor's Head samples.

4.3 – Electron Microprobe Data

As a tool to compliment petrographic analysis, detailed chemical analysis were obtained from several samples to positively identify opaque mineral phases. Representative samples were selected so that each major opaque phase could be identified in samples from the Taylor's Head and Tangier formations. Heterogeneous grains were analyzed more than once in order to resolve chemical variance. The Electron microprobe was calibrated to analyze for oxides, specifically iron, titanium, and manganese oxides. Eighty five analyses were obtained (Appendix B).

After the data was obtained, stoichiometric conversions were applied to correct for different oxidation states of iron. Next, structural formulas were calculated for each of the 85 samples. Major opaque phases which were identified include: titanite, rutile, magnetite and ilmenite. Although titanite and rutile are not opaque minerals they were analyzed because they did reflect some light during initial reflected light petrographic assessment. Magnetite and Ilmenite crystals were found in considerable abundance in samples with high magnetic susceptibility. Magnetite usually occurred as euhudral crystals (Figure 4.1).

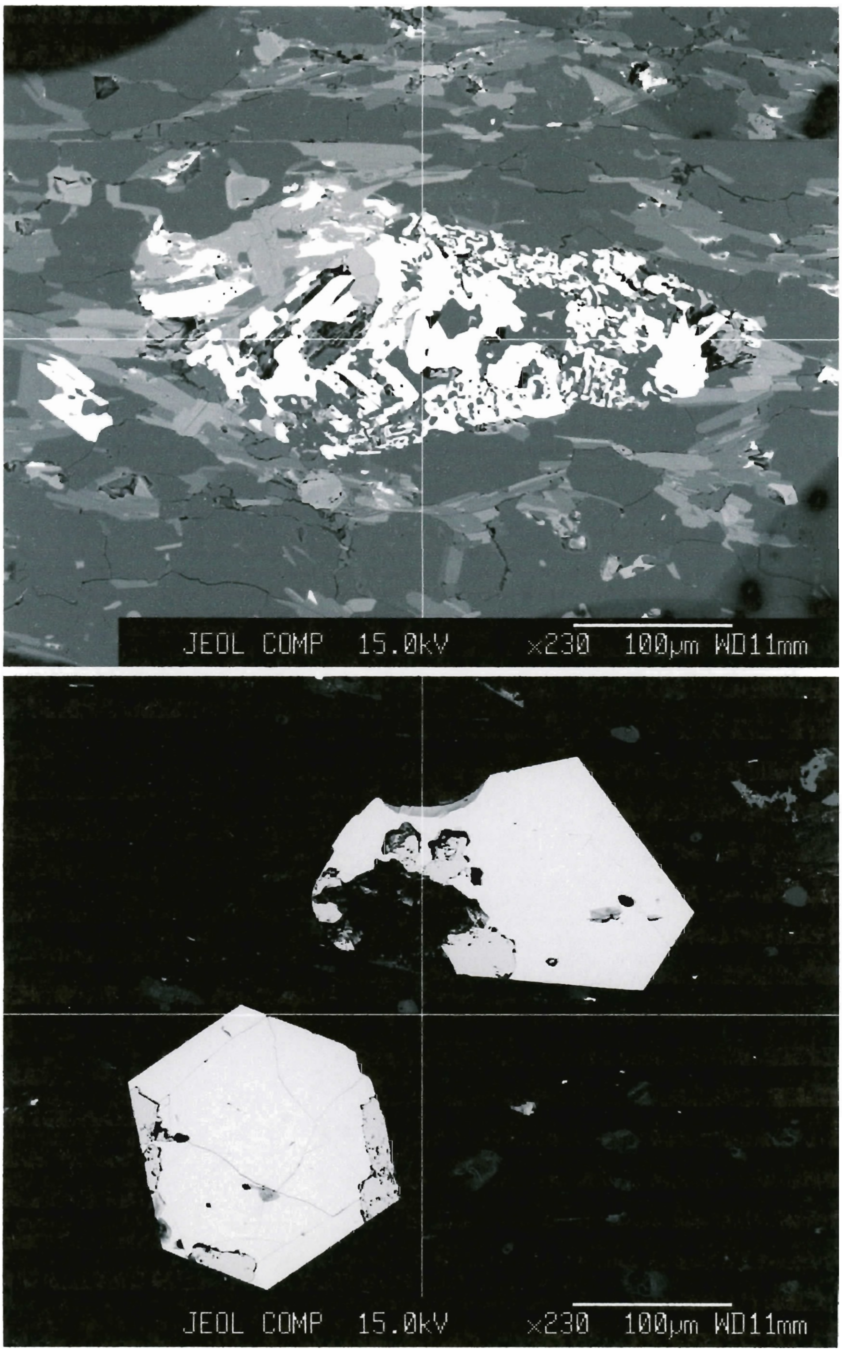

Figure 4.1 – Photos of magnetic minerals from the Taylor's Head formation. Magnetic ilmenite (top) and magnetite (bottom).

CHAPTER 5 – DISCUSSION

5.1 – Correlation of Magnetics and Stratigraphy

The purpose of this project was to evaluate the magnetic response of the Goldenville group and its relationship to lithostratigraphy. This has been done successfully. Prior to this study, variation in airborne magnetic patterns were related to magnetite in the Goldenville group and pyrrhotite in the Halifax Group with no further stratigraphic constrants (Haysom et al., 1997; King, 1994). Results of this study show that the cause of the magnetics in the Meguma Supergroup is more complex. The packages seen in the airborne magnetic images correspond with discrete stratigraphic rock units.

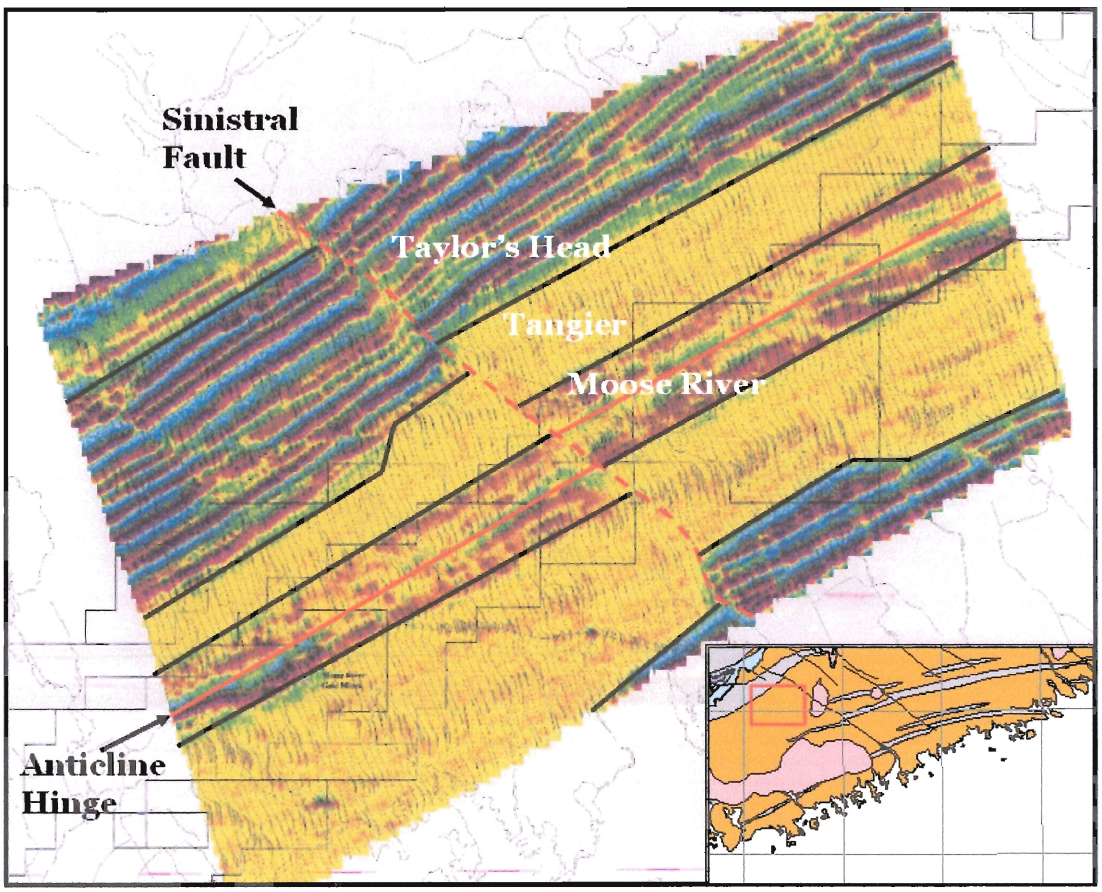

Figure 5.1 – High resolution airborne magnetic survey of the Moose River area with stratigraphic subdivisions of the Goldenville Group. After Hudgins 1997.

Units outlined using the high resolution Moose River (Hudgins, 1997; Figure 5.1) and Caribou (Anderle, 1988) airborne surveys were extrapolated using field mapping and regional airborne magnetic maps.

The magnetic susceptibility of each unit was successfully characterized. Each of the lithologic units in the study area has a unique signature seen in Figures 3.2 and 3.3. Susceptibility measurements were used in this study as an outcrop scale measure of the magnetic response of a sample. Figure 5.2 shows the relationship between the magnetic susceptibility and the relative percentage of opaque minerals within each sample. The horizontal axis for this figure is not percentage values but rather the amount of opaques relative to other samples. We can see from Figure 5.2 that as estimated percentage of opaque material increases the susceptibility increases. This correlation supports the notion that variation seen in the Goldenville Group magnetics are caused by varying amounts of opaque minerals contained in each of the newly outlined stratigraphic units.

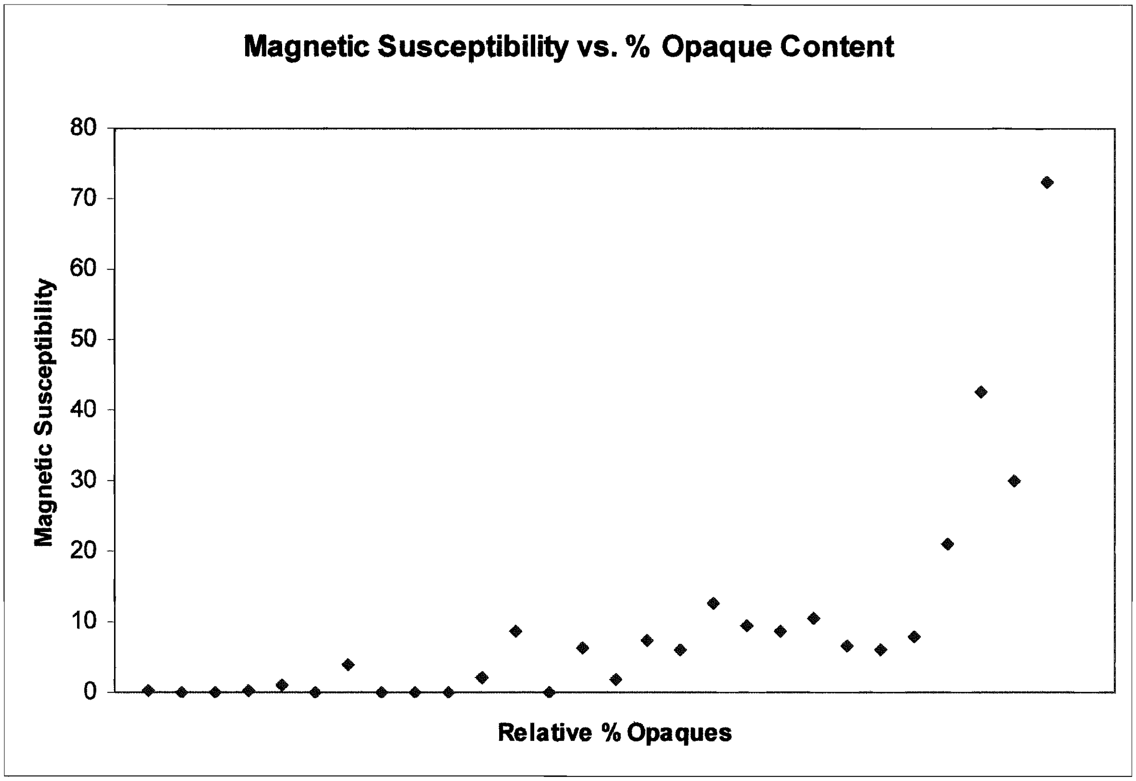

Figure 5.2 – Comparison between magnetic susceptibility and relative % of opaque minerals for each sample.

5.1.1 – The Taylor's Head Formation

The Taylor's Head Formation is the highest unit in the study area. It dominantly consists of thick metasandstone cycles with green metasiltstone tops. The airborne magnetic response of the Taylor's Head Formation is bimodal. The gradient images show this unit as a series of alternating bands of high and low response. These bands run parallel to known regional stratigraphy. From Figure 3.4 it is evident that bands of high and low magnetic response are not dependent upon grain size change. This indicates that high and low bands of magnetic response represent 100m scale stratigraphically controlled packages. Magnetic susceptibility of the Taylor's Head formation is also bimodal. The lowest peak being similar in position and range to the Tangier formation plots. The mean value of the second peak is three orders of magnitude greater than that of the first. The magnetic character of the Taylor's Head Formation is caused by the presence/absence of magnetite and minor amounts of ilmenite. This means that the 100m scale packages of high magnetic response contains these magnetic minerals in both the sandstones and siltstones. Also, packages of low magnetic response are depleted in these minerals throughout. Evident from Figure 4.1, euhedral crystals of magnetite suggest metamorphic origin.

5.1.2 – The Tangier Formation

The Tangier Formation which is stratigraphically above the Moose River Formation is dominated by thick metasandstone cycles with black slates. The airborne magnetic response of this unit is low and consistent relative to the rest of the Goldenville Group. The magnetic susceptibility of the Tangier Formation corresponds well with the airborne magnetics. The susceptibility of this unit has a low mean value (0.06×10^{-3} SI units) with a narrow range. The lack of magnetic response in this unit is consistent with the lack of magnetic pyrrhotite and magnetite found in petrographic studies.

5.1.3 – The Moose River Formation

The Moose River Formation is the lowest unit in the study area. It is comprised of interbedded green metasiltstones and black slates. The airborne magnetic response of this formation is characterized by consistent intermediate response. The magnetic susceptibility of the Moose River Formation exhibits a broad even bell curve with a mean value of 0.21 (10^{-3} SI units). The magnetic character of the Moose River Formation is due to varying amounts visible pyrrhotite seen throughout the unit.

5.2 – Implications

Each of the magnetic / lithologic contacts outlined in this study represent changes in regional changes in the nature of the Goldenville Group. These contacts represent depositional horizons over which there are significant mineralogic and chemical changes. The contact between the Moose River and Tangier Formations is a sharp, straight contact represented by the introduction of sand into the Goldenville. The lower Moose River is a fine-grain dominated sequence whereas the overlying Tangier Formation is sandstone dominated. However, both units contain black slates.

The stratigraphic contact between the Tangier and Taylor's Head Formations is represented by a change in the fine grained rocks. The lower Tangier contains black slates alternating with thick metasandtone units. The Taylor's Head Formation contains metasandstones with green metasiltstones. This distinguishes the units lithologically. Also, this contact is represented by a significant change in mineralogy. This was seen in petrographic studies by a huge increase in magnetite (and to a lesser extent ilmenite) mineralization. From Figure 5.1, there is evidence that the Taylor's Head Formation may truncate the Tangier Formation. Irregularities such as discontinuous magnetic bands seen at the boundary suggest this contact may be erosional. The variation in thickness of the Tangier Formation on either side of the anticline hinge is further evidence for an erosional contact between these units.

5.3 – Suggestions for Future Work

This study provides grounds for a number of follow up studies on the Goldenville Group. Future work might include investigations as to the nature of magnetite mineralization. Metamorphic magnetite crystals were noted throughout petrographic studies. Uncovering the reasons why magnetite preferentially forms in discrete stratigraphic horizons might provide better understanding of depositional variation in the Goldenville Group. Also, similar investigations as to the cause of magnetic variations in the Meguma Supergroup may uncover similar stratigraphic subdivisions on the Eastern Shore and throughout the Meguma Terrane.

CHAPTER 6 – CONCLUSIONS

Magnetic images produced from the Goldenville Group have major implications for regional mapping. Wherever the images show anomalies which parallel known regional stratigraphy, it is likely these represent discrete stratigraphic packages. Evaluation of these anomalies is necessary.

The Goldenville Group is traditionally thought of as monotonous sequences of massive metasandstones with no discernable variation. Over the course of this study I have shown the vast changes in the Goldenville Group's magnetic character, lithology, mineralogy and chemistry correspond with distinct stratigraphic horizons. It is likely to suggest that these horizons represent large scale changes depositional changes throughout the Goldenville Group.

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