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**A Knowledge-Based Model for the Integration
of Remote Sensing into a Mineral Exploration Program.**

by

John Keith Hornsby

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A thesis submitted to the Faculty of Graduate Studies
and Research in partial fulfilment of the requirements
for the degree of Doctor of Philosophy in
Earth Sciences

Ottawa-Carleton Centre for Geoscience Studies
Department of Earth Sciences
Carleton University
Ottawa, Ontario
April, 1990

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A KNOWLEDGE-BASED MODEL FOR THE INTEGRATION
OF REMOTE SENSING INTO A MINERAL EXPLORATION PROGRAM

submitted by

John Keith Hornsby, B.F.S., M.A.

in partial fulfilment of the requirements
for the degree of Doctor of Philosophy in
Geology

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ABSTRACT

The application of remote sensing to mineral exploration must involve consideration of the environmental conditions of the area under study, the biophysical characteristics, sensor and data characteristics, and methods of data analysis. All these factors may be considered dynamic, each varying either in space or time. The environmental and biophysical conditions will vary at different locations, and the remote sensing technology is dynamic due to the rapid development in sensor and processing technology. Examples of remote sensing applied to exploration are often site specific cases demonstrating the capabilities of a particular sensor. An inherent complexity of working in the Canadian environment is the cover of vegetation and varying depths of overburden separating the bedrock geology of interest, from the sensor. What is required is to "find an intelligent approach to customizing a remote sensing exploration program". The objective of this thesis has been to research, develop and demonstrate such an intelligent or knowledge-based model for the application of remote sensing to mineral exploration in the Canadian environment.

The study area chosen to test the model is situated in the Grenville Province. It covers an area of 900 square kilometres, located approximately 180 kilometres west of Ottawa, Ontario. Exploration and mining activities have taken place in the region for gold, lead, and zinc associated with metavolcanics and overlying carbonate rocks.

The remote sensing exploration model is hierarchical, progressing through reconnaissance and detailed exploration levels with associated stages to achieve the goal of targeting sites of high mineral potential. The model focuses on obtaining evidence to support a working model of mineralization. The strategic approach which has been developed is based on the concept of geobotany. The basis for this concept is that vegetation will, to varying degrees, have characteristics directly attributable to the underlying geology. Since remote sensing data is a result of reflectance and emittance at the earth's surface, this is a key concept within the model.

The model provides a structured approach for integrating remote sensing into an exploration program. A methodology has been developed to identify anomalous areas in the remote sensing data using a geobotanical strategy. In achieving this, data processing procedures

were determined and geobotanical relationships identified. In addition, the relationship of terrain (elevation, slope, aspect) on vegetation occurrence, was determined. The model recognized the importance of incorporating other supporting and complementary data sets. A methodology was therefore developed for the integration of geophysical, geochemical, and geobotanical anomalies to produce mineral potential maps.

Compared to the location of known mineral occurrences, 50% of the occurrences fall within areas indicated by the modelling as high potential areas. 25% fell in each of medium and low potential areas.

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CHAPTER 1: INTRODUCTION

1.0 PREAMBLE

The general absence of publications dealing with the application of remote sensing within the context of a mineral exploration program, is a reflection of the lag in developing applications of remote sensing in the earth sciences. This has been recognized by Tosaya (1988) who states, 'the long-term goal is to find an intelligent approach to customizing a remote sensing exploration program'. This research focuses on such an intelligent or structured approach through the development of a knowledge-based model for integrating remote sensing into a geological exploration program.

The characteristics of expert systems are employed in this research for the purpose of developing a set of rules which would clearly define the decisions which the exploration manager must consider. This is important for the application of this model in a practical setting.

The continuous and discontinuous vegetation cover over most of Canada results in a need to develop image analysis and interpretation methods which are based on geobotanical theory. Sensors detect electromagnetic radiation reflected and emitted from the earth's surface; in order to extract the maximum geologic information from the data it is necessary to

determine geobotanical relationships within the area of exploration interest. The strategy of the exploration model developed here is, therefore, based on geobotany.

Since this thesis is concerned with the use of remote sensing in conjunction with other more traditional geologic data types, another important component of the work is the integration of these different data sets to identify areas of greatest mineral potential.

Within the first chapter geobotany is discussed at length due to the importance of this theory to the model. Along with a section dealing with knowledge-based systems, this provides an appropriate background for the discussion of the design of the exploration model at the end of the chapter.

1.1 APPLICATION OF REMOTE SENSING TO MINERAL EXPLORATION IN CANADA

Remote sensing in Canada, beyond the aerial photography level, began in the early 1970's with physicists in the imaging sciences at the National Research Council forming a new organization called the Canada Centre for Remote Sensing (CCRS). This coincided with the first ERTS satellites (later renamed Landsat) being launched by NASA in the U.S.A. The mandate of CCRS is to develop and promote the use of remote sensing technology and the dissemination

of remote sensing data. The first ERTS images produced made it apparent that the scientists at that time had some awareness of the potential for applications of this type of data that further technological development would provide. The quality and amount of information from current images are far greater than those early images. It is perhaps unfortunate, but seemingly symptomatic of new technologies, that the developers of the technology were over zealous in their statements about applications. As a result some applications specialists such as geologists were disturbed by statements of capabilities which could not possibly be met by the imagery at that time. Since then, however, more application specific individuals have become intimately involved in the development and technology transfer of remote sensing. Remote sensing data and methods are now being realistically incorporated into exploration programs.

In the earth sciences as in all areas of remote sensing application (forestry, agriculture, etc.), early papers tended to be somewhat subjective and qualitative dwelling on the 'look what we can see !' approach rather than concentrating on real applications problems and information requirements. This still can happen when a new sensor is developed.

Research and development of geological applications of

remote sensing has passed through the 'look what we can see!' stage to such specific goals as the identification of sites which have the potential for mineralization. The presence of glacial overburden to varying extents over much of Canada, and largely continuous vegetation cover, results in a challenge for the geologist to extract geological information from the imagery. Interpretation of geological features must be based on the surface expression of the geologic features reflected in the soils, vegetation and topography. These are the biophysical phenomena which reflect and emit electromagnetic radiation back to the sensors. An understanding of the relationships of the contributing elements of the geosphere and biosphere are crucial to a comprehensive interpretation of any imagery. It is like the extrapolation from geomorphic features at the earth's surface to structural features which extend beneath the surface. In remote sensing this is complicated by having to interpret images produced from different parts of the spectrum, including the non-visible portions. Consequently the earth scientist must interpret an image of the earth's surface through all parts of the spectrum responsible for the image. The earth features are the same, but all trees are not green when viewed in the infrared. A good portion of the value of remote sensing data comes from being able to see in these other wavelengths since an object or feature may have some specific characteristic in some other portion

of the spectrum.

1.1.1 Lineament Detection

Remote sensing data has been used extensively to map geologic lineaments (Harris 1982, Yatabe 1984, Toubourg 1982). Lineaments are expressed in images, as tonal alignments in a linear or curvilinear form. These may be obvious but sometimes are so subtle that an expert interpreter is needed to extract the information from the image. According to Gillnet (1984) several generalizations can be made about lineaments:

- 1) Lineaments are naturally occurring and obvious features of the landscape which are present on all continents and exhibit systematic patterns in two or more azimuth sets generally separated by approximate angles of 45 to 90 degrees;
- 2) Lineaments are quite similar to joint sets but on a far larger scale, because lineaments are not restricted to a particular lithologic unit or individual geologic structure. Moreover, lineament trends persist and often transect stratigraphic columns and a variety of geologic structural features;

- 3) Lineaments at the surface exhibit traces that are linear, or curvilinear, and vary in length from a few kilometres to tens or hundreds of kilometres;
- 4) Lineaments in cross-section extend vertically, or near vertically, in the earth's crust for a few hundred meters to several kilometres, depending on their length; and
- 5) Lineaments rarely exhibit relative displacements between the two walls of the fracture and therefore, few of them can be classed as faults without supporting data.

The interpretation of lineaments from images tends to be partially subjective and different interpreters may produce different interpretations of the same area. Computerized methods are under development to attempt to automate the extraction process of the linears (Moore & Waltz 1983, Hornsby et al 1985). It is not yet possible to replicate the ability of humans to recognize patterns. Edge-enhancement techniques may be used to enhance obvious tonal changes in an image but they are not always effective in distinguishing low frequency changes (small grey level changes between adjacent pixels) for classification purposes.

1.1.2 Lithologic Discrimination

Research into using multispectral data to identify rock types has concentrated to a large extent on the determination of distinctive spectral response patterns characteristic of specific rock types (Abrams et al. 1983, Ashley et al. 1980, Buckingham & Sommer 1983, Marsh et al. 1983). This has proved successfull in areas having little vegetation cover such as Nevada and Wyoming in the United States.

The spectral signature of rocks and minerals is controlled by the physical and chemical properties of the constituent minerals. In visible and near-infrared wavelengths (less than one micron in wavelength) the spectral reflectance of minerals is determined by the presence or absence of transition elements (Goetz et al., 1983). Charge transfer bonds from the exchange of electrons between neighbouring metal ions, create absorptions in the wavelengths shorter than 0.4 microns and extend into the visible portion of the spectrum. These charge transfer bonds are also responsible for the rise in reflectance towards the longer wavelengths. Wavelengths between 1.0 and 2.5 microns in the infrared region contain spectral features diagnostic of the composition of minerals. Absorption features for bound and unbound water at 1.4 and 1.9 microns may be used for diagnostic purposes in the laboratory; however, for remote sensing purposes these

correspond to atmospheric absorption bands thereby limiting their utility.

Clays exhibit decreasing reflectance beyond 1.6 microns due to attached hydroxyl groups. These make it possible for clay rich areas associated with hydrothermal alteration to be identified by using images taken in the 1.6 micron region and in the 2.1 to 2.4 micron spectral region. Alunite, pyrophyllite, and muscovite also reduce the reflectance in this region (Goetz et al., 1983).

1.2 MINERAL EXPLORATION AND GEOBOTANY

In recent years an organized effort has been made by Canadian researchers in remote sensing and the earth sciences to understand and develop geobotanical methods for applied remote sensing. There are two reasons for this. The first recognizes that plants under stress cause changes in their spectral responses and that the development of high spectral and spatial resolution sensors make it possible to detect these changes. The second was from a recognition of the requirement to understand geobotanical relationships in order to interpret correctly any remotely sensed data. The current spatial accuracy and spectral precision of data from sensors have improved substantially to the point where reliable and reproducible results can be made of vegetation

condition and properties as they relate to a variety of geological controls and influences. Geobotany is an extension of geochemistry and biogeochemistry and therefore is best described by reviewing the principles behind biogeochemical exploration.

1.2.1 Biogeochemical Exploration

Geochemical prospecting is a method of searching for concealed bodies of metallic ores by means of chemical techniques. This is dependent on the location of anomalous concentrations of elements of interest. Geochemical methods of prospecting may be divided into: plant or biogeochemistry, soil geochemistry, bog geochemistry, water geochemistry, stream geochemistry, overburden geochemistry and rock geochemistry (Brooks, 1972).

Biogeochemistry in mineral exploration is based on the concept that the study of the chemical composition of plant ash will provide an indication of economic mineralization. In order to appreciate biogeochemical methods it is necessary to understand the occurrence and movement of elements within the growing medium of the vegetation and their subsequent absorption into the plant. Figure 1.1 illustrates the biogeochemical cycle as illustrated by Hawkes and Webb (1962).

Elements are taken up through the root system and through the plant where they are deposited in the wood and leaves. Elements contained in the leaves are later leached by rain water after falling to the ground, and recycled through the soil profile. These tend to be complexes of soluble components such as carbonates of the alkali metals, sulfates, phosphates and humic complexes of iron and manganese. As a result there is an accumulation of elements in the humic layers of soils.

1.2.1.1 Elements Within Soils

There are six major factors responsible for soil formation; nature of the parent material, climate, topography, age of the developing profile, and biologic activity. In most cases climate is the primary influencing factor even more so than the parent material except in young soils where there has been little time for profile development.

The parent material is most important in biogeochemical prospecting since it controls the abundance of major and minor elements within a soil. Topography will affect the soil development by influencing such characteristics as localized microclimate, soil depth, and

Figure 1.1: The biogeochemical cycle (Hawkes and Webb, 1962).

water movement. Water moving down a slope will leach out elements and precipitate them at the base of the hill. This often leads to changes in the soil pH at the base of the hills.

In terms of succession soil development and vegetation type are clearly linked. The termination of succession with climax vegetation often coincides with a mature soil.

1.2.1.2 Element Mobility and Distribution

Supergene processes are important in the mobility and elemental differentiation within soils. Low temperature and pressure conditions promote hydration, solution, oxidation, precipitation, and reactions of ions in solution with ions in existing minerals. The mobilization of elements is also strongly influenced by Eh and pH, and the stability of the minerals themselves.

Elements are distributed in a soil as a function of the soil type, and depth in the profile. The parent material will determine the abundance of the elements available in the profile; however, the mobility of these elements determines the distribution within the soil profile. Table 1.1 gives an indication of the abundance of elements in soils, crust, and igneous rocks. The concentration of

these elements can vary considerably as illustrated in figure 1.2.

Four factors can be attributed to mobilizing and distributing elements within a soil profile. The first is the breakdown of soil minerals. The relative stability of the mineral is largely dependent on the ionic potential (ionic charge). Ions with low chemical potential (less than 2) tend to remain in solution and those with high potential will precipitate more easily. Figure 1.3 gives the ionic potential of the elements and table 1.2 summarizes the chemical stability of minerals.

Biologic mechanisms by such organisms as lichens and bacteria also serve as weathering agents resulting in the mobilization of elements. Lichens will act as a chemical weathering agent by producing mucous substances. By producing carbon dioxide and organic acids at their roots, many plants increase the rate of solubility of minerals contributing to their mobility.

Bacteria can also be effective in the breakdown of minerals. Nutrifiers and Bacillus magaterium have a great affect on calcium carbonate, magnesium carbonate, and phosphates. Lactic and butyric acid producing anaerobes will break down calcite, magnesite, aragonite, dolomite, and

Element	Soil (ppm)	Crust (ppm)	Sediments (ppm)	Igneous rocks (ppm)
Li	4000	5000	4500	4400
Mn	850	975	760	1000
Na	500	450	680	640
Zr	100	190	200	170
Sc	300	385	450	350
Cr	200	150	130	117
V	100	145	130	90
Rb	60	165	270	200
Zn	50	125	80	80
Ce	50	46	50	40
Si	40	95	95	100
Fe	30	45	60	50
Co	20	15	30	30
Cu	20	75	57	70
Nb	15	20	20	20
Pb	10	15	20	16
Sn	10	40	16	32
B	10	10	56	13
Ca	10	35	22	18
Th	13	10	11	13
Ba	6	4.5	5	4.2
Ga	5	4	4.5	2
As	5	3.4	6.6	2
Sr	5	1	10	10
Mg	2.5	2.3	2	1.7
U	1	2.4	3.2	2.6
Ag	1	0.06	0.5	0.2
Cd	0.5	0.2	0.5	0.13
Se	0.5	0.07	0.6	0.01
W		1.2	2	2
Sb		0.6	1.25	0.3
Hg	0.01	0.07	0.04	0.06
Pb		0.34	0.01	0.1
Au		0.001		0.001

Table 1.1: Average abundance of trace elements in soils, the earth's crust, sediments, and igneous rocks (Andrew-Jones, 1968).

Figure 1.2: Range of abundance values of some trace elements commonly found in soils (Andrew-Jones, 1968).

siderite. Bacillus amylobacter and Bacillus extroquers are strongly corrosive to feldspars resulting in the solubilization of potassium and silicon.

With cool climate soils the majority of elements are absorbed onto clay minerals or humus due to their high cation exchange capacity. The hydroxyl groups attached to the aluminium of the plate-like clay minerals result in an overall negative charge due to the excess in oxygen and the disassociation of the hydrogen.

Another reason for the overall negative charge and therefore high cation exchange capacity is the substitution of an atom such as magnesium or aluminium within the lattice structure. Elements such as boron, chromium, molybdenum, selenium, and vanadium are often available as soluble anions and may be absorbed by clays where iron and aluminium have been removed from the clay particles.

Organic matter in the soil will affect the concentration of cations. At higher pH values the exchange capacity of humus is also high and generally exceeds that of clay minerals. At these higher pH values ionization of the weak acid groups is increased and bonding will take place more readily. The exchange capacity of clay is seldom greater than 100meq/100g. In humic material it can be as high as

500meq/100g. Humic layers tend to become enriched in elements such as arsenic, cadmium, cobalt, gold, lead, manganese, nickel, silver, tin, uranium, and zinc.

The quantity and distribution of humus in a soil is controlled primarily by rainfall and permeability of the soil. Humus contains a large number of colloidal organic compounds and humic and fulvic acids. Fulvic acids assist in mobilizing elements, in particular iron and aluminium which will result in illuviation. Humic acids on the other hand will impede illuviation. It is worth remembering that the degree of enrichment of elements in the humic layer depends on the type of vegetation since plants vary greatly in their ability to accumulate various elements.

1.2.1.3 Uptake of Elements by Plants

Brooks (1972) has outlined twelve variables which affect the uptake of elements by plants; type of plant, organ sampled, age of organ, root depth, pH, health of plant, drainage, availability of element, antagonism of other elements, rainfall, variable shading, and temperature of soil.

The type of plant sampled is important since plants

differ in their ability to accumulate elements from the soil, and also in their response to increasing or decreasing soil constituents. This is dependent to a certain extent on the class of plant. Generally the smaller and more primitive the species the greater the enrichment for a particular element.

The plant organ sampled will vary in the concentrations of particular elements when compared to other organs of the plant. Leaves of plants have higher concentrations of trace elements. It has been found that the elemental contents of tree organs decreases in the order leaves, twigs, cones, wood, roots, and bark (Carlisle and Cleveland, 1958). For zinc in particular it was observed that needles, cones, and leaves of trees give inconsistent data, the best results being obtained from twigs. These twigs were in the 1 to 3 year old range (Warren & Delavault, 1949). Brooks (1972) however found little difference in the reliability of leaves compared with twigs in prospecting for copper, molybdenum, nickel, uranium, and zinc.

There has been evidence to indicate that the age of the plant or plant organ sampled will result in variations in the elemental content in plants of the same species. Leaves will also exhibit seasonal variations. The metal

content of many deciduous leaves is at a maximum just before exfoliation. Elements tend to be concentrated in actively growing tissue such as shoots and young leaves, and are lowest in the sapwood and heartwood of the trees.

The health of a plant may also result in variable trace element accumulation. There is at times an increase due to the breakdown of the regulatory mechanisms due to disease. This is not, however, always reliable. pH will greatly affect the reliability of biogeochemical methods. This is illustrated by figure 1.4. The pH of a soil also exerts an influence since oxidation potentials for most reactions are pH dependent. In this way changes in the pH of a soil will drastically affect the availability to a significant degree since the elements can be precipitated or brought into solution depending on such things as the cation exchange capacity of clay minerals. The effect of pH has been discussed by a number of authors. Jamison (1942) indicates copper is readily mobilized in alkaline soils. He found 100% recovery of added copper at pH 4.0 and only 33% at pH 6.0. Zinc behaves much the same as copper in accumulation by plants. It has an increased availability in acid soils (Aldrich & Turrel, 1951). Manganese is highly soluble below pH 5.5 and at higher pH values it is converted to insoluble manganese oxides (Mulder and Gerretson, 1952). Similarly tungsten and molybdenum are made more available at

higher pH's. They are precipitated in the range of pH 3 to 5. Table 1.3 provides the pH values at which ions are precipitated as hydroxides.

The depth of the root system of different plant species can vary dramatically as shown in table 1.4 where depths range from 0.8 to 200 feet. The depth of the root depends on the climate and whether the plant is a phreatophyte (which depends on the zone of saturation below the water table for moisture) or a xerophyte (which depends on surface water from rainfall and therefore has shallow root systems). Although deeper root depths are likely better for detecting mineral deposits, the translocation of elements through the roots and up to the leaves may limit the final concentration of the particular elements in the leaves. The larger the roots the lower the enrichment of trace elements in the upper part of the plant as is illustrated in table 1.4. When sampling vegetation it should be remembered that root systems tend to translocate to aerial parts situated on the same side of the plant.

Drainage will affect the availability of elements since many elements become more mobile under waterlogged conditions and this will then be reflected in greater uptake by plants.

From an ecological point of view, aspect is an

4.0 4.5 5.0 5.5 6.0 6.5 7.0 7.5 8.0 8.5 9.0 9.5 10.0

Figure 1.4: Effect of pH on the availability of plant nutrient (from Ignatieff, 1952).

Ion	pH	Ion	pH	Ion	pH
Fe +	2.0	Cr +	5.3	Pb +	6.8
Sn +	2.0	Cu +	5.3	Zn +	5.3-6.8
Th +	3.5	Fe +	5.5	Hg +	7.3
Hg +	3.0	Cd +	6.7	Ag +	7.5-8.0
Al +	4.1	Ni +	6.7	Mn +	8.5-8.8
UO +	4.2	Co +	6.8	Mg +	10.5

Table 1.3: pH values at which ions are precipitated as hydroxides (from Malyuga, 1964).

important consideration since it will control the photosynthetic processes which will in turn affect the uptake of elements by plants. Table 1.5 summarizes the factors affecting elemental uptake by plants and methods for reducing their effect when undertaking biogeochemical surveys.

The principles of geochemistry and biogeochemistry have provided important details dealing with the occurrence of elements in soils, their mobility and distribution, and their eventual uptake into plants. This provides the working base to develop the concept of geobotany and the application of geobotanical methods in remote sensing.

1.2.2 Geobotany

The traditional concept of geobotany as an extension of geochemistry and biogeochemistry in which botanical associations with mineralization are made based on:

- 1) mapping the nature and distribution of plant communities;
- 2) the nature and distribution of indicator plants; and
- 3) the recognition of morphologic changes in plants
(Brooks, 1972).

Zone	Plant	Depth of roots (feet)
Tundra	<i>Betula nana</i>	0.8
	<i>Larix sibirica</i>	1.2
Forest podzol	<i>Picea excelsa</i>	6
	<i>Pinus sylvestris</i>	7.5
	<i>Populus alba</i>	9
Forest-steppe and steppe	<i>Pinus sylvestris</i>	11.4
	<i>Betula verrucosa</i>	12
Desert and semidesert	<i>Actinaea acutula</i>	0.8
	<i>Artemisia spinescens</i>	5
	<i>Tamarix ramosissima</i>	15
	<i>Aneides aphylla</i>	15
	<i>Quercus sp.</i>	28
	<i>Artemisia tridentata</i>	30
	<i>Haloxyton aphyllum</i>	30
	<i>Alhagi pseudohagi</i>	45
	<i>Sarcobatus vermiculatus</i>	57
	<i>Atriplex canescens</i>	62
	<i>Pinus ponderosa</i>	80
	<i>Juniperus monosperma</i>	200

Table 1.4: Depth of root penetration of woody plants and shrubs in different climatic zones (from Cannon, 1964).

Factor	Relative importance	Method of reducing effect
Type of plant	Very great	Selection of plants by orientation survey
Organ sampled	Great	Selection of organ by orientation survey
Age of organ	Significant	Selection by orientation survey
Root depth	Significant	Use of ratios of two elemental concentrations in same sample
pH	Fairly significant	Selection of elemental ratios of pair of elements of same availability over pH range encountered
Health of plant	Fairly significant	Select healthy specimens only
Drainage	Fairly significant	Avoid poorly drained areas where possible; also use elemental ratios
Availability of element	Fairly significant	Use elemental ratios with both elements of same availability
Antagonism of other elements	Minor	None
Rainfall	Minor	Carry out work over short period
Variable shading	Minor	Avoid shady sites if possible or use elemental ratios
Temperature of soil	Minor	Carry out work over short period

Table 1.5: Factors affecting elemental uptake by plants and methods of reducing their effect (from Brooks, 1972).

1.2.2.1 Indicator Communities

Indicator communities do not necessarily indicate mineralization, but instead may characterize a region in which mineralization may occur. For example, serpentinite resulting from the alteration of ultramafic rocks, is high in magnesium, nickel, chromium, and iron and low in calcium. This results in altered plant communities which are characteristically sterile and unproductive and have unusual floras of narrowly endemic species (Cannon, 1971). In contrast to this, calcium-rich terrain such as soils developed on limestone and dolomite, will tend to have plants tolerant to, or with requirements for calcium such as Thuja occidentalis (cedar).

1.2.2.2 Indicator Plants

Plants which are used as indicators of mineralization will be either:

- 1) those that have adapted to living exclusively on rocks or soils which supply unusual amounts of a particular element;
- 2) those that have acquired an immunity to large amounts of a particular metal by being able to reject the metal

at the roots; or

- 3) those species of wide distribution that favour mineralized ground under certain local conditions because of pH, water conditions, or availability of plant nutrients.

1.2.2.3 Stress Indicators

The occurrence of excesses or deficiencies of trace elements in soils may cause a variety of morphological, physiological, and mutational changes in plants. Physiologic effects are characterized by either diminished or enhanced growth. The most indicative morphologic/physiologic change occurs as a result of chlorosis in which excesses of metals such as copper, nickel, magnesium, and chromium interfere with iron metabolism in the plant and produce a yellowing of the leaves.

1.2.3 Geobotany, Remote Sensing and Mineral Exploration

Geobotany offers a theoretical basis for the application of remote sensing in mineral exploration. Since the sensors largely receive energy from the surface of the earth, which in the Canadian context is largely from vegetation, it is necessary to establish or attempt to recognize chemical anomalies on the basis of their effect and

resulting appearance at the earth's surface as displayed by the characteristics of vegetation. Due to the complexities inherent in the natural environment it is by no means a simple undertaking. As in many scientific investigations the complex is made more simple by 'averaging' out the complexities and trying to establish consistencies from which a greater understanding is possible. Progress is not always quick, however, since the generalities may sometime mask the significant subtlties. For example, in some early geobotanical work it was thought that alders were indicative of the occurrence of gold. It is certainly an overstatment, however, if this is translated into meaning that if a prospector can find alders, then he will find gold. The context in which this relationship between gold and alders was made, likely had some site specific controls. It would also not be the gold itself which resulted in the occurrence of the alders, but elements related to the occurrence of the gold. It is a necessity therefore to establish an understanding of the geobotanical relationships in an area, before the identification of significant anomalies can be made: . . .

1.2.3.1 Spectral or Target Geobotany

The adoption of geobotanical theory to remote sensing

has concentrated on the identification of morphological and physiological changes due to anomalous metal concentrations in specific types of vegetation, as a function of the spectral response patterns (Horler 1985, Singhroy et al 1986, Rencz et al 1986). Figure 1.5 illustrates the concept and application of this approach. In a study by Horler (1983) it was found that there was a high correlation between reflected wavelengths and chlorophyll content for all species studied, with some variation in the quantitative values depending on the type of plant. The most noticeable spectral change was that as the chlorophyll content of leaves increased, the reflected light in the 700nm range shifted progressively to longer wavelengths. The position of the edge of the curve in this portion of the spectrum therefore becomes a good measure of the amount of chlorophyll within a leaf. As a result this may be used for exploration purposes where vegetation is suffering from metal induced chlorosis. This shifting of the reflectance curve to shorter wavelengths in stressed vegetation has been termed the blue-shift or red-edge shift. It is the result of high internal leaf scattering causing high near-infrared reflectance, and chlorophyll absorption giving low red reflectance.

Application of this method to exploration geology presents several problems:

Figure 1.5: The concept of spectral geobotany.

- 1) A need for very high spatial resolution (<2 metres, preferably <1) resulting in large amount of data for small areas, and the use of an airborne platform;
- 2) A special sensor is required to attain the high spectral precision necessary to detect the portion of the reflectance curve where the red-edge occurs; and
- 3) A great deal of computational time is required to model the reflectance curves to detect anomalies.

1.2.3.2 Background Geobotany

The theory of Regional or Background Geobotany was introduced in the remote sensing context in 1986. It is an attempt to make the geobotanical concept more applicable in an exploration setting while introducing a necessary step for successfully applying geobotany in remote sensing for the purpose of mineral exploration. (Hornsby & Bruce, 1986, 1987). It relies on applying the geobotany concept to the community level rather than the species level, and as a result does not require the use of special sensors onboard aircraft. Instead, Landsat derived data is used, and cost in terms of data acquisition and processing is reduced.

Regional geobotany is based on the hypothesis that the nature and distribution of plant communities occur as a result of environmental conditions, so variations in distribution from the established norm of an area may be indicative of anomalous changes in the geology. This model is illustrated in figure 1.6. In analysis of the remote sensing imagery the distribution of vegetation communities and species within each community will also reflect the occurrence of indicator plants and morphologic changes due to stress conditions. In this way all the traditional botanical associations with mineralization may be investigated, rather than relying solely on stress induced physiologic changes required by the spectral geobotany model.

What the regional model does require is an understanding of the general ecologic conditions of an area in terms of the relationships between the bedrock units, surficial materials including soils, topography, plant communities and the resulting spectral response patterns.

Figure 1.6: The concept of background geobotany.

1.3 MINERAL EXPLORATION AND KNOWLEDGE-BASED 'EXPERT' SYSTEMS

Expert, or knowledge-based systems have become the subject of a considerable amount of research and development activity within the last few years. There are now journals entirely devoted to the subject, particularly from the perspective of system design. Advances in computer hardware and software design are enabling the progress towards fifth generation computers despite the inherent complexities (Fabbri et al 1986, Erickson and Likens 1984, Mitchell et al 1985, McKeown et al 1985, McCammon 1984, Ros et al 1984, Smith and Pazner, 1984, Wilkinson and Fisher 1984).

The concept behind these systems is applicable to a wide variety of applications problems. The initial key step in starting to build an expert system is to identify a specific problem which the system will address. Early work in artificial intelligence attempted to simulate the process of thinking by finding methods for solving broad classes of problems (Waterman, 1985). This approach was found to be ineffective since the more classes of problems a program was designed to handle, the more poorly it handled any single problem. Efforts were then shifted to developing general methods and techniques which could be applied. Progress was made with this strategy, but the

development of these specialized computer related phenomena did not consider to any great extent that part of the system which by definition is the most important, the knowledge-base. The knowledge-based system uses data, rules, and inference (reasoning, to solve problems based on knowledge that the user does not have.

1.3.1 System Components

To understand the functioning of a knowledge-based system, it is necessary to consider its structural components and the function and interaction of these components. The two main components of an expert system are the knowledge-base, and the inference engine.

The knowledge-base holds a collection of facts and rules derived from the 'domain expert'. The domain expert being the person whose knowledge is being engineered into the system. Johnson (1983) provides a detailed definition for the term "expert":

An expert is a person who, because of training and experience, is able to do things the rest of us cannot; experts are not only proficient but also smooth and efficient in the actions they take. Experts know a great many things and have tricks

and caveats for applying what they know to problems and tasks; they are also good at plowing through irrelevant information in order to get at basic issues, and they are good at recognizing problems which they face as instances of types with which they are familiar. Underlying the behaviour of experts is the body of operative knowledge we have termed expertise. It is reasonable to suppose, therefore, that experts are the ones to ask when we wish to represent the expertise that make their behaviour possible.

The facts within a knowledge-base are simple statements which are either true or false. For example:

SUBJECT	RELATION	OBJECT
the animal	has	hair
the animal	flies	

The rules in a knowledge-base consists of two or more facts in the form of an IF _ THEN statement, for example:

IF
the animal gives milk (antecedent)

THEN

the animal is a mammal (consequent)

The knowledge-base embodies the domain specific knowledge, and is therefore the heart of the system.

What has been termed the inference engine is the part of the system which provides reasoning capabilities. The inference engine contains the general problem solving knowledge. It determines which data is required to solve the problem, uses the contents of the knowledge-base to draw inferences, and records these inferences back to the knowledge-base. This is done through an interpreter and scheduler. The interpreter decides how to apply the rules to infer new knowledge, and the scheduler decides the order in which the rules should be applied. It iterates in this way until nothing further can be inferred from the facts and rules. Three types of reasoning are used:

- 1) DEDUCTION, or forward chaining, starts with some given facts provided by the user and database and derives additional facts;
- 2) INDUCTION, or backward chaining begins with an hypothesis provided by the user and attempts to verify it; and

- 3) MIXED CHAINING, which combines deduction and induction to solve problems, which is useful when there are neither sufficient facts nor a reasonable hypothesis.

The structure of the inference engine varies depending on the nature of the problem domain and the way in which the knowledge is represented and organized.

In order to better understand these concepts and mechanisms behind an expert system, the mineral consultation system 'Prospector' will be discussed.

1.3.2 PROSPECTOR: A Mineral Consultation Expert System

Prospector is perhaps the best known expert system to be developed to date in the mineral exploration field. Developed at SRI International, it is a computer program designed to aid geologists in evaluating potential mineral resources (McCammon, 1986). There were three main considerations in the development of the system:

- 1) the need for continuing exploration for mineral resources;
- 2) the difficulty of staying technically current; and
- 3) the desirability of bringing to bear the knowledge of

several specialists on a given resource problem (Hart et al, 1978).

The knowledge-base in Prospector consists of a number of models of mineral deposit types. In running the program the exploration geologist begins by entering the characteristics of a particular prospect of interest into the database. These facts deal with the geologic setting, structural controls, kinds of rocks, minerals, and alteration products present or suspected. The program then compares these facts with the models of different mineral deposit types and notes the similarities, differences and missing information. The models in the knowledge-base consist of a set of rules. The program then queries the geologist in a dialogue to obtain additional relevant information and to make an assessment of the mineral potential of the prospect.

1.3.2.1 Knowledge-base

The knowledge-base contains the expert knowledge as a series of rules in the form:

If E then H else not H

which means, the observed evidence E either confirms or

rejects the hypothesis H (McCammon, 1986). In order to account for uncertainty, the rule takes the form; if E then (to a certain degree) H. Evidence is combined to form single or compound pieces of evidence by the logical operators of AND (conjunction), OR (disjunction), and NOT (complementation). The rules are chained together where one rule is the negative evidence for another, through several pieces of evidence pertaining to the same hypothesis, and through the same piece of evidence pertaining to several different hypotheses.

Since the models in the knowledge-base are from the subjective judgements of expert economic geologists as well as objectively derivable facts, the use of subjective probabilities in the inference network aid in providing more sound decision making than yes/no answers can provide.

1.3.2.2 Inference Network

During the session with the computer the user geologist is prompted with questions. These are answered with numbers between -5 and 5 indicating the certainty of a response. A certainty of -5 is equivalent to a no answer and 5 a yes answer. A response of 0 would indicate the geologist has no opinion. If this occurs, the program transfers the

dialogue onto another portion of the inference net to try to answer the question. In the event there is no alternative, the answer is considered to be NO since most deposit models only allow for positive evidence.

The user can also be asked to select choices for a given question. If more than one is selected, then multiple lines of evidence can be pursued.

1.3.2.3 Benefits and Drawbacks

One of the ways to assess the validity of developing and using expert systems is to consider them in comparison to human expertise since this is what is being emulated. Table 1.6a and b provide a summary of favourable characteristics and drawbacks, respectively.

1.4 A REMOTE SENSING KNOWLEDGE-BASED MODEL FOR MINERAL EXPLORATION.

It is the purpose of this thesis to address the problem of how to implement remote sensing into an exploration program in the Canadian environment. The scope of this problem is quite broad yet it requires addressing in a comprehensive manner to try to bring together exhibited capabilities as well as to research new ones in the process of developing a structured approach. Presently,

a)	HUMAN EXPERTISE	ARTIFICIAL EXPERTISE
	Perishable	Permanent
	Difficult to transfer	Easy to transfer
	Difficult to document	Easy to document
	Unpredictable	Consistent
	Expensive	Affordable
b)	Creative	Uninspired
	Adaptive	Needs to be told
	Sensory experience	Symbolic input
	Broad focus	Narrow focus
	Commonsense knowledge	Technical Knowledge

Table 1.6: Comparison of human and artificial expertise;a)
Pros, b) Cons.

in most cases the approach by the exploration geologist is to obtain a satellite image and attempt to extract information from it often independently of other data sources. While the principles of air photo interpretation are applied in the interpretation process, the geologist often does not realize the consequences of having selected data of particular spectral and spatial characteristics. As a result, from the very beginning the geologist may have chosen the wrong data type for extracting the information required. The best approach is to define the geologic information needs, then obtain the necessary information through the integration of different data sets. The type of remote sensing data and analysis methods will be defined by the geologic information requirement.

1.4.1 The Model

The design of the model is hierarchical in nature making it well suited to an expert system. The primary level is illustrated by figure 1.7. Similar to the Prospector system this system centres on the definition of a model of mineralization. This is a process very familiar to the economic geologist who gathers facts on an area which either support the working hypothesis or force the geologist to alter the working hypothesis. Certain geologic

Figure 1.7: Knowledge-based exploration model framework.

deposit are not present then there will not be that type of deposit in the area under study. As demonstrated by the Prospector system, there tend to be only a few metallotects but many more characteristics not unique to any one deposit type, and still necessary for a particular deposit to occur.

1.4.1.1 Primary Structure Level and Dynamic Components

The focus of the model is the working hypothesis. Geologic facts or evidence are required to make valid the hypothesis. In the process of identifying the type of deposit and its location, the model passes through three phases. These phases are defined by scale. The reconnaissance phase, which gathers information of a regional nature; the detailed phase, which attempts to pinpoint specific locations of mineralization once favourable conditions have been found in the reconnaissance phase; and finally the prospect evaluation phase, which identifies the extent of mineralization.

In this thesis emphasis is placed on the role of remote sensing in providing the evidence to support the working model of mineralization. As in any exploration program a strategy is required. The strategic approach for utilizing remote sensing is termed here as the

program a strategy is required. The strategic approach for utilizing remote sensing is termed here as the geobotanical strategic approach. Since this thesis is concerned with exploration in the Canadian environment, vegetation and overburden are key elements to contend with and therefore require a strategy which includes their characteristics. This geobotanical strategy is based on the concepts of regional and spectral geobotany discussed in section 1.2.

1.4.1.2 Secondary Level

Figure 1.8 illustrates the relationships between the primary level consisting of the reconnaissance, detailed evaluation, and prospect evaluation phases and the secondary level of the hierarchy. This secondary level consists of five stages: physical analysis, data acquisition, data analysis, data interpretation, and data integration. These stages employ various analysis techniques to extract the necessary geologic information which is then fed back into the working model. Figure 1.9 indicates the criteria which need to be considered at each stage for the implementation of the geobotanical strategy.

Figure 1.3: Primary and secondary levels of exploration model..

Figure 1.9: Stages with criteria required for geobotanical exploration strategy.

1.4.1.3 Strategic Criteria

The physical evaluation stage requires the geologist to gain a general understanding of:

- 1) the types of lithologies and therefore the distribution of chemical sources;
- 2) the depth of overburden and glacial directions to evaluate the dispersion of elements from the bedrock;
- 3) elevation, slope and aspect influences on the occurrence of vegetation, and relationships of vegetation to underlying bedrock topography and surficial geology;
- 4) the nature of vegetation communities to identify dominant communities;
- 5) basic spatial distribution of the communities identified; and
- 6) the possible influence of other environmental factors which could affect the nature and distribution of vegetation, such as flooding or sources of pollution.

Planning of the data acquisition stage is important for optimizing the conditions for detecting geobotanical associations and anomalies. Spring and fall images have

traditionally been thought to be best due to the sensitivity of vegetation at these times of the year. Stress conditions may be displayed as varied physiological responses in the vegetation. The spatial resolution of the data will control the scale at which information may be extracted. Data from the Landsat multispectral scanner (MSS) works reasonably well at a scale of 1:150,000 and is only suitable for very broad regional evaluations. The Thematic Mapper (TM) data is suitable for study at a scale of 1:50,000 due to the 30 metre pixel size.

The image processing stage consists of two main parts. The first stage involves computer enhancement of satellite data to increase the visual interpretability of the imagery. Classification of the data into the vegetation communities established during the first stage need only be done if the geologist would like the computer to aid in the definition of certain units. Using spectral response values, the computer can provide more consistent grouping of data over large areas than can a human interpreter, where patterns or textures exist in the imagery; however, interpreter input can be important or an aid in the definition of certain units. In such cases interpreter input is an important addition to the overall interpretation.

The fourth stage of interpretation is most important

since it is the stage where the geological information is extracted. The experience of the interpreter is of course important, as is familiarity with the area and data as established in stages one and two.

The integration stage may be incorporated in the interpretation stage since the interpreter will naturally make interpretations based on other knowledge of the geology of the area under study. It is presented here as a separate stage to stress that the information derived from the remote sensing data should be considered in conjunction with other sources of geologic information. For example, an anomaly in the spectra may also show up in geochemical and geophysical data, further supporting a decision to follow up on a particular location.

1.4.2 Comment

The subsequent chapters of this thesis are focused on each of the tactical stages in proving the validity of this model.

CHAPTER 2: PHYSICAL ANALYSIS: Geological Setting

As stated at the end of the last chapter in section 1.4.1.3 (strategic criteria) this tactical stage is intended to gain information concerning:

- (a) the bedrock lithology to establish the geochemical settings within the study area;
- (b) information on the nature of the overburden to evaluate the dispersion of elements from the bedrock;
- (c) topographic characteristics and controls;
- (d) general vegetation characteristics and spatial distribution;
- (e) other environmental influences within the area of concern.

This information gathered from available materials will form the initial knowledge-base from which decisions will be made.

2.0 GRENVILLE STUDY AREA

The study area covers 900 square kilometres (30 km x 30 km). It is situated approximately 180 kilometres west of Ottawa, Ontario (see figure 2.1) (Appendix A). It includes parts of the townships of Effingham, Abinger, Angelsea, and Barrie. Land-use in the region consists largely of cottages along the shores of lakes. The town of Cloyne

A map of the study area in the St. Lawrence and Saguenay Fjords. The map shows the coastline of the fjords, with several lakes and islands labeled. The labels include: Campbell L., Michel L., Lake, Saguenay, Stokematta L., and Saguenay L. The map is oriented with North at the top.

337000 m.E 4965000 m.N

51

is situated along the southern boundary of the study area on highway 41.

Access to the area is provided by highways 506 (E-W) and 41 (N-S) as well as secondary roads providing access to the numerous cottages. There is no ready access to the northeast quadrant of the area except along a dirt road which reaches as far as the west arm of Shawenegog Lake.

The main considerations in choosing this area were:

- 1) terrain is relatively undisturbed;
- 2) mineralization present;
- 3) known regional geochemical anomaly;
- 4) good access into the area; and
- 5) data availability

Exploration and mining activities have taken place in the region over the last one hundred years. They were largely for the exploitation of small amounts of gold, lead, and zinc. Occurrences of these metals are related to the metavolcanics and overlying carbonate rocks. There is currently no active mining in the study area.

2.1 TECTONIC AND REGIONAL GEOLOGIC SETTING

This section describes the tectonic setting of the study

area and is based on previous investigations and theories. The area is situated within the Grenville Supergroup of the Grenville Province. A brief discussion follows on the various theories put forward to explain the historical geology of the Grenville Province as a whole, then more specifically the sequence of events responsible for the geology of the Supergroup. The occurrences of mineralization and the tectonic controls are addressed.

The Grenville Province constitutes an area approximately 1000 by 480 kilometres, extending from Georgian Bay to the Atlantic coast of Labrador. It represents a more extensive orogenic zone which stretches from Mexico and Columbia northwestward to the Sveconorwegian province of Norway. Isotopic dates indicate three peak times of activity; 1300 Ma., 1100+50 Ma., and 950+50 Ma. (Baer, 1981b).

The age of the rocks in the Grenville are of particular interest since they relate to economic mineral deposits. While the east-west trending Archean greenstone belts of the Abitibi region of Quebec are truncated by the Grenville Front, it is reasonable to assume that the terrain southeast of the Front might also be favourable for gold and base-metal exploration.

Figure 2.2 shows the distribution of Archean, Aphebian, and Helikian rocks in the Grenville Province (Baer et al, 1978). Archean rocks have been traced across the Grenville Front such as at Surprise Lake near Chibougamau. In many cases the older rocks cannot be traced into the Grenville because of the generally high grade of metamorphism which makes recognition difficult. Rb-Sr and U-Pb analyses have also been used to partially delineate the older rocks.

2.1.1 Theories on the Tectonic Evolution of the Grenville Province.

The explanation for the evolution of the Grenville Belt is one of considerable debate. A variety of models have been proposed and will be outlined.

2.1.1.1 Wynne-Edwards (1972)

This model proposed that there was deposition of up to 10 kilometres of platform carbonates, quartzites, and shales belonging to the Grenville Supergroup. These are deposited on an Archean and Early Proterozoic cratonic basement. This sequence was deeply buried and subsequent erosion has removed most of the supracrustal cover exposing

Figure 2.2: Distribution of Archean, Aphebian, and Helikian rocks (from Sangster and Bourne, 1982).

the catazonal level of the orogenic belt.

2.1.1.2 Dewey and Burke (1973)

This is a continental collision type of model. It was proposed that intervening oceanic lithosphere largely was destroyed between two colliding continental plates, and was preserved only as ophiolites and blueschists. The extensive convergence was explained by the thickening of the overriding plate causing geotherms to rise and partial melting to start in the lower regions of the thickening plate. Dewey and Burke (1973) proposed that the main suture must lie southeast of the Grenville Front.

2.1.1.3 Brown-Chappell-Moore-Thompson (1975)

This theory, based on plate tectonics, consists of a cycle involving subduction of oceanic lithosphere, generation of an island-arc complex (together with partial melting of the down going slab to produce calc-alkaline volcanism and granodiorite intrusions), followed by a second cycle during which the island arc was uplifted, eroded and uncovered by miogeoclinal sediments. The miogeocline was subsequently deformed during continental collision. The island arc to the ocean closure

phase took 250 m.y. As stated in the paper by Brown et al (1975), the model is based on four points of evidence: (1) relict oceanic lithosphere is preserved in the terrain northeast of Madoc, Ontario; (2) granitic to dioritic batholiths were intruded into the oceanic crustal material; (3) platformal sediments were deposited unconformably over intruded oceanic crust; and (4) intense regional deformation and metamorphism of the basement and cover.

2.2.1.4 Baer (1976)

Baer proposed a model based on plate tectonics. There were three stages to this: (1) emplacement of anorthositic rocks into pre-existing sialic basement in the period 1500-1400 Ma.; (2) the development of a proto-Atlantic ocean 1300 Ma. ago, developed along northeast trending fractures to the southeast of the present belt; and (3) closing of the ocean and resulting continental collision giving rise to reactivation and deformation of the Grenville Province about 1100 Ma. The suture, according to this model, should be somewhere in the Appalachians.

2.2.1.5 Wynne-Edwards (1976)

This model was based on the hypothesis that

ductile spreading followed by contraction of the crust was the orogenic mechanism responsible for reworking. The continental crust shifted northward over an easterly trending spreading centre. The crust thinned as it became ductile over the zone of thermal upwelling, allowing the formation of an epicontinental sea and associated sediments. The ductile crust and sediments then moved off the spreading centre.

2.2.1.6 Baer (1977)

This model by Baer proposed that the whole Grenville Belt was one dextral shear zone 500 kilometres wide on the evidence of sigmoidal foliation trends. In a 1981 publication Baer described a model of intra-plate deformation, the necessary stresses being built up due to the plates jamming together.

2.1.2 Central Metasedimentary Belt and the Grenville Supergroup.

The Grenville Province is divided into a number of major geologic zones of which the Central Metasedimentary Belt (CMB) is one (see figure 2.3). The boundaries of the CMB encompass the Grenville Supergroup in central Ontario and south-western Quebec. The Grenville Supergroup is a

middle Proterozoic accumulation of supracrustal rocks, containing most of the known metallic and industrial mineral deposits.

2.1.2.1 Geology of the Grenville Supergroup

The Grenville Supergroup was divided into a number of tectonic domains by Brock and Moore (1983) (see figure 2.4). These are the Elzevir Terrain, Bancroft Terrain, and Westport Terrain.

Elzevir Terrain

The Elzevir terrain has been divided into three main groups. These are the Flinton (Moore & Thompson, 1972, 1980), Hermon and Mayo (Lumbers, 1967) (see table 2.1). The Hermon and Mayo groups were defined in the Bancroft-Madoc area where they attain a thickness up to 8200 metres. The Hermon Group is characterized by volcanics, and the Mayo by carbonate sedimentary rocks with intercalated siliceous clastic units. A U-Pb age of 1286 ± 15 Ma. for the lowest member of the Hermon Group gives an approximate age for deposition of the Grenville Supergroup (Silver and Lumbers, 1966).

The Flinton Group is preserved in a series of

Figure 2.3: Major tectonic subdivisions of the Grenville Province in Ontario and Western Quebec (from Easton et al 1986).

Figure 2.4: Tectonic subdivisions of the Central Metasedimentary Belt (from Easton et al, 1986).

GROUP	FORMATION	DESCRIPTION
Flinton	Stewart	marble, graphitic marble
	Madoc	pelite
	Fernleigh	thin-bedded black shale and limestone, pyritic in part
	Meyers Cave	dolostone, limestone, dolostone conglomerate, black pyritic shale
	Lessard	calcareous and non-calcareous feldspathic sandstone
	Bishop Corners	basal, hematitic quartzarenite (locally cross-bedded), quartzarenite-pebble conglomerate and shale
UNCONFORMITY		
	Lasswade	marble, minor calcareous metasandstone and metasilstone, rare recrystallized chert
	Apsley	poorly-sorted feldspathic metasandstone with upper and lower members of calcareous metasandstone and metasilstone
Mayo	Dungannon	80% marble; remainder mainly calcareous metasandstone and metasilstone, poorly-sorted feldspathic metasandstone and rare recrystallized chert; mafic flows and ironstone rare where the base of formation overlies Tudor metavolcanic rocks
	Burnt Lake	mainly rhyolitic, trachytic, dacitic, and andesitic metavolcanic rocks with minor metabasaltic flows; lensoid marble units and sandy siliceous metasedimentary rocks occur locally
	Luriff	75% pillowed basaltic, remainder dacitic and felsic flows and pyroclastic rocks, minor ironstone
Hermon	Vansickle	mainly poorly-sorted feldspathic metasandstone locally with abundant marble, felsic and mafic metavolcanic rocks, metaconglomerate, and well-sorted quartz-rich metasandstone; arkosic metasedimentary rocks are commonly associated with felsic metavolcanic rocks
	Oak Lake	mainly metamorphosed felsic pyroclastic rocks and arkose with some mafic and felsic flows; rare marble and metaconglomerate in upper part of the formation
	Tudor	mainly metamorphosed pillowed basaltic and andesitic flows

Table 2.1: Table of formations for the part of the Grenville Supergroup exposed in the Elzevir Terrain (from Carter, 1984).

narrow synclines in the area northeast of Madoc. Lithologic units are comprised of calcareous and non-calcareous metasedimentary rocks. There is also an abundance of marble. The Flinton Group is thought to have been deposited at 1080 Ma. (Moore & Thompson 1980, Easton 1986).

Bancroft Terrain

The Bancroft Terrain consists of clastic metasedimentary rocks. The stratigraphic sequence in the Bancroft Terrain is thought to be a lateral facies transition from north to south from clastic/carbonate sequence in the north to a clastic/volcanic/carbonate sequence in the south, reflecting a deepening basin to the south (Easton et al, 1986).

Westport Terrain

This terrain was described by Wynne-Edwards (1967) as a 4600 metre sequence of intercalated quartzarenites, marbles, and quartzofeldspathic gneisses.

Despite difficulties in making stratigraphic correlations between the terrains there are some lithostratigraphic similarities. In all areas there is a siliceous clastic sequence which passes upward into a

carbonate sequence. Volcanic units occur at the clastic/carbonate contacts or at the base of the stratigraphic sequence. Finally, dolomitic marbles tend to be low in the carbonate stratigraphic sequence.

Igneous Activity

Two main intervals of intrusive igneous activity occurred in the Grenville Supergroup. The first occurred between 1250 and 1220 Ma., and consisted mainly of diorite, gabbro, tonalite, and nepheline-bearing intrusions. The second interval of activity occurred between 1050 and 1100 Ma. It consisted of granodiorite, granite, and syenite plutons. These were syn-tectonic and post-tectonic. The intrusions are largely concordant with regional structures except for local dykes. Most of the intrusions were affected by metamorphism which ended about 1070 Ma.

Metamorphism

The Grenvillian orogenic cycle consists of two orogenic events; the Elzevirian (1200-1225 Ma.) and the Ottawa (1050-1100 Ma.) (Moore & Thompson, 1980). Upper amphibolite conditions were reached in most of the Bancroft Terrain during the Ottawa orogeny. Upper greenschist to lower amphibolite facies occur in the Elzevir terrain.

Granulite facies were reached in some of the Westport Terrain and the Central Gneiss Belt (Wynne-Edwards, 1972; Davidson et al, 1984). In the Madoc area a major zone of greenschist facies is centered on the thickest accumulation of volcanic rocks (see figure 2.5).

Structure

In terms of structure the PreCambrian rocks have been affected by multi-phase deformation which produced a strong northeasterly structural trend throughout most of the Central Belt. Northeast striking, southeast dipping fold structures are the dominant features. A single foliation parallel to lithologic layering is predominant.

2.1.3 Tectonic History

The geologic history of the CMB in central Ontario and southwest Quebec is given in tables 2.2 and 2.3. This was compiled by Easton et al (1986) from geochronological data produced by Moore and Thompson (1980), Brock and Moore (1983), Sangster and Bourne (1982), Lumbers (1982, 1967), and Davidson et al (1984).

In the paper by Sangster and Bourne (1982) two hypotheses are outlined for the origin of the Grenville

Figure 2.5: General geology and isograds of the Central Metasedimentary Belt of central Ontario and southwest Quebec (from Freeman, 1978 and Baer et al, 1977).

Unit/Event	Age/Method/Ref.	Comment	Synopsis
Pegmatites	1030±20(z)(2) 980±15(r)(12)	many uraninite ages fall between 980-1050 Ma	980-1030 Ma 10+ Ma gap
Metamorphism	1040-1075(z)(6)	meta. zircons, titanite	1040-1070 Ma
Post-Tectonic plutons	1090(z)(1) 1096±46(r)(11) 1071±17(r)(10) 1051±21(r)(10)	Loon Lake, core Deloro Pluton Loon Lake, rim(meta?) Loon Lake, core	1070-1090 Ma
Uplift, erosion sedimentation	ca. 1080 (8)	Flinton Group	ca. 1080 Ma 20-30 Ma gap
Metamorphism/ Isotopic Resetting	ca. 1100(r)(1) 1107±35(r)(9)	Apsley Gneiss meta- somatism	ca. 1100-1110 Ma
Syntectonic Plutons	1104±25(z)(2) 1120±30(r)(4)		1100-1120 Ma 100+ Ma gap
Syenite Suite	1219±18/-12(z)(6) 1258±41(r)(7)	Laronde Ck. stock Blue Mtn. syenite	1220-1250 Ma
Mafic Intrusions	1238(z)(1) 1243(z)(1) 1247±32(r)(1)	Tallan Lake Sill " " " " " "	1240 Ma
Early Plutons	1226±25(z)(2) 1254(z)(5) 1205(z)(1)	Weslemkoom Hinchinbroke Loon Lake rim	1230-1250 Ma
Volcanism	1286±15(z)(2) 1250(z)(3) 1240±50(r)(4)	Tudor Volcanics(Hermon Gp.) Oak Lake volcanics Tudor Volcanics	1250-1290 Ma 40 Ma gap
Basement/Older Rocks	1333±24(r)(1) 1410-1500(r,z)(13,14)	Apsley gneiss granite plutons, Central Gneiss Belt	1330 Ma

Table 2.2: Chronology of geologic events, Elzevir and Bancroft Terrains, Southeastern Ontario (from Easton, 1986).

B.P.) Event	Comment
100 Westport and related plutons D ₁ -gentle warping	catazonal?
150 Emplacement of pegmatite M ₁ -intermediate grade metamorphism D ₁ -northeast trend D ₂ -isoclinal folds Deposition of mature to immature clastic sedimentary rocks	Flinton Group
25 - M ₁ [*] , high grade metamorphism - Emplacement of quartz monzonite and potassic granites (catazonal) - Emplacement of late gabbro, diorite and nepheline syenite - Emplacement of mafic sills and dykes - Emplacement of diorite, trondhjemite and soda granite (mesozonal) - M ₁ ⁺ , low grade to intermediate metamorphism	BDS. units 2 & 3
50 - D ₁ , northeast trend - Emplacement of albite granites and syenites (epizonal) - Deposition of basic to intermediate volcanic rocks, carbonates, feldspathic metasandstones (base not exposed)	BDS. unit 1 Hermon and Mayo Groups = Grenville Supergroup
BDS = biotite-diorite series of Lumbers (1967) D = period of deformation M = metamorphic event M ⁺ = subdivision of metamorphic event	

Table 2 3: Proposed sequence of geological evolution of the Grenville Supergroup in Southeastern Ontario (from Lumbers, 1967, and Moore and Thompson, 1972).

Supergroup rocks. These are based on models proposed by Brown et al (1975) and Baer (1967) which were mentioned briefly in the context of the Grenville Province as a whole.

In terms of the Supergroup, Brown suggests that ultramafic rocks beneath the base of the metavolcanic sequence in southeastern Ontario are representative of material derived from the ocean floor. The granodiorites are considered to have been derived from the partial melting of the downgoing slab, and the marbles were deposited in a shallow continental sea behind the island arc. The conglomerate at the base of the Flinton Group is considered evidence of sediments from a continental source.

Baer (1976) on the other hand believes the Grenville Supergroup rocks to be rift-related rather than part of an island-arc. He states that the age of the Grenville rocks are of an age similar to areas located adjacent to the Grenville Front. He suggests that the Grenville Supergroup rocks were deposited within an aulocogene whose margins correspond roughly to the current eastern and western margins of the Supergroup. He theorized that the surface of the fault blocks would be the focus of volcanic material and deposition of coarse clastics. The Hermon and Mayo Groups would be in the fault zone and the Flinton on the fault blocks.

The problems with Baer's hypothesis as pointed out by Sangster and Bourne (1982) are:

- 1) In a rift situation, the Hermon and Mayo groups should be a similar age being deposited in an aulocogene. The earliest evidence of rifting (1285 Ma Rb-Sr) post dates the formation of the two groups;
- 2) Lead isotope data indicate little significant contribution to the Supergroup rocks by continentally derived material; and
- 3) There appears to be a considerable gap in age between the Hermon/Mayo and Flinton Groups. The Flinton Group is only cut by pegmatites whereas the Hermon and Mayo Groups are cut by a variety of intrusives of varying composition.

2.1.4 Mineral Deposits

A variety of mineral deposit types occur in the CMB. Easton et al (1986) grouped these into metallic and industrial mineral deposits as shown in table 2.4. They outlined the genetic processes responsible for the deposition of each of these types of minerals. For the metallic deposits the four processes were:

1. SYNGENETIC VOLCANIC AND SEDIMENTARY DEPOSITS
 - ⇒ A. Stratabound pyritic sulfides
 - ⇒ B. Stratiform zinc
 - ⇒ C. Stratiform Cu-Sb-Ag-Hg-barite
 - D. Stratiform quartz-magnetite ironstone
 - ⇒ E. Stratiform magnesium
 2. SYNGENETIC MAGMATIC DEPOSITS
 - A. Copper-nickel
 - ⇒ B. Iron-titanium
 3. EPIGENETIC DEPOSITS
 - ⇒ A. Contact metasomatic iron
 - ⇒ B. Gold-quartz vein
 - ⇒ C. Metamorphic-metisomatic molybdenum
 - D. Uranium
 - ⇒ E. Post-Oroviçian Ba-F-Sr-Pb veins
 4. SUPERGENE DEPOSITS
 - ⇒ A. Hematite
-
1. ORIGINAL SEDIMENTARY AND VOLCANIC DEPOSITS
 - ⇒ A. Calcium carbonate
 - ⇒ B. Dolomite
 - C. Barite
 - D. Anhydrite
 - E. Basalt
 - ⇒ F. Graphite
 2. METASOMATIC DEPOSITS
 - ⇒ A. Quartz (in veins)
 - ⇒ B. Talc-tremolite
 - C. Hematite
 - D. Mica
 3. METAMORPHIC DEPOSITS (all have some degree of primary compositional control)

⇒ A. Talc-tremolite	⇒ I. Brucite
⇒ B. Marbles	J. Fluorite
⇒ C. Graphite	K. Sillimanite
D. Garnet	L. Wollastonite
E. Vermiculite	⇒ M. Hematite
F. Zircon	⇒ N. Mica
G. Beryl	O. Stone
H. Apatite	
 4. IGNEOUS DEPOSITS

A. Feldspar	E. Beryl
B. Quartz	⇒ F. Mica
⇒ C. Nepheline	⇒ G. Stone
D. Zircon	H. Apatite

Table 2.4: Genetic classification of metallic and industrial mineral deposits of the Central Metasedimentary Belt (from Carter, 1984).

- 1) Syngenetic processes related to volcanism and sedimentation;
- 2) Epigenetic processes related to diagenesis, regional metamorphism, and igneous activity;
- 3) Magmatic processes related to igneous intrusion; and
- 4) Supergene processes.

For the industrial minerals the four processes responsible for the deposition of the suites were:

- 1) Original sedimentary and volcanic deposits, these being only slightly modified by later metamorphism;
- 2) Metasomatic deposits, commonly the result of circulation of heated fluids;
- 3) Metamorphic deposits, all of which have some degree of primary compositional control, particularly when it comes to economic deposits; and
- 4) Igneous deposits, where igneous processes are responsible for the mineral concentrations.

2.1.4.1 Chronology of Deposits.

Figure 2.6, 2.7, 2.8 are diagrams showing the general relationships between geology and mineral deposits over time. According to Easton et al (1986) the following events generally account for the occurrence of mineral deposits in the region:

SYNGENETIC VOLCANIC AND SEDIMENTARY

EPIGENETIC

Intrusives

Marble

Metaclastics

Metavolcanics

Figure 2.6: Stratigraphic setting of syngenetic and epigenetic metallic mineral deposits in the central Metasedimentary Belt.

Figure 2.7: Generalized relationship of geology and mineral deposits in the Grenville Province of Southeastern Ontario (from Sangster and Bourne, 1982).

Figure 2.8: Stratigraphic associations of metallic mineral deposits within the Grenville Supergroup (from Carter, 1984).

- 1) Erosion of the craton resulted in clastic detritus being deposited as sandstones of the Lower Grenville Supergroup. These may have been enriched in uranium derived from the craton to the north. The sandstones in turn being the source of the metamorphic concentrations of uranium;
- 2) Deposition of a suite of volcanic rocks then occurred in the CMB generally consisting of a basal volcanic sequence capped by a felsic volcanic succession. The New Calumet Zn-Pb-Ag deposit in southwestern Quebec is thought to be an example of volcanogenic exhalative activity;
- 3) Deposition of the carbonates and clastics of the Mayo Group occurred during and after deposition of the upper volcanic succession. Concentrations of Cu, Sb, Ag, Hg, barite and magnesium carbonates formed in the carbonate depositional environment. According to Easton et al (1986) some of the zinc deposits were closely associated with evaporite horizons and stromatolites.
- 4) Two intervals of plutonic intrusive activity occurred in the Grenville Supergroup. The first between 1250 and 1220 Ma being mainly dioritic, gabbroic, or tonalitic in composition, and the second between 1110 and 1070 Ma

2

MicroD

having a granite and granodiorite composition. The second intrusion was associated with the main periods of regional metamorphism. Plutons of both ages are being used as sources of building stone. Gabbroic intrusions of the first intrusion host Cu-Ni sulfides as segregations in ultramafic facies, or iron-titanium oxides within anorthositic facies. Contact metasomatic iron deposits were formed in carbonate rocks. Large talc-tremolite deposits formed as a result of contact metasomatism with granitic intrusions on carbonate and/or volcanic rocks.

- 5) The next geologic event was a period of consolidation and uplift and subsequent deposition and metamorphism of the Flinton Group. The metamorphic event resulted in the formation of pegmatite dykes and calc-silicate skarns, accompanied by the formation of concentrations of uranium and molybdenum. Graphite deposits formed as a result of the metamorphism of organic debris or reactions between silica and calcium-magnesium carbonates. In areas of low grade metamorphism, quartz-carbonate veins carrying gold, silver, and base-metals formed.
- 6) Further consolidation and uplift of the Precambrian rocks resulted in deposition of Paleozoic platformal

sedimentary rocks. Hematite from the Precambrian rocks was concentrated in the basal sandstones of the Paleozoic sequence and fractures in the underlying rocks;

- 7) The final major geologic event of the region was the block-faulting and formation of the Ottawa-Bonnechere graben. This fractured and faulted the Paleozoic rocks, and calcite-barite-fluorite-celestite-galenaveins formed in these structural zones on the up-dip margins of the Paleozoic sedimentary basins (Easton et al 1986).

2.2 BEDROCK GEOLOGY

2.2.1 Lithology

Bedrock within the study area is Late PreCambrian in age. All the lithologic units in the area have undergone regional metamorphism during the Grenvillian orogeny, including the igneous rocks. In general terms the northern half of the study area is granite and granite porphyry (see figure 2.9). The southern half is comprised of metavolcanic and metasedimentary carbonate/clastic rocks. The metavolcanics range from basalts to rhyolites. Syenite around Skootamata Lake in the south-west corner of the area is part of the much larger Skootamatta stock. These can be divided into four main groups; metavolcanics, early

Source: O.G.S. map 2053

SCALE
0 2 4km

- Granite gneiss
- Granite and syenite
- Paragneiss
- Marble
- Basic volcanic rocks

Figure 2.9: General geology of the Mazinaw Lake study area.

metasediments, intrusives, and late metasediments.

2.2.1.1 Metavolcanics

The composition of the metavolcanic succession ranges from basalt to rhyolite. The following is a brief description of the different metavolcanic units.

Basalt Metavolcanics

The oldest volcanic rocks are basalts occurring as pillow lavas, massive and amygdaloidal flows and autoclastic breccia. These occur south of Lower Mazinaw lake. According to Moore and Morton (1986), outcrops east of the Elzevir Batholith indicate a maximum exposed thickness of 5.5 kilometres in which individual flows vary from 1 to 15 metres thick. According to Brown et al (1975), a gabbro-diorite pluton with ultramafic inclusions cut by a mafic-intermediate dike system southwest of the map area, predates the Elzevir pluton. It underlies the basalt and is concordant with it, suggesting that it is a part of an oceanic crust on which the basalts were extruded. The basalts vary from fine-grained massive flows to fine-medium grained porphyritic types.

Andesite Metavolcanics

In the region around Lower Mazinaw Lake and west and south of Marble Lake, andesite flows, tuff breccia, and lapilli tuff overlie the basalts. Lapilli tuff and tuff breccia are the most widespread. These deposits consist of 20 to 70 percent angular to sub-rounded fragments. Individual units range from 2 to 100 metres in thickness. The fragments have been flattened and elongated to varying degrees. Fragments range from 2 millimeters to 1.5 metres across, averaging 6 centimetres in tuff-breccia and 1 centimetre in lapilli tuff (Moore & Morton, 1986). The fragments are composed of basalt, gabbro, andesite, diorite, quartz diorite, volcaniclastic rocks and minor dacite, enclosed by a fine to medium-grained matrix of sodic plagioclase, biotite, quartz, and hornblende. Andesite dykes can commonly be seen to cut through the upper part of the basalt succession.

Dacitic Metavolcanics

Dacite lapilli tuff and tuff breccia occur south of Marble Lake and southwest of Kashwakamak Lake. The dacites are distinguished from the andesites by a lower colour index and by the presence of relict quartz and plagioclase phenocrysts (Moore & Morton, 1986).

Stratigraphically, the dacitic tuffs overlie the andesite lapilli tuff. They vary from being layered to massive successions containing andesite and dacite rock fragments. The size of fragments increases to the west where dacite stocks and dykes are exposed south of Kashwakamak Lake. The stocks sometimes contain disseminated pyrite and chalcopyrite, and in places are cut by quartz-biotite-potassic feldspar stringers carrying pyrite, chalcopyrite and bornite.

Rhyolite Metavolcanics

Rhyolitic pyroclastic rocks occur in a limited area around Lower Mazinaw Lake. Rhyolite dikes are common through the upper volcanic succession. These are quartz-plagioclase-muscovite rich. The pyroclastic rocks are typically layered and contain rhyolite, dacite, and andesite fragments.

2.2.1.2 Early Metasediments

The first succession of metasediments were divided into the following 5 units by Moore and Morton (1986): clastic mafic metasediments, clastic intermediate to felsic metasediments, sulphide graphite metasediments, and carbonate and clastic metasediments.

Clastic Mafic Metasediments

Clastic mafic metasediments are exposed only in a very limited extent south of Lower Mazinaw Lake. The unit is interlayered with basalt and bedded to massive in nature. The rocks are composed of amphibolite, calcite, chlorite, epidote, and plagioclase with lesser amounts of talc, magnetite, hematite, pyrite, pyrrhotite, arsenopyrite, biotite and quartz. Bed thickness ranges from 5 centimetres to 4 metres. Gold prospects are associated with the metasediments.

Clastic Intermediate to Felsic Metasediments

This unit occurs directly south of Lower Mazinaw Lake. It is a thick succession of metasediments similar in mineralogy to andesite and dacite. Beds are several metres thick. Graded bedding and soft sediment deformation are present.

Sulphide-Graphite Metasediment

In their report Moore and Morton (1986) note the occurrence of black fine-grained sulphide bearing metasediments as interflow layers in the basaltic metavolcanics. They are thinly laminated, intensely folded

and weathered to gossan in limited exposures. The main constituents are quartz, sodic plagioclase, biotite, muscovite and approximately 10% pyrite and pyrrhotite.

Carbonate and Clastic Metasediments

North of the town of Cloyne along highway 41 are lenses and beds of dolomite and calcite marbles, sandy dolostone, dolomitic siltstone and wacke. The beds vary from 5 centimetres to 15 metres thick. Primary sedimentary features are present. The rocks are primarily calcite and dolomite with hornblende, quartz, muscovite, chlorite, garnet and staurolite. Irregular grains of quartz and plagioclase (2 mm. to 1 cm.) are in a finer carbonate-quartz-plagioclase-biotite matrix. The grains are elongated parallel to the primary layering.

Carbonate Metasediments

Carbonate metasediments occur extensively in the south-east portion of the study area around Marble, Mississagagnon and Kashwakamak Lakes. They occur unconformably over the metavolcanic succession. They consist of massive and layered fine to coarse grained marble. Four different units were identified by Moore and Morton (1986): 1) unit dominated by dolomite; 2) unit dominated by calcite;

3) calcite/dolomite marble with small mafic to intermediate intrusions; 4) calcite/dolomite marble with numerous wacke beds.

Disseminated and massive strings of pyrite occur in beds north of Marble Lake and south of Kashwakamak Lake. Actinolite and tremolite are also abundant north of Marble Lake. Minor quantities of gold, lead, zinc, copper, antimony, arsenic and tungsten are associated with the marble units.

2.2.1.3 Intrusives

Five intrusive units occur in the study area. These are; mafic and ultramafic rocks, intermediate rocks, felsic to intermediate rocks, Mazinaw Lake granite, and the Skootamatta Stock.

Mafic and Ultramafic Intrusives

Dikes, sills and small plutons of gabbro, hornblende and peridotite occur scattered throughout the study area. Dikes and sills cut through all the metavolcanic and early metasediments. Mineralogy is similar to the basaltic rocks except that the peridotite contains talc and serpentine (Moore & Morton, 1986). Textures vary from medium to

coarse grained augen schist. Hornblende porphyroclasts are contained in a matrix of plagioclase.

Intermediate Intrusives

Fine to medium grained equigranular and porphyritic intermediate stocks and dykes occur east of Lower Mazinaw Lake and south of Pringle Lake. They are thought to be high level intrusions related to andesitic volcanism since they contain basalt and andesite fragments, however, they are cut by andesite and dacite dykes. Mineralogical composition is plagioclase, hornblende, biotite, quartz, chlorite, and epidote with accessory muscovite, sphene, apatite, magnetite, pyrite, chalcopyrite, and bornite. Minor quantities of pyrite and chalcopyrite occur around Pringle Lake.

Felsic to Intermediate Intrusives

The Elzevir batholith has intruded the volcanic succession in the western part of the study area. This varies from granodiorite to diorite which are medium or coarse grained and massive to well foliated (parallel to adjacent metavolcanics). The granodiorite is comprised of oligoclase, microcline, biotite and quartz with accessory muscovite, epidote, hornblende, sphene, zircon, allanite and

magnetite.

Mazinaw Lake Granite and Small Potassic Intrusions

The Mazinaw Lake granite occurs extensively in the northern half of the study area. It is a fine to medium-grained equigranular to porphyritic intrusion that is gradational into dacite and rhyolite flows and tuff north of Tiny Shabomeka Lake.

The granite and associated felsic metavolcanics consist of microcline, albite, quartz, magnetite, and biotite, with or without hornblende, sphene, apatite, muscovite, and pyrite.

Skootamatta Stock

Skootamatta syenite underlies a large portion of Angelsea Township. In the study area it occurs around Skootamatta Lake. The syenite is intrusive into the basalt and diorite of the Elzevir batholith. The contacts are sharp with a few fragments of basalt occurring in the syenite.

2.2.1.4 Late Metasediments - Finton Group

Bishop Corners Formation

The Bishop Corners formation of muscovite schist, garnet-biotite schist, and quartzite occurs along the Fernleigh syncline between the younger Myer Cave formation and the early carbonate metasediments. At the base of the unit is 6 metres of biotite schist which grades from chlorite-hornblende schist and up to quartz muscovite schist (Moore & Morton, 1986). It contains magnetite porphyroblasts with minor garnet and staurolite in a matrix of quartz, oligoclase, apatite, and pyrite. Above the schist is 15 metres of white fine-grained quartzite with muscovite, kyanite, hematite, and tourmaline. Cross-bedding and hematitic laminae are present. Above the quartzite is a oligomictic conglomerate comprised of well rounded and sorted pebbles and cobbles of quartzite in a micaceous quartzite matrix. Clasts are 10 to 20 centimetres long.

Myer Cave Formation

A fine-grained dolomitic marble making up the Myer Cave formation is exposed along the Fernleigh syncline. Overlying metasediments are comprised of fine-grained black pelite and dark grey marble in 3 to 10 metre layers. The upper unit of the formation is characterized by coarse

carbonate clast conglomerate and breccia beds. Clasts are angular to sub-rounded, poorly sorted, and 1 millimetre to 1 metre in length.

2.2.2 Structural Geology

Due to the intrusive and metamorphic events which have taken place in the region, it has been difficult for geologists to map the geometry of the rock units. The pre-Flinton successions lie in a broad northeast trending syncline closing westward and ringed by plutons (Moore and Morton, 1976). The topographic lows containing Mississagagon and Kashwakamak lakes are basins in the underlying carbonates. The discordance at the base of the Bishops Corner formation indicates deformation of the carbonate succession. Variable fabric orientations in amphibolites indicate pre syn-intrusive (pre-Flinton) metamorphism. This could have occurred in conjunction with the emplacement of the plutons.

The northeast trending syncline is isoclinal with sharp hinges. Schistosity and foliation is parallel to the axial traces and represents the first post-Flinton deformation. The parallel nature of the limbs and schistosity suggests fold hinge lines are mainly sub-horizontal. The Fernleigh syncline is steeply

overturned southeastward.

Flattening of clasts in the Flinton Group indicate strain, particularly in the more ductile clasts. Linear strain features plunge northeast.

2.2.2.1 Folding

Folds from the first deformation are somewhat variable and sub-parallel to extension features. Cleavage-bedding in the Hermon metavolcanics show minor and major folds plunging 60 to 70 degrees northeast. Conglomerate clasts of the Flinton Group on the other hand show the principal strain direction to be oriented steeply southwest.

Second post-Flinton deformation has folded the primary deformation surfaces. Crenulations, kink bands and regional bedding of the metasedimentary/metavolcanic fold belts around the major plutons suggest a third deformation phase late in the geologic history.

2.2.2.2 Faulting

A number of lineaments have been observed in the area where the position of rock units indicate a fault; however, little displacement can be observed. Interpretation of a

fault along the north limb of the Fernleigh syncline is based on prominent schistosity and lenticular quartz veining typically in the Flinton pelite (Meen 1944, Hewitt 1956, 1964). There is, however, no discontinuity other than the unconformity. Similarly, another fault indicated by Meen (1944) and Hewitt (1964) southward from Lower Mazinaw Lake could not be identified with significant displacement.

The escarpment down the east shore of Lower Mazinaw Lake is interpreted by Moore and Morton (1986) to be of tectonic origin since there is no evidence to support horizontal or vertical displacement. An early fault has been interpreted south of the lake due to volcanic and volcanic-sedimentary succession changes across the projection of the lineament. Moore and Morton (1986) indicate that many smaller faults, perhaps of significant magnitude have gone unnoticed since they strike sub-parallel to layering and have been metamorphosed and deformed.

West-northwest trending lineaments occur around Mississagagon Lake. These are veins containing calcite, borite, and fluorite. These may have been active in Lower Paleozoic time.

2.2.3 Geologic History

Interpretations by Moore and Morton (1986) and Condie and Moore (1977) support the island-arc theory for the tectonic evolution of the area. A thick succession of submarine tholeiites were extruded (metavolcanic basalts) followed by eruption of more silicic tholeiites, carbonate sedimentation and/or calc-alkalic volcanism. The tuffs and volcanic clastics contributed to the carbonate basins. When the volcanic activity ended the tholeiites were covered by carbonate rocks. In the latter stages of volcanism it is suggested that large masses of diorite and granodiorite magma intruded on the lower part of the succession. The volcanics were domed and metamorphosed resulting in the metamorphic grade decreasing outward from narrow aureoles to a low regional metamorphic grade.

A period of uplift under tropical conditions was followed by deep weathering resulting in a thick oxidized regolith. Subsequent erosion of the regolith in Flinton time resulted in red shales, sandstones and conglomerate in local basins. With continued uplift detritus became less mature and included feldspar and lithic clasts derived from the batholiths. A northward paleoslope is demonstrated by fluvial sedimentation to the south and shallow marine conditions to the north.

Deformation about northeast trending variable plunging axes and regional metamorphism followed deposition of the Flinton Group. No further activity occurred until the Mesozoic when the region was block faulted for the Ottawa Valley graben system.

Metal deposits occurred first during periodic volcanic inactivity and with the emplacement and cooling of small intrusions in the volcanic centres. Volcanic activity concurrent with carbonate deposition resulted in metals from local fumaroles being deposited in the carbonates. During the period of erosion of regolith and basement rocks, metals from the basement were precipitated in some carbonate and clastic facies.

2.3 QUATERNARY / SURFICIAL GEOLOGY

Surficial geology of the study area has been mapped at a scale of 1:125,000. This was published in 1972 by the Ontario Geological Survey (Surficial Geology of Kingston (north half) Map Area, Ontario).

The area is largely covered by a thin discontinuous sandy till cover as well as muck and peat deposits in poorly drained lowlands. The area south of Lower Mazinaw and Marble Lakes was a glacial spillway. Glacial striae

indicate ice direction to the south-southwest. Ice-contact stratified drift occurs on the western shore of Mazinaw Lake adjacent to the narrows and south of Lower Mazinaw and Marble Lakes. In this area the surficial deposits are not important to the model due to their uniform nature.

2.4 PHYSIOGRAPHY

The terrain is generally of low relief ranging from an elevation of 26 metres (850 ft.) at Big Gull Lake, to 37 metres (1220 ft.) on the east side of Lower Mazinaw Lake. The east half of the study area consists generally of southwest-northeast trending ridges and valleys. The west half tends to have a more undulating topographic expression with some trends occurring in a northwest-southeast direction. Near vertical cliffs occur along the east shore of Mazinaw Lake where the main lake and Lower Mazinaw Lake come together. These cliffs are referred to as Mazinaw Rock and Old Walt Rock. Both are within the Bon Echo Provincial Park boundaries.

The drainage system follows the topographic trends previously stated, with swamps occurring in topographic lows and in flat lying areas adjacent to lakes. The rivers and lakes are part of the Mississippi system which flows into the Ottawa River.

2.5 METALLOGENY

Two groups of metallic mineral deposits have been documented in the area. The first is lead-zinc-gold mineralization in the volcanogenic metasediments, and in carbonate metasediments directly overlying the metavolcanics, also in and at the base of the Flinton Group. The second is copper and associated sulphide mineralization in metavolcanics and associated shallow intrusive rocks and in some volcanogenic metasediments (Moore and Morton, 1986) (see figure 2.10).

2.5.1 Metasedimentary Associated Pb-Zn-Au

Moore and Morton (1986) identify two types of lead-zinc-gold mineralization in the pre-Flinton metasediments within or overlying metavolcanics. The two groups are as follows:

- 1) pyrite, sphalerite, and arsenopyrite with or without pyrrhotite, galena, and gold, in basaltic interflow metasediments; and
- 2) galena, sphalerite, chalcopyrite, and pyrite with

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scale 1:100 000

337000 m.E 4965000 m.N

Figure 2.10: Location of mineral occurrences.

1. Star Gold Mine	Au, ZnS, CuFeS ₂
2. Star Gold Mine	Au, ZnS, CuFeS ₂
3. Helena Occurrence	Au, Mo
4. Big Dipper Occurrence	Au
5. Mazinaw Base Metals	ZnS, PbS
6. Cook Occurrence	Au, Pb, Cu, ZnS
7. Stead Occurrence	Au, ZnS
8. Camgar Occurrence	Au
9. Buffadison Occurrence	Cu, ZnS, CuFeS ₂

or without arsenopyrite and gold, in dolomitic or calcitic marble overlying metavolcanics.

In group one mineralization is associated with calcite, magnetite, hematite, quartz, zoisite, amphibole, and chlorite in bedded rocks. These are thought to represent sediments derived from basaltic flows and tuff. Gold occurs in quartz veins and stringers within the metasediments and appears associated with pyrite and arsenopyrite.

The second type of mineralization occurs stratigraphically close to the main volcanic succession. They occur in quartz carbonate vein systems in association with tourmaline, and interbeds of andesite-dacite tuff or tuffaceous wacke.

The occurrence of sulphide mineralization in the Flinton Group likely resulted from the erosion of metals from the pre-Flinton volcanic rocks and subsequent concentration in a favourable sedimentary environment. The sulphide mineralization occurs in the dolomite horizon of the Myers Cave Formation

2.5.2 Metavolcanic Associated Sulphides

Three distinct sulphide assemblages have been identified which are associated with the metavolcanics and intrusive rocks. These are based on the following mineralogy and rock associations:

- 1) pyrite and pyrrhotite with traces of chalcopyrite occurring in basalt flows, peridotite, gabbro, andesite flows and tuff, and rhyolite flows and tuff;
- 2) pyrite and magnetite (with or without chalcopyrite) and arsenopyrite in rhyolite flows, tuff and associated granitic intrusions; and
- 3) pyrite and chalcopyrite with or without bornite and chalcocite, occurring in quartz diorite, diorite, dacite porphory stocks and andesite-dacite metavolcanics.

The first type is found abundantly as disseminations, amygdaloidal fillings, narrow stringers, and rims around mafic fragments. They appear to be related to either circulating meteoric waters immediately after deposition or during metamorphism, or to small fumarolic vents far removed from the centres of volcanism (Moore and Morton, 1986).

The second type is composed of magnetite porphyroblasts and stringers associated with single crystals of pyrite,

with traces of chalcopyrite and arsenopyrite.

The third type is suggestive of the "porphyry copper" type of deposit. The sulphide minerals occur as disseminations, single veins, or stockwork stringers associated with diorite, quartz diorite and dacite porphyry stocks. The Euffadison Occurrence east of Lower Mazinaw Lake is the only example of this type of deposit in the area. Deposits associated with metasediments could represent exhalative sulphide deposition associated with periods of quiescence between or after submarine eruption of basaltic flows (Moore and Morton, 1986).

CHAPTER 3: DATA ACQUISITION

In any exploration program, a geologist does not rely on a single set of data to meet the information needs of the program. Different data types have differing strengths and weaknesses. Efficient exploration programs are those that define the information needs and employ the appropriate methods or technologies to meet those needs.

3.1 REMOTE SENSING DATA

The remote sensing data acquired in this research is commercially available at varying costs. Since the emphasis of the thesis is to develop an approach which is compatible with the present needs and capabilities of the industry, the use of experimental sensors was not encouraged. In deciding upon the types of remote sensing data to be used three factors were considered:

- 1) The Biophysical Environment
- 2) The Size of the Area Being Explored
and
- 3) The Geological Environment/Characteristics

These three factors represent crucial decisions which are required at the project planning phase of the exploration program. The correct decisions require informed or 'expert' knowledge. The order in which these factors are listed may

appear wrong at first glance. The driving force of the thesis model is the requirement for specific geologic information to prove or disprove the mineral deposit model, which suggests the third factor should be considered first. To explain the order presented, the fundamentals of remote sensing must be considered as outlined in chapter 1. Remote sensing sensors, whether in the visible, infrared, or radar wavelengths, detect energy interactions with earth surface features. Therefore, any geologic information to be derived from the imagery is manifested in some expression at the earth's surface. In the majority of cases in Canada, it is the cover of vegetation which must represent geological conditions beneath the surface. As a result, the visible/reflected infrared sensors are most appropriate since vegetation has the most dynamic reflectance characteristics in these wavelengths, particularly in the infrared portion of the spectrum.

There is of course an exception to every rule. While radar data provides relatively little vegetation information (this will be illustrated in section chapter 5), it is excellent for detecting geological lineaments due to the frequent correlation between lineaments or structures and changes in topography. The side looking scanning geometry of airborne radar systems enhances subtle terrain features. Topography has always played a key role in photo interpretation. Identification of different geologic features

is often made possible by the geomorphology at the earth's surface. For this reason, a digital elevation model was obtained for the study area.

The second factor, the size of the area being explored, determines the spatial resolution of the data which is required. If the area is several hundred square kilometres in size, the use of high resolution airborne multispectral data (1-10 metres) is inappropriate until more specific areas can be identified. Satellite data would provide the means to view the entire region and extract information which would enable selection of smaller target areas for more detailed investigations. Satellite-based sensors also vary in spectral resolution from 10 metres (SPOT Panchromatic) to 1.1 Kilometres (NOAA AVHRR). The latter is most appropriate for continental scale investigations.

The third factor, geological environment and characteristics, at the early planning stages plays a less significant role than during the later phases of data processing and interpretation. An example where this is significant is in the planning of the actual data collection mission for radar. If the majority of structures trend in a north-south direction the radar should be flown with the look direction perpendicular to this, either east or west.

3.1.1 Landsat Thematic Mapper

The Grenville study area has near continuous vegetation cover of mixed coniferous and deciduous species. This dictates the use of a visible/infrared type of sensor in order to employ the geobotanical strategic approach as discussed in section 1.4.1.1. The size of the study area is relatively small (30x30 kilometres). It was kept small so that investigations could be carried out in sufficient detail to develop the exploration model.

Preliminary investigations into background geobotany in the Sudbury Basin compared Landsat TM (30 metre spatial resolution) and Landsat MSS (60X80 metre spatial resolution) resolutions. Results indicated that the two data types often provided complementary information. The TM sensor, however, did provide more information at a less regional and more detailed level (Hornsby & Bruce, 1985). This is attributed to its greater spatial and spectral resolutions. The MSS sensor has four broad bands in the visible and infrared portions of the spectrum between 0.5-1.1um while the TM sensor has six more narrow bands in the visible and infrared from 0.45-2.35um. A TM image was therefore obtained for the study area. This was imaged June 22, 1984. This date ensured all vegetation types would be in leaf thereby eliminating the possibility of seasonal differences.

3.1.2 Airborne Radar

Airborne radar data was acquired for the detection of geologic lineaments. Two systems were flown; the STAR-1 system (Intera Technologies Ltd., X-band) and the C-SAR system (CCRS, C-Band). Characteristics of these two scanners are provided in table 3.1.

The dominant structural and topographic trends in the area are northeast-southwest, and to a lesser degree north-south. Flight lines were planned parallel to these directions in order to have a perpendicular look direction. Unfortunately, insufficient coverage was acquired of the study area to meet the needs of the investigations. The data was therefore used to supplement lineament interpretations made on the Landsat data.

3.2 GEOPHYSICAL DATA

Geophysical data was obtained in digital form from the Geological Survey of Canada. The digital data was received at a pixel size of 100 metres by 100 metres. This was resampled to 30 by 30 metres for integrating with the remote sensing data sets.

STAR-1 SPECIFICATIONS

C-SAR SPECIFICATIONS

Wavelength	X-Band	C-Band
Polarization	HH	HH, HV, VH, VV
Viewing Direction	Left or Right	
Operating Altitude	17,000-33,000 ft.	
Recording	On-Board full bandwidth digital recording of image data	
Image Data Format	Digital 4096 8-bit Pixel/Scan Line	

	High Res.	Std. Res.	High Res.	Std. Res.
Ground Swath Width (km)	23	46	18	64
Range Pixel Size (m)	6	12	5	19
Azimuth Pixel Size (m)	4	4	6	10
Azimuth Looks (#)	7	7	7	7

Table 3.1 : STAR-1 / C-SAR airborne Radar specification

3.3 GEOCHEMICAL AND BIOGEOCHEMICAL DATA

Geochemical data was obtained from the Geological Survey of Canada, Terrain Sciences Division, and from sampling in the field. Till was sampled on the basis of variance interpreted in the Landsat imagery in order to characterize terrain types. Leaf samples were also taken in order to try to identify biogeochemical anomalies. Maple and Oak were sampled since they were most consistently distributed over the study area. Figure 3.1 identifies field sampling locations in the study area. Absolute values by element are provided in Appendix 2. The need for geochemical and biogeochemical data was considered significant since the geobotanical strategy relies on biogeochemical associations.

3.3.1 Field Sampling

Thirty-seven till samples were collected over the study area. These were taken below the soil horizon in material which could be positively identified as glacial in origin. The till cover in the area is thin and relatively homogeneous being a reddish-brown sandy composition with sub-angular to sub-rounded pebble sized clasts. The samples were prepared for analysis by seiving through a 200 mesh screen.

Vegetation was also sampled and analyzed for chemical

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Figure 3.1 : Field sample locations.

constituents. A total of 36 sites were sampled. Either oak or maple were sampled or both depending on the occurrence of these species at the sample locations.

Geochemical sampling was carried out during reconnaissance and detailed phases of investigation.

3.4 GEOBOTANICAL DATA

Fundamental to this exploration model is the establishing of geobotanical relationships at the community level early in the reconnaissance phase of investigation. This is accomplished through the combined interpretation of the Landsat data for identifying areas of homogeneous response, and the subsequent description of associated sites in these areas in terms of the plant community, surficial and bedrock geology. For each site a detailed description was recorded based on the parameters in table 3.3.

3.4.1 Digital Elevation Model

A digital elevation model was produced of the study area by the Surveys and Mapping Branch of Energy Mines and Resources Canada. Topographic information such as contours and point elevation were taken from 1:50,000 scale maps of the area and rasterized. A linear transformation was utilized to

CATEGORY	CRITERIA	
Terrain	Elevation Slope Aspect Roughness	
Soil	pH % Moisture	
Surficial Geology	Origin Landform Texture Orientation Sorting Colour	clay/silt/sand/gravel
Bedrock	% Outcrop Rock Type Primary Minerals Textures Structures	
Vegetation	Species Crown Closure Understory Ground Cover	% of mix height diameter

Table 3.3: Categories of field data collected.

distribute the range of elevations into 256 intensity levels.

3.5 SUMMARY OF DECISIONS

As stated at the beginning of this chapter, decisions related to remote sensing data acquisition relate to three factors; the biophysical environment, the size of the area being explored, and the geological environment characteristics. The following questions identify and describe the decisions required for deciding upon the type of remote sensing data required:

Question: Is the area vegetated with <10% outcrop?

Explanation: Geobotanical investigations have demonstrated that in areas of vegetated terrain visible and infrared wavelengths, in particular the red and near to middle infrared, provide optimal results.

Inference: The use of sensors sensitive to the red and infrared portions of the spectrum is recommended.

Question: Is the area of exploration interest: a) >8100sq. km., b) 225 - 8100 sq. km., c) <225 sq. km. in size?

Explanation: The size of the area will influence the spatial resolution required. Reconnaissance requires relatively low resolution to identify major structures and geological characteristics. The detailed phase of exploration will require greater spatial resolution once specific areas have been identified for further exploration activity.

Inference (a) LANDSAT MSS with a spatial resolution of 60 x

80 recommended. If structure of particular interest SEASAT data may be used in addition to the MSS data.

Inference (b) LANDSAT TM with a spatial resolution of 30 x 30 metres is recommended. Airborne radar data is recommended for structural investigations.

Inference (c) Airborne multispectral data may be used for the level of investigations where specific point targets may be selected.

Question: Have you identified geobotanical associations?

Explanation: In areas of vegetated terrain, understanding geobotanical relationships is required for interpretation of the remote sensing data

Inference: Associations exist between underlying bedrock surficial materials, soils and vegetation. Geological interpretation of the data sets is possible.

CHAPTER 4: DATA PROCESSING

The data processing stage of the exploration strategy consists of three distinct parts: image correction, image enhancement and image classification. Image correction involves the transformation of the original raw data, in order to account for radiometric and geometric distortions. The radiometric corrections to the data are necessary to correct for regular and irregular discontinuities which have been caused by sensor miscalibration and initial signal processing, or atmospheric influences such as haze. Image enhancement consists of the digital manipulation of the data in order to improve the visual interpretability. The image classification portion of the data processing stage consists of the interactive grouping of the data (pixels) into classes of known physical characteristics based on the geologists' knowledge of the area. The subsequent statistical grouping of the digital data is based on this location dependent knowledge.

The three data processing steps occur at different times in the exploration strategy. The corrections occur immediately after the data acquisition phase in order to transform the data into a consistent useable data set.

Image enhancement may occur several times during the

analysis. Typically, preliminary enhancements are produced in order to become familiar with the terrain and to plan supporting field investigations. Visual interpretations are made from the enhanced images by the geologist using standard photogeologic techniques. Other enhancements may be made after more location dependent information is obtained on the area under investigation. This permits alteration of specific parameters within the enhancement procedures, thereby optimizing the enhancement.

Image classification is a final procedure in image processing. After the terrain has been characterized in accordance with the data, other areas may be mapped by the statistical grouping of the pixels based on similar spectral response characteristics. In this way a thematic representation of the original data is produced.

The data processing phase also involves the manipulation of other data sets for later integration with the remote sensing data. Supporting geochemical and geophysical data is processed in order to make the data geometrically compatible with the remote sensing images. This, however, is undertaken after the image interpretation phase. Integration of the interpretations from the different data sets in terms of their geologic information is necessary. Integration of the initial data sets in some cases may be desirable, but often the best

way is to integrate the resulting geologic interpretations in order to prove or disprove the working model of mineralization. There exists the hazard of combining data sets which use different energy sources and thereby detect different physical characteristics of the earth surface phenomena.

The processing of the remote sensing data may be readily subdivided into the three levels of exploration. Definition of the variables in each of the techniques may be varied depending on the characteristics of the data.

4.1 RECONNAISSANCE - Exploration Phase 1 Correction / Enhancement

Image processing in the Reconnaissance phase falls into two of the steps, correction (radiometric and geometric) and enhancement. The objective is to transform the data to remove error or distortions in the radiometry and geometry (see figure 4.1).

4.1.1 Radiometric Correction

Many of the radiometric distortions are removed from the satellite data on board the platform or at the receiving

Figure 4.11: Histogram of principal component 2.

Figure 4.12: Histogram of principal component 2 after linear stretch.

station. The LANDSAT TM data acquired for this work displayed no radiometric distortions; therefore this image processing method was not required.

4.1.2 Geometric Correction

The geometry of the TM data was corrected using an algorithm which resamples the data based on the transformation established between point locations identified on the image and the corresponding points on an NTS 1:50,000 topographic map (Canada, 1978).

Before further image processing was performed a mask was created over the water bodies in the scene. The mask was then used to write an intensity value of 0 to all the pixels associated with water. By performing this operation, enhancements could be optimized for land since only the land areas would have a spectral response greater than 0. The same operation was performed for an area in the southwest portion of the study area. That area was removed since errors existed in the digital elevation model (DEM).

4.1.3 Contrast Stretch Enhancement

A linear contrast stretch enhancement was performed on TM bands 3,4 and 5 (Lillesand & Kiefer, 1979). These bands

have been found to be optimal for enhancing vegetation (Hornsby and Bruce 1985). Minimum and maximum intensity values were selected from the histograms allowing areas of little information in the tails of the data distribution to be excluded. These values were mapped over the full dynamic range of 0 to 255 (see figures 4.2 to 4.7)(Appendix D). The following minimum and maximum intensity values were used:

	MIN	MAX
TM band 3	15	24
TM band 1	73	135
TM band 5	45	95

Figure 4.8 is the resulting enhanced image.

4.1.4 Principal Component Enhancement

A principal component enhancement was performed on the data in order to derive an enhancement for visual interpretation (Lillesand & Kiefer, 1979). The resulting colour rendition from this algorithm represents variance within the image. The statistics calculated for the transformation are provided in table 4.1.

The resulting enhancement required a contrast stretch to be applied in order to distribute the data over the full 0 to 255 dynamic range. The following minimum and maximum intensity values were used (see figures 4.9 to 4.14).

Figure 4.4: Histogram of TM band 4.

Figure 4.5: Histogram of TM band 4 after linear stretch.

SCALE 1: 98679, 1: 98679 SIZE: 15.4KM, 15.4KM OFFSET: . KM, . KM
 FILE:HAZENH.PIX DATE:07-APR-89
 RED: LUT :Input Channel: 3 LUT Segment(6):str
 GREEN: LUT :Input Channel: 4 LUT Segment(7):str
 BLUE: LUT :Input Channel: 5 LUT Segment(8):str
 TM bands 3,4,5 Contrast Stretch Enhancement (PAGE)

Figure 4.8: Contrast stretched enhanced composite image
 of TM 3,4,&5.

Input Channels: 1 2 3 4 5 6
 Output Channels: 7 8 9
 Eigen Channels: 1 2 3
 Sampling Window: 0 0 512 512
 Sampling Bitmap: none used
 Sample size : 2401

Channel means:
 53.31 21.92 16.69 76.14 49.26 15.09

Channel deviations:
 23.37 9.80 7.71 49.93 31.91 9.04

Covariance matrix for input channels:

546.33					
222.50	96.05				
170.42	73.85	59.48			
809.36	394.94	285.13	2492.80		
533.21	261.51	197.50	1540.30	1018.11	
158.68	76.67	60.57	403.72	277.35	81.72

Eigenvalues of covariance matrix:
 .4E+04 .3E+03 .5E+02 .5E+01 .2E+01 .5E+00

Eigenvectors of covariance matrix:

.29	.14	.10	.79	.50	.13
.86	.27	.23	-.34	-.10	.04
-.18	.03	.17	-.50	.75	.37
-.26	.27	.55	.13	-.41	.61
-.23	.40	.55	-.02	.13	-.68
-.13	.82	-.54	-.03	-.01	.08

Scaling (whitening) values:

Eigen Channel	Output Channel	Min	Max	Range	Scale Factor	Bias Value
1	7	-104.675	88.230	193.905	1.320	138.195
2	8	-25.135	38.465	64.600	3.963	99.606
3	9	-24.094	49.468	74.562	3.433	82.725

Table 4.1: Statistical calculations for principal component enhancement. (Note: The sum of the diagonal elements of the covariance matrix equals the sum of the eigenvalues.)

Figure 4.11: Histogram of principal component 2.

Figure 4.12: Histogram of principal component 2 after linear stretch.

Figure 4.13: Histogram of principal component 3.

Figure 4.14: Histogram of principal component 3 after linear contrast stretch.

	MIN	MAX
PCE 1	140	230
PCE 2	40	110
PCE 3	40	140

The final enhanced image was displayed with PC1 in red, PC2 in blue, and PC3 in green to distinguish them more clearly. This is shown in figure 4.15.

4.1.5 Directional Filtering

Directional convolution filters were applied to TM band 5 in order to enhance lineaments recorded in the image (Hornsby et al, 1984). This algorithm increases the contrast between adjacent pixels which differ greatly in the values of their intensities. Four filter kernels, or matrices, were used to enhance in the following directions: north-south, northeast-southwest, east-west, southeast-northwest. Table 4.2 provides the kernels used in the filtering. Linear contrast stretches were applied to each filtered image as listed below (see figures 4.16 to 4.19). Figures 4.20 and 4.23 are the enhanced images corresponding to the directional filters.

	MIN	MAX
North - South	120	165
Northeast - Southwest	90	138
East - West	80	130
Southeast - Northwest	82	145

SCALE 1: 98679, 1: 98679 SIZE: 15.40M, 15.40M OFFSET: 10M, 10M
 FILE:HAZENH.PIX DATE:07-APR-89
 RED: LUT :Input Channel: 13 LUT Segment(10):pca
 GREEN: LUT :Input Channel: 14 LUT Segment(11):pca
 BLUE: LUT :Input Channel: 15 LUT Segment(12):pca
 Principal Component Enhancement of TM Bands 1,2,3,4,5,7 (PAC)

Figure 4.15: Principal component enhanced image.

North - South

1	1	1	1	1
1	1	1	1	1
0	0	0	0	0
-1	-1	-1	-1	-1
-1	-1	-1	-1	-1

Northeast - Southwest

0	1	1	1	1
-1	0	1	1	1
-1	-1	0	0	1
-1	-1	-1	0	1
-1	-1	-1	-1	0

East - West

-1	-1	0	1	1
-1	-1	0	1	1
-1	-1	0	1	1
-1	-1	0	1	1
-1	-1	0	1	1

Southeast - Northwest

-1	-1	-1	-1	0
-1	-1	-1	0	1
-1	-1	0	1	1
-1	0	1	1	1
0	1	1	1	1

Table 4.2: Convolution filter kernels for directional filtering of TM band 5.

SCALE 1: 199359, 1: 199359 SIZE: 15.4KM, 15.4KM
 FILE: FILTER.PIX
 LUT : Input Channel: 2 LUT Segment(1): STRETCH
 North Directional Filter TM Band 5

Figure 4.16: North filtered TM band 5.

Figure 4.17: Histogram for north filtered TM band 5.

SCALE 1: 199359, 1: 199359 SIZE: 15.40M, 15.40M
 FILE: FILTER.PIX
 LUT : Input Channel: 3 LUT Segment(1): STRETCH
 Northeast Directional Filter TM Band 5

Figure 4.18: Northeast directional filtered image.

Figure 4.19: Histogram for northeast filtered image.

Figure 4.20: East directional filtered image.

Figure 4.21: Histogram for east filtered image.

SCALE 1: 199359, 1: 199359 SIZE: 15.4KM, 15.4KM
 FILE: FILTER.PIX
 LUT : Input Channel: 5 LUT Segment(1): STRETCH
 Southeast Directional Filter TM Band 5

Figure 4.22: Southeast directional filtered image.

Figure 4.23: Histogram for southeast filtered image.

4.1.6 Unsupervised Classification

This image analysis method groups image pixels into a defined number of classes using a migrating means technique (Lillesand & Kiefer, 1979). It clusters four dimensional histogram data based on calculating means for each class. Pixels are then assigned to the class with which they are most statistically similar. TM bands 1, 3, 4 and 5 were used for the clustering. The algorithm calculates the squared distances between the histogram vector and each cluster mean for each entry in the histogram, and calculates sums of histogram vectors and counts for each cluster. An iterative process of calculating new cluster means occurs until all cluster means have moved less than the specified (in this case 9) distance threshold. The result of this operation is given in table 4.3.

Classification of the entire image was done using a maximum likelihood classifier which uses a gaussian threshold to determine if a given pixel falls within the class or not.

CLASS	MEAN				COUNT
1	.0	.0	.0	.0	42860
2	56.9	12.2	9.9	4.4	24964
3	61.4	16.0	16.0	11.9	10232
4	61.7	18.3	73.3	49.9	16008
5	61.6	18.1	94.4	59.6	36708
6	61.7	18.2	111.5	67.8	41813
7	62.3	18.9	128.3	78.3	51923
8	64.7	21.3	103.0	78.4	10274

Table 4.3: Cluster means and counts for unsupervised classification.

The threshold is the radius of a hyperellipse surrounding the mean of the class in four-dimensional space. Pixels not falling into any of the classes were assigned to a null class. The results of this operation are provided in table 4.4.

Class	Pixels	%Image
1	42860	16.35
2	17242	6.58
3	23268	8.88
4	24597	9.38
5	32435	12.37
6	38746	14.78
7	56585	21.59
8	24989	9.53
null	1422	.54
overlap	0	.00
Total	262144	100.00

Table 4.4: Number of pixels and percent of image covered by each class.

The classified image is provided in Chapter 5.

4.2 DETAILED EVALUATION - Exploration Phase 2 Classification / Integration

The detailed evaluation exploration phase relies on the input from interpretations made from the contrast stretch, principal component, and unsupervised classification enhancements combined with the field geobotanical measurements to produce a geobotanical classification. The availability of the digital elevation model allows a separate investigation

of the influence of the terrain components of elevation, slope, and aspect on the occurrence of the vegetation (see figure 4.24).

The objective of this phase of the exploration is to identify area targets having background geobotanical anomalies. Background anomalies may vary from approximately 100 metres to several square kilometres. The Prospect Evaluation level identifies specific targets. These background anomalies may be identified solely from the image data or in conjunction with other supporting geologic data sets such as geochemistry and geophysics.

4.2.1 LANDSAT TM-Based Geobotanical Classification

The image processing technique is referred to as a supervised classification (Lillesand & Kiefer, 1979). This involves the interactive procedure of identifying areas on the image of known geobotanical character and grouping the remaining image pixels based on these 'training areas'. The classification algorithm uses a maximum likelihood classifier to group the pixels, assigning them on the basis of statistical similarity to the mean intensity values of each class.

The vegetation community classes established from the field investigations are provided in table 4.5.

Figure 4.24: Data processing at the detailed level (part 1).

1)	Or/Ms	Or - <u>Quercus rubra</u> (red oak)
2)	Or/Ms/Be	Ms - <u>Acer saccharum</u> (sugar maple)
3)	Bw	Bw - <u>Betula papyrifera</u> (white birch)
4)	Bw/Po	Be - <u>Fagus grandifolia</u> (beech)
5)	Bw/Po/Ms/Or	Po - <u>Populus tremuloides</u> (trembling aspen)
6)	Bw/Po/Pw	Pw - <u>Pinus strobus</u> (white pine)
7)	Pw/Ce	Ce - <u>Thuja occidentalis</u> (white cedar)
8)	Swamp	

Table 4.5: Vegetation community classes. Order of species (x/y) indicates relative abundance from greatest to least.

In order to define anomalous occurrences of these vegetation communities it was necessary to identify the biophysical conditions which favour the development of each of the tree species making up the defined community classes. This information was derived from Hosie (1979) and Fowells (1965). Table 4.6 is a summary of the soil and topographic conditions in which each species occurs, as well as a relative measure of the species tolerance to environmental change.

4.2.1.1 Red Oak (*Quercus rubra*)

Red oak grows in soils ranging from clay to sandy loam. Soils may be deep and stone-free through to shallow rocky soils (Fowells, 1965). The depth of soil and the amount of available soil moisture affect the site quality. Red Oak is most frequently found on northerly and easterly aspects and lower and middle slopes, including ravines and valley floors. The best sites are characterized by the presence of fine

SPECIES -----	SOIL TYPE -----	SOIL DEPTH -----	SOIL MOISTURE -----	TOPOGRAPHY -----	TOLERANCE -----
Red Oak	clay - sandy loam	deep - shallow	moist, well drained	north & east aspects lower & middle slopes valley floors	interm.
Sugar Maple	podzol, loam	deep	moist, well drained		high
Beech	grey- brown podzol, laterite	deep	moist well drained	slopes & ridges	high
White Birch	podzol brown- grey	deep - shallow	varies, well drained	all elevation, slope, & aspect	low
Trembling Aspen	all	deep - shallow	moist - dry	all elevation, slope & aspect	low
White Pine	sandy loam - bog	deep - shallow	moist well - poor drainage	all elevation, slope & aspect	interm.
White Cedar	peat, clay - gravel	deep- shallow	moist- wet	valleys & uplands	high

Table 4.6: Ranges of soil conditions, topographic characteristics, and overall tolerance rating by tree species.

textured soil and topography or subsoil strata that favour a high water table.

Red oak has an intermediate level of tolerance. It is intolerant of competition, and characteristically grows on rocky or gravelly uplands in pure stands, or mixture with other hardwoods and occasional conifers (Hosie, 1979). Common associates are trembling aspen and eastern white pine.

4.2.1.2 Sugar Maple (*Acer saccharum*)

Sugar maple is found primarily on brown and grey-brown podzolic soils (Fowell, 1965). Sandy loam, loam, and occasionally silty loam soils support the better stands of sugar maple with the best development occurring on the loam soils. This species only thrives on fertile, moist, and well-drained soils. Sugar maple most commonly grow on soils of pH 5.5 to 7.3 but can occur in strongly acid to slightly alkaline conditions.

Sugar maple is very tolerant of shade and is able to withstand several years of complete suppression. It may form pure stands or grow in mixture with other hardwoods or with hardwoods and scattered conifers (Hosie, 1979).

4.2.1.3 Beech (*Fagus grandifolia*)

Beech generally occurs on grey-brown podzolic and laterite soils. It is seldom found in limestone valleys (Fowells, 1965). Soils of a loamy texture and those with a high humus content are more favourable than lighter soils. Soil pH's ranging from 4.1 to 6.0 are preferred. Beech occurs at higher elevations. It prefers moist well-drained slopes and rich bottomlands (Hosie, 1979).

This species is very tolerant, similar to sugar maple. Locally, however, one species or the other may dominate the forest understory and in that area appear more tolerant. It may grow in small pure stands but is more often mixed with sugar maple, yellow birch, and eastern hemlock.

4.2.1.4 White Birch (*Betula papyrifera*)

White birch usually grows on podzol soils; however, it also occurs on grey-brown and brown podzolic soils (Fowells, 1965). Optimal soil conditions are well-drained sandy loams. It is also common on shallow stony soils and even bog and peat soils. Parent material is often glacial till and outwash derived from granites, schists, gneisses, sandstones, shales, and limestone. A wide range of soil moisture conditions are also tolerated by white birch. It is more abundant on drier than average soils. White birch occurs at all elevations,

slopes, and aspects. It is considered an intolerant species.

White birch in Ontario, occurs in pure and mixed stands (Hosie, 1979). It is frequently associated with jack pine, poplar, and black spruce. It also occurs occasionally as individual trees in tolerant hardwood stands.

4.2.1.5 Poplar (*Populus tremuloides*)

Poplar grows on a variety of soils ranging from shallow rocky soils and sandy loam to heavy clays (Fowells, 1965). Growth and development are strongly influenced by soil conditions. Optimal soil conditions are porous loamy and humic with an abundance of lime. Growth on sandy soils is poor because of low moisture and nutrient levels. Growth on clay soils is also poor due to lack of aeration. Aspen is considered very intolerant throughout its life.

As a young tree it grows in pure stands in many areas but is usually succeeded by more tolerant conifers and hardwoods (Hosie, 1965). It also occurs in mixed stands with white spruce, black spruce, balsam fir, white birch, poplar, and jack pine.

4.2.1.6 White Pine (*Pinus strobus*)

Parent soil material for white pine is derived from granites, gneisses, schists, sandstones, and less commonly from phyllites, slates, shales, and limestone (Fowells, 1965). Preferred soils are sandy and well drained. It also grows on loams and silty soils with either good or impeded drainage. The soil groups on which white pine occur are podzol and podzolic. Materials are commonly glaciofluvial and aeolian in origin, with lacustrine deposits and loamy and finer till soils being less frequently occupied. White pine is characteristically associated with acid soils.

White pine grows in pure stands and in mixed stands with other conifers and hardwoods (Hosie, 1979). Associated species include hemlock, yellow birch, sugar maple, white spruce, balsam fir.

4.2.1.7 White Cedar (*Thuja occidentalis*)

White cedar grows best on neutral or alkaline soils of limestone origin (Fowells, 1965). Where cedar occurs in swamps, the site quality increases as the depth of the peat decreases, and as internal drainage improves. It grows both in swamps and on uplands but does not develop well on very wet or dry conditions. Upland sites are commonly moist, well-drained, shallow calcareous clay to gravel. White cedar is

very tolerant.

This species grows in pure and mixed stands. Common associated species are white pine, yellow birch, hemlock, silver maple, and black ash (Hosie, 1965).

4.2.2 Digital Elevation Model-Based Classification

A supervised classification was produced using the same training sites established for the TM classification but using the data set of elevation, slope, and aspect as the data to classify. Single channel images of elevation, slope, and aspect were generated from the DTM (Lemay et al, 1980) (see figures 4.25 to 4.28).

Elevation was calculated for each output pixel using a five-point interpolation scheme based on the following equation:

$$\text{Height(metres)} = \text{Scale} * (\text{DTM Value}) + \text{Offset}$$

The coefficients used for the elevation interpolation were also used to calculate the slope and aspect corresponding to each pixel. The digital output values for slope range from 0 to 90 and the aspect values are given relative to north in

Figure 4.25: Image of elevation data.

Figure 4.26: Image of slope data.

Figure 4.27: Image of aspect data.

Figure 4.28: 3-Dimensional perspective of digital elevation model.

degrees divided by two, since the maximum digital value possible is 255.

4.2.3 'Terrain Free' Classification

Areas commonly classified in both the TM-based and DTM-based classification were extracted using a logical subtraction operation between the corresponding themes to arrive at a third set of classes. The resulting 'terrain free' classes represent geobotanical classes without the influence of topography.

4.2.4 Identification of Remote Sensing Geobotanical Anomalies

Background geobotanical anomalies were identified from the spatial distributions of the terrain free classes taking into consideration the species characteristics described in section 4.2.1 (see figure 4.29). Two criteria were used to identify these areas:

- 1) areas of concentration, and
- 2) areas devoid of a class where no other environmental controls readily account for this absence.

Figure 4.29: Determination of geobotanical anomalies.

4.2.5 Integration of Biogeochemical Data

Data from the 74 field sample locations for maple were analyzed statistically to determine the biochemical thresholds for the elements Au, Zn, Ba and Mo. Data from 42 till samples were also analyzed statistically for geochemical thresholds. These elements were examined in detail from the suite of chemical elements, since they displayed anomalous variance in the data set and they act as pathfinders as well as direct indicators of the mineralization under investigation.

Gold and zinc are direct indicators. Anomalous concentrations of these elements represent potential ore bodies. Molybdenum, barium and mercury are elements associated with lead-zinc-gold and copper mineralization (Rose et al. 1979).

4.2.5.1 Element Associations and Characteristics

In general, molybdenum is a pathfinder for porphyry copper deposits, but less effectively for volcanogenic Cu, Pb, and Zn. In the Grenville, however, Mo tends to be related to uranium pegmatites. The metal toxicity of molybdenum has the geobotanical effect of stunting and causing yellow-orange colouration (Cannon, 1960). Contrast in molybdenum anomalies

range from 10/1 to 100/1 in plants due to its high mobility (Warren et al, 1949; Baranova, 1957; Malyuga, 1964).

Barium is associated with volcanogenic massive-sulphide Zn-Cu-Pb and Mississippi Valley Pb-Zn deposits (Rose et al., 1979). It accompanies Pb-Zn sulphide ores as barite. Barium has an intermediate mobility.

Mercury is a pathfinder element for complex Pb-Zn-Ag ores (Rose et al., 1979). It has a high mobility. The close association of Hg with precious metals and the elements of volcanogenic deposits makes it a useful pathfinder for Au, Ag, Sb and massive sulphides. In an example from Brooks and Berger (1978), soil samples exhibited high concentrations of Hg near the fault zones containing ore-grade gold deposits. The gold occurred in replacement zones in Paleozoic carbonate sediments.

Zinc is associated with Cu, Pb, Ag, Au, Sb, As, and Se in base-metal and precious metal deposits. Zinc is an essential nutrient for almost all plants, but is toxic to most plants if it is present in excessive amounts. It can cause chloritic leaves with green veins, white dwarfed forms, dead areas on leaf tips, and/or stunted roots (Cannon, 1960). It has a moderately high mobility.

Gold is associated with Ag, As, Sb, Hg, Se, and Te in precious metal deposits, and Zn, Fe, and Cu in many sulphide deposits (Rose, 1979). It has a high mobility and can enter plants and be concentrated as a cyanide complex.

4.2.5.2 Defining Anomalies

In an exploration program the threshold is defined as the upper limit of normal variation in the background (Rose et al, 1979, Levinson, 1974). Values above the threshold are considered anomalous and therefore represent indicators of possible economic mineralization. Thresholds for the three elements were determined using the method developed by Miesch (1981) and adapted by Koch (1987).

A common method used in geochemical analyses, is to identify the threshold as the value equal to the mean, or the log of the mean, plus one, two, or three standard deviations (Siegel, 1974, Beus and Grigorian, 1977, Rose et al, 1979, and Kovalevskii, 1979). Another method is to separate geochemical frequency distributions on log-probability curves (White, 1959, Lepeltier, 1969, Sinclair, 1976, McCammon, 1976, McCammon et al, 1979). This is similar to the method for analysis of grain size distributions. The gap statistic described by Miesch (1981) seeks to improve on these previous methods by introducing the ability to include probability to

indicate the likelihood that the threshold separates two geochemical populations.

The statistic is the maximum gap between adjacent values in an ordered array after each gap has been adjusted for the expected frequency (Miesch, 1981). The values are transformed by either $\ln(x-a)$ or $\ln(a-x)$ then standardized so that the mean is zero and the variance is unity. The expected frequency is determined from a fitted normal curve with unit area.

The gap statistic was used to identify the anomalous values from the local background for Au, Zn, Mo, and Ba. Due to the low density of anomalous points, integration of these sites was done on a point by point basis.

4.2.6 Integration of Geophysical Data

The total field magnetic data was geocoded and rasterized to match the database already established with the remote sensing data. The original data was sampled at a resolution of 100 metres in pixel size. This was subsequently resampled to 30 metres to match and enable integration with the other data sets. Anomalously high values were defined on the basis of graphical change in the distribution of the magnetic data (see figures 4.30 to 4.32). Figure 4.33 is the

magnetic data in image form.

4.2.7 Identification of Integrated Data Anomalies

Refinement of the geobotanical anomalies was made by interpreting the anomalies with the supporting geochemical and geophysical data sets (see figure 4.34). Areas with corresponding anomalous values were identified as having the greatest potential.

4.3 SUMMARY OF DECISIONS

The process of decision making related to the processing of the various data sets, lends itself well to division within the framework of the three levels of exploration activity. The first question for the exploration geologist is therefore:

Question: What level of exploration activity is currently underway: 1) Reconnaissance, 2) Detailed, 3) Prospect Evaluation.

Explanation: Data processing methods and techniques are dependent on the level of exploration activity. Data must be available from the reconnaissance phase before processing at a detailed level commences.

Inference: (1) Correction and enhancement of multispectral and radar data set.

Inference: (2) Classification and integration of data set.

Figure 4.30: Histogram of original magnetic data.

Figure 4.31: Histogram of magnetic data after linear stretch.

Figure 4.32: Histogram of magnetic data after equalization stretch.

Figure 4.33: Image of magnetic data. White and purple correspond to magnetic highs. Dark blue are lowest values.

Figure 4.34: Data processing detailed level (part 2). Identification of integrated anomalies.

Inference: (3) Modelling of spectral curves and multiple data set.

The geologist is directed into one of three paths from this point. Through the exploration program each path must be followed sequentially since the knowledge from one level is used in subsequent levels.

RECONNAISSANCE LEVEL

Question: Does the data have radiometric errors such as:
(1)striping, (2)line dropouts?

Explanation: Radiometric errors in the data should be corrected before geometric correction and enhancements are made.

Inference: (1) Correct striping using (appropriate algorithm)

(2)Correct dropout lines using (appropriate algorithm)

Question: Is the data geocoded to the working map projection base?

Explanation: To integrate the remote sensing with complimentary data sets it is necessary to correct geometric distortions in the data.

Inference: Image to map registration or image to image registration.

Question: What type of remote sensing data do you have;
(1)LANDSAT MSS, (2)LANDSAT TM, (3) SEASAT?

Explanation: The enhancement parameters will vary depending on the type of data being used.

Inference: (2) The following enhancement should be applied on TM bands 3,4 and 5:

- . linear contrast stretch
- . principal component enhancement
- . directional convolution filtering (on TM5)
- . unsupervised classification

DETAILED LEVEL

Question: Have the geobotanical associations for the area been established?

Explanation: In order to interpret the remote sensing data set, the basic vegetation communities need to be identified in order to apply the geobotanical exploration strategy.

Inference: Conduct a supervised classification on the TM data.

Question: Is a digital terrain model available for the area?

Explanation: By incorporating a digital elevation model into the analysis, the distributions of individual vegetation communities attributable to terrain influences, may be removed in order to identify geobotanical anomalies.

Inference: The geologist should follow the following procedure:

- 1) generate elevation, slope, and aspect images from the terrain model;
- 2) classify using the same training sites used to classify the TM data;
- 3) logically subtract the resulting class from the corresponding TM class.

Question: Is till geochemistry available for the study area?

Explanation: Geochemical anomalies will aid in identifying areas of greatest mineral potential when they correspond with the geobotanical anomalies.

Inference: Geocode the geochemical data with the remote

sensing data set and rasterize.

Question: Is geophysical data available for the study area?

Explanation: Geophysical anomalies will aid in identifying areas of greatest mineral potential when they correspond with the geobotanical anomalies.

Inference: Geocode the geochemical data with the remote sensing data set and rasterize.

Question: Is airborne radar data available?

Explanation: The use of airborne data for obtaining structural information is well documented.

Inference: Geocode the radar data and contrast sketch for interpretation.

CHAPTER 5 - INTERPRETATION

This chapter deals with the interpretation of the remote sensing and supporting data sets for the purpose of obtaining geologic evidence supporting the metasedimentary hosted Pb-Zn-Au (hydrothermal vein), and/or metavolcanic sulphide type deposits, the possible economic metals being gold, zinc-lead, and copper.

5.1 RECONNAISSANCE - Exploration Level 1

The preliminary nature of reconnaissance level exploration dictates the use of basic methods and techniques such as the enhancements described in chapter 4. The interpretation of these data sets relies on the photointerpretive abilities of the geologist. Interpretation of Landsat data requires the same basic approach as traditional photo-geologic techniques. The segmentation or classification of the image into distinct units is done by examining the criteria of tone, texture, pattern, size, shape, and association in the image (see figure 5.1).

5.1.1 Contrast Stretch Enhancement

Visual interpretation of the contrast stretch enhancement (figure 4.8) of TM bands 3, 4, and 5 resulted in the

Figure 5.1: Remote sensing data interpretation, reconnaissance level.

characteristics for each unit is provided in table 5.1 (see figure 5.2).

5.1.1.1 Unit 1

Unit 1 appears yellow in the composite image. It has an irregular shape and pattern, and the texture varies from mottled to smooth. The size varies from less than 1 kilometre to approximately 4 kilometres. The unit includes cultural features such as roads and hydro lines. The occurrence of this class in the study area is limited. All areas are in the eastern half of the study area.

5.1.1.2 Unit 2

Unit 2 has a red-brown colour. It is irregular in shape and pattern. It has a mottled appearance due to tonal variations. The size of the areas varies from less than 1 kilometre to 3 kilometres along the long axis. It occurs in conjunction with, or immediately adjacent to unit 4. The unit occurs at locations throughout the entire study area.

5.1.1.3 Unit 3

Unit 3 appears dark blue in the image. It is mottled to

Terrain Unit	Tone	Texture	Pattern	Shape	Size
-----	-----	-----	-----	-----	-----
1	yellow	mottled- smooth	irregular	irreg.	<1-4km
2	red- brown	mottled	irregular	irreg.	<1-3km
3	dark blue	mottled- smooth	irregular	irreg.	<1-3km
4	medium blue	mottled- smooth	irregular	irreg.	1-6km
5	light blue	mottled- smooth	irregular	irreg.	1-4km

Table 5.1: Image characteristics of interpreted units
from contrast stretch image of TM bands 3,4,
and 5.

Figure 5.2: Interpretation of contrast stretch enhancement of TM bands 3,4,&5.

smooth in texture and has an irregular shape and pattern. Size varies from less than a kilometre to 3 kilometres. The unit tends to occur in topographic lows. This unit occurs primarily east of Mazinaw Lake.

5.1.1.4 Unit 4

This medium blue coloured unit varies from appearing mottled to smooth in texture. The pattern and shape is irregular and occurs extensively throughout the entire area. The size varies from 1 to 6 kilometres, and it occurs in association with unit 2.

5.1.1.5 Unit 5

The final interpreted unit appears light blue and has a smooth and mottled texture of irregular shape and pattern. The size varies from 1 to 4 kilometres. This unit occurs extensively around Lower Mazinaw Lake.

5.1.2.6 Interpretation Summary

It is apparent from these image characteristics that tone or colour provides more information for interpretation than other image characteristics. The irregular patterns and shapes

limit the amount of structural information that may be drawn from this image. A northeast-southwest orientation is apparent from the lakes as well as the units interpreted. Units 1, 3, and 5 are located in definable polygonal locations within the study area. Units 2 and 4 are widespread and therefore suggest they are of little geological significance. From this interpretation it is possible to select field transects which traverse these units efficiently. Road access provides relatively easy access to all the units. Determination of the significance of each unit requires that field surveys be conducted.

5.1.2 Principal Component Enhancement

A visual interpretation of the principal component enhancement resulted in the identification of 7 units. These are summarized in table 5.2 (see figure 5.3).

5.1.2.1 Unit 1

Unit 1 is red in colour with a smooth texture. The pattern is irregular although polygons representing this unit tend to occur in patches with a northeast-southwest and north-south trend. Their shape also exhibits this trend in some cases, although in others the shape is irregular. Size varies from less than 1 kilometre to 4 kilometres along the longest

Terrain Unit	Tone	Texture	Pattern	Shape	Size
-----	-----	-----	-----	-----	-----
1	red	smooth	irregular patches NE-SW & N-S trend	irreg.- linear	<1-4km
2	orange	smooth	irregular areas NE-SW & N-S trend	irreg.- linear	<1-7km
3	green	mottled	irregular	v.irreg.	1-3km
4	light blue	smooth	spaced in NE-SW & N-S trend	semi- circular	<1-2km
5	dark blue	mottled	irregular	irreg.- linear	<1-3km
6	light yellow	mottled	NE-SW trend	irreg.	1-3km
7	yellow	smooth	localized grouping	irreg.	<1-1km

Table 5.2: Image characteristics of interpreted units from principal component enhancement.

Figure 5.3: Interpretation of principal component enhancement.

axis. This unit occurs in association with unit 2, and also with topographic highs. Unit 1 occurs on topographic highs running north-south on the west side of Mazinaw Lake, and northeast-southwest on the east side of the lake.

5.1.2.2 Unit 2

This unit is orange and occurs in close proximity to unit 1. It displays the same texture, pattern, and shape characteristics as unit 1, although the size is larger, ranging from less than 1 kilometre up to 7 kilometres. This unit occurs on the west side of Mazinaw Lake and south of the east arm of the lake.

5.1.2.3 Unit 3

Unit 3 is green with a mottled texture. It displays an irregular pattern and very irregular shape. Size varies from 1 to 3 kilometres in length. The association with topographic lows and water suggests its very irregular shape may be attributable to drainage channels. East of Mazinaw Lake this unit extends diagonally northeast-southwest. West of Mazinaw Lake it extends from north to south.

5.1.2.4 Unit 4

The fourth unit appears light blue in colour with a smooth texture. This unit occurs in an irregular pattern with a northeast-southwest, and a north-south trend. The shapes are semi-circular from less than 1 kilometre to 2 kilometres in size. Unit 4 occurs at locations throughout the entire study area.

5.1.2.5 Unit 5

Unit 5 is dark blue with a mottled texture and irregular pattern. Shape varies from being irregular to linear. Size ranges from less than 1 to 3 kilometres in length. This unit is scattered at various locations through the study area.

5.1.2.6 Unit 6

Unit 6 is a mottled light-yellow. It is limited in extent, occurring east of Mazinaw Lake and exhibiting a northeast-southwest trending pattern of irregular shape. Size varies from 1 to 3 kilometres in length.

5.1.2.7 Unit 7

Unit 7 is yellow in colour. The unit has a smooth texture

and irregular shape. A pattern may be inferred from the localized grouping of small areas of this unit. The size ranges up to 1 kilometre in length. It occurs west and east of Lower Mazinaw Lake.

5.1.2.8 Interpretation Summary

This enhancement provides more information than the contrast stretch enhancement based on the number of units interpreted. Again colour is a controlling characteristic in the interpretation procedure although textures, patterns, shapes, and sizes also vary. A dominant characteristic which is displayed by several units is the northeast-southwest orientation east of Mazinaw Lake, and the north-south orientation west of the lake.

5.1.3 Convolution Filtering Interpretation

A lineament interpretation was completed based on the four directional filters discussed in section 4.1.5. Figures 5.4, 5.5, 5.6, and 5.7 correspond to the north, northeast, east, and southeast filtered images respectively. Figure 5.8 is the compilation of the 4 interpretations.

5.1.3.1 North Filter

The north directional filter enhances linear and curvilinear features running in an east-west direction (see figure 5.4). The density of mapped lineaments is greatest in the northeast quadrant of the image, although some lineaments appear to traverse Mazinaw Lake and appear on the west side of the lake. The southern half of the area has relatively few lineaments. The lineaments mapped to the south are oriented more in a northeast-southwest direction.

The different density of lineaments in the three areas (northeast, northwest, and southeast) suggests different structural domains. This would also suggest that each area has different rock types. It is also worth noting the interpretation of several southeast-northwest trending lineaments west of Lower Mazinaw Lake. They indicate another lithotectonic difference compared to the regions north and east of this area.

5.1.3.2 Northeast Filter

The northeast filter enhances lineaments occurring in a southeast-northwest direction (see figure 5.5). Interpreted lineaments occur in approximately this direction over much of the study area, apart from the southeast portion of the image

NTS 322000 m.E 4980000 m.N

scale 1:100 000

337000 m.E 4965000 m.N

Figure 5.4: Lineament interpretation from north directional filtered image.

MICROCOPY RESOLUTION: 37 CHART

NATIONAL BUREAU OF STANDARDS

STANDARD REFERENCE MATERIAL 1010a

(ANSI and ISO TEST CHART No. 2)

NTS 322000 m.E 4980000 m.N

scale 1:100 000

337000 m.E 4965000 m.N

Figure 5.5: Lineament interpretation from northeast directional filtered image.

where no lineaments were mapped. This indicates a probable change in lithology due to the changing structural characteristics. This is consistent with the interpretations from the north filter. The greater density of lineaments occurs to the west of Mazinaw and Lower Mazinaw Lake.

5.1.3.3 East Filter

In direct contrast to what was indicated by the northeast filter, the greatest density of lineaments occur east of Mazinaw and Lower Mazinaw Lake. The east filter enhances lineaments in a north-south direction (see figure 5.6). Only 2 north-south trending lineaments were mapped west of Mazinaw Lake and 3 south of Lower Mazinaw Lake. Overall there were fewer lineaments identified from this direction than the other three directions.

5.1.3.4 Southeast Filter

This filter enhances lineaments which occur in a northeast-southwest direction (see figure 5.7). Many such lineaments were identified in the study area with the exception of its southwestern portion. Several dominant trends are apparent east of Mazinaw Lake and Lower Mazinaw Lake.

The density of lineaments having this orientation

NTS 322000 m.E 4980000 m.N

scale 1:100 000

337000 m.E 4965000 m.N

Figure 5.6: Lineament interpretation from east directional filtered image.

NTS 322000 m.E 4980000 m.N

scale 1:100 000

337000 m.E 4965000 m.N

Figure 5.7: Lineament interpretation from southeast directional filtered image.

suggests that the principal strike of the area is northeast-southwest. The region in the southwest corner is likely quite different from the rest of the study area since no lineaments were mapped in that specific area.

5.1.3.5 Interpretation Summary

Figure 5.8 combines all the interpreted lineaments into a single map. Four distinct areas are apparent from the interpretation. They are as follows:

1) Region east of Mazinaw Lake

Characterized by a dense pattern of perpendicular and obliquely intersecting lineaments of up to 4 kilometres in length. Principal directions are northeast-southwest and northwest-southeast.

2) Region east and south of Lower Mazinaw Lake

Characterized by intermediate to low density (relative to lineaments over the whole study area) of lineaments striking in a northeast-southwest and northwest-southeast direction. Up to 5 kilometres in length.

3) Region west of Mazinaw and Lower Mazinaw Lake

Characterized by lineaments striking in a north-south and

NTS 322000 m.E 4980000 m.N

scale 1:100 000

337000 m.E 4965000 m.N

Figure 5.8: Combined lineament interpretation from directional and contrast stretch enhancements.

east-west direction, up to 3 kilometres in length.

4) Region southwest of Lower Mazinaw Lake. Characterized by a nearly complete lack of interpreted lineaments. The circular drainage pattern suggests a domal nature to the bedrock and structures in this area.

The relatively short length (i.e., < 5 km.) of the lineaments indicates they may be related to jointing patterns and fracture related structures. The few larger lineaments which strike in a northeast-southwest direction may represent regional structures such as faults, fold axis and lithologic contacts. These lineaments correspond to lake and drainage orientations in the southeast corner of the study area and east of the arm of Mazinaw Lake. A north-south fault may be interpreted on the basis of the elongated shape of Mazinaw and Lower Mazinaw Lakes in this direction.

Table 5.3 provides a statistical summary of the lineaments in 12 degree intervals. Corresponding rose diagrams for lineament frequency and length are provided in figures 5.9 and 5.10 respectively.

The two principal trends are supported by the diagrams. The northeast-southwest and north-south ones are consistent with both lineament length and frequency.

INTERVAL	FREQUENCY	TOTAL LENGTH (km)	MEAN	ST. DEV.
.1 - 12	5	8.77	1.75	0.78
12.1 - 24	7	11.58	1.66	0.52
24.1 - 36	7	9.66	1.38	0.48
36.1 - 48	7	11.29	1.61	0.75
48.1 - 60	2	2.92	1.46	0.08
60.1 - 72	2	2.50	1.25	0.53
72.1 - 84	2	3.31	1.65	8.69E-02
84.1 - 96	6	9.80	1.22	0.54
96.1 - 108	2	2.76	1.38	0.18
108.1 - 120	1	1.19	1.19	0.00
120.1 - 132	2	2.21	1.10	0.31
132.1 - 144	2	5.52	2.76	0.52
144.1 - 156	1	0.95	0.95	0.00
156.1 - 168	3	5.39	1.80	0.59
168.1 - 180	2	2.38	1.19	0.49
	---	-----		
	53	80.21 Kilometres		

Table 5.3: Lineament statistical summary. (0 degrees = East, 180 degrees = West).

5.1.4 Unsupervised Classification Interpretation

The unsupervised classification as shown in figure 5.11 resulted in 8 classes. Three of these need not be considered immediately because two correspond to water and one to the area masked out of the image. Five classes correspond to reflectance characteristics from the land surface. The distribution of the land classes may be categorized as follows:

Class 1 Roads and disturbed areas.

Class 2 Occurs along shorelines and areas at low elevation

Figure 5.9: Rose diagram of lineament frequency.

Figure 5.10: Rose diagram of lineament length.

SCALE 1: 99679, 1: 99679 SIZE: 15.4KM, 15.4KM OFFSET: . KM, . KM
FILE:UNCLASS.PIX DATE:12-APR-89
RED: PCE :Red component of channel 1 using PCT se
GREEN: PCE :Green component of channel 1 using PCT se
BLUE: PCE :Blue component of channel 1 using PCT se
unsupervised classification (PAGE)

Figure 5.11: Unsupervised classification of TM data.

including swamp. The class is distributed over the entire study area and displays a northeast-southwest orientation east of Mazinaw Lake.

Class 3 This class is widely distributed over the study area. It occurs in the mid-elevation range and primarily in the northern two-thirds of the area.

Class 4 Occurs in areas of steep slope and relatively high elevation. This class often follows ridgelines.

Class 5 This class occurs in areas of high elevation and steep slope. It also includes hydropower lines and some roads. It is most extensive in the northwest corner of the study area, at Mazinaw Rock, and north of Mississagagon Lake.

These classes appear to correlate well with topography. Not much can be interpreted from the distribution of these classes apart from their correspondence with the physical parameters just discussed. The results are best used as a guide for planning field investigations and providing an indication of the readily identifiable differences in the spectral data.

5.1.5 Summary of Interpreted Information

At this stage field investigations would not have been completed; therefore, the lineaments and units interpreted from the imagery remain abstract lines and polygons. The significance of these features is suggested through association with other elements in the image as well as their photogeologic characteristics.

5.1.5.1 Geologic Analysis

1) The study area can be divided into 4 litho-tectonic regions primarily on the basis of the lineament interpretation. These are: the region east of Mazinaw Lake; the region east and south of Lower Mazinaw Lake; the region west of Mazinaw and Lower Mazinaw Lakes; and the region southwest of Lower Mazinaw Lake. This is supported by the trends exhibited in the contrast stretch and principal component enhancements.

2) Several possible faults and folds in the southeast quadrant of the image strike northeast-southwest; others occur along the length of Mazinaw Lake.

3) Distribution of units and classes suggests some topographic influence on vegetation cover. Variation in topography corresponds to the litho-tectonic units defined; for example,

the northeast-southwest striking ridges east of Mazinaw Lake.

5.1.5.2 Logistic Analysis

1) In the region east of Mazinaw Lake, transects should run in a northwest-southeast direction and cross the northeast-southwest orientation of the terrain.

2) In the region west of Mazinaw Lake, transects should run in an east-west direction due to the more north-south orientation of the terrain.

3) An effective transect will cross as many interpreted units as possible in the shortest distance. Road access is good for meeting the transect requirements.

5.2 DETAILED EVALUATION - Exploration Level 2

As described in section 4.2, the detailed evaluation phase relies on information from the interpretations of the reconnaissance level and the subsequent field investigations. Together with data collected in the field, and further processing of the remote sensing data, it becomes possible to identify geobotanical anomalies.

5.2.1 TM - Based Vegetation Classification

The distribution of 7 vegetation communities, swamp, outcrop, disturbed ground (areas changed due to human activities such as roads and quarries) and water were mapped over the study area using the supervised classification method described in section 4.2.1. The following is a description of the distributions of each of the vegetation communities.

5.2.1.1 Class 1 - Or/Ms (Red Oak/Sugar Maple)

The oak/maple class occurs, predominantly, immediately east and west of Mazinaw Lake and in the southern quarter of the study area (see figure 5.12). This class also follows the topographic contours resulting from the northeast-southwest structural trend east of Mazinaw Lake. The preference for north and east aspect slopes (table 4.6) is evident in the dense growth east and along the west sides of Mazinaw Lake.

5.2.1.2 Or/Ms/Be (Red Oak/Sugar Maple/Beech)

The oak/maple/beech class is widely distributed throughout the area except in a few areas east and west of Mazinaw Lake (see figure 5.13). The areas of concentration are similar to Class 1 Or/Ms, but more broadly occurring.

Figure 5.12: Distribution of Or/Ms class.

Figure 5.13: Distribution of Or/Ms/Be class.

5.2.1.3 Bw (White Birch)

The distribution of birch differs from the first two community classes (see figure 5.14). It is scattered over the entire area with two areas of concentration, one on the west side at the north end of Lower Mazinaw Lake, and one south of the west arm of Mazinaw Lake.

5.2.1.4 Bw/Po (White Birch/Trembling Aspen)

The birch/poplar class has a similar distribution to the birch class but displays greater densities along ridges (see figure 5.15). The occurrence of birch and poplar as a distinctive vegetation community is not surprising based on the similar soil and topographic characteristics preferred by each species.

5.2.1.5 Bw/Po/Ms/Or (White Birch/Trembling Aspen/ Sugar Maple/Red Oak)

The birch/poplar/maple/oak class is distributed principally along the west side of Mazinaw Lake, east of the narrows and along ridges trending northeast on the east side of Mazinaw Lake (see figure 5.16). Several smaller areas of concentration occur in the southeast portion of the area.

Figure 5.14: Distribution of Bw class.

Figure 5.15: Distribution of Bw/Po class.

Figure 5.16: Distribution of Bw/Po/Ms/Or class.

5.2.1.6 Bw/Po/Pw (White Birch/Trembling Aspen/White Pine)

This class displays dense almost dendritic patterns in the study area (see figure 5.17). The southeastern portion of the area south of Mississagagon differs, displaying fewer occurrences of this vegetation community.

5.2.1.7 Pw/Ce (White Pine/Cedar)

The largest and most dense stands of this class occur in the vicinity of swamps and generally moist areas of low relief (see figure 5.18). This is to be expected due to the preference of cedar for moist-wet, peaty valleys and uplands. The ability of pine to grow in moist poorly drained conditions has resulted in these two species being in the same areas.

TM bands 4 and 5 displayed the greatest variance between the classes as shown by the mean band values in table 5.4. The difference between the other mean band values was minimal, less than 1 in the case of band 1.

5.2.2 Terrain Influences - Areas of TM/DTM Class Overlap

In order to determine the influence of the terrain elements (elevation, slope, aspect) on the distribution of the mapped vegetation communities, the overlap between the TM and

Figure 5.17: Distribution of Bw/Po/Pw class.

Figure 5.18: Distribution of Pw/Ce class.

Or/Ms	Or/Ms	Bw	Bw/Po	Bw/Po	Bw/Po	Pw/Ce	Swamp	Out-	Dist-	Water
	/Be			Ms/Or	Pw			Crop	urbed	
-----	-----	--	-----	-----	-----	-----	-----	-----	-----	-----

TM1

64.0	63.8	63.3	63.1	63.9	63.2	63.4	66.0	71.4	67.4	58.3
------	------	------	------	------	------	------	------	------	------	------

1.0	1.1	1.1	1.1	1.2	1.2	1.2	2.5	4.5	6.2	1.4
-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----

TM2

27.9	27.2	26.5	27.3	27.4	26.6	26.0	28.0	31.1	29.0	18.5
------	------	------	------	------	------	------	------	------	------	------

0.7	0.8	0.8	0.8	0.8	0.9	0.9	1.9	3.6	4.7	0.6
-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----

TM3

20.6	20.1	19.4	19.2	20.0	19.6	19.7	23.1	27.5	24.4	13.5
------	------	------	------	------	------	------	------	------	------	------

0.7	0.7	0.7	0.6	0.8	0.9	0.9	2.5	5.1	6.8	0.6
-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----

TM4

139.3	126.0	120.8	124.2	128.9	107.4	84.8	80.0	99.4	80.1	11.3
-------	-------	-------	-------	-------	-------	------	------	------	------	------

3.4	5.0	4.7	5.6	6.7	5.4	6.2	7.2	9.4	15.9	0.7
-----	-----	-----	-----	-----	-----	-----	-----	-----	------	-----

TM5

85.2	77.8	70.6	74.9	80.8	65.6	56.0	67.4	86.5	70.3	5.5
------	------	------	------	------	------	------	------	------	------	-----

2.5	2.6	2.5	2.5	2.8	3.3	5.4	5.8	9.1	16.3	1.0
-----	-----	-----	-----	-----	-----	-----	-----	-----	------	-----

TM6

22.8	21.4	19.7	20.8	22.1	19.1	17.5	21.9	30.6	23.6	4.0
------	------	------	------	------	------	------	------	------	------	-----

1.3	1.6	1.5	1.5	1.5	1.6	2.0	4.0	6.3	8.2	0.8
-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----

Table 5.4: Mean and deviation statistics from TM-based classification.

DTM classes was examined visually and statistically. The overlap was calculated as a percentage of each TM class, providing a measure of the influence of terrain on the vegetation communities. Dominant trends for slope, aspect, and elevation are presented in table 5.5. Mean and deviation statistics are given in table 5.6.

5.2.2.1 Or/Ms (Red Oak/Sugar Maple)

This class occurs on average close to the 293 metre level which is in the lower half of the elevation range. It occurs predominantly on fairly steep (mean 28 degrees) southeast facing slopes. This terrain orientation corresponds to the southwest-northeast bedrock controlled ridges in the area (see figure 5.19).

5.2.2.2 Or/Ms/Be (Red Oak/Sugar Maple/Beech)

This class is similar to class 1 as suggested by the species mix. Overlap between TM and DTM is slightly higher at 12.8% compared to 10.6% for class 1. This class, however, is more widespread in the study area and on average, at higher elevations (305 metres). Slope angle is essentially the same as class 1 (12.5%), but it has an aspect of 90 degrees. On the DTM classification the class occurs almost exclusively on north-northwest south-southeast striking ridges (slopes east

CLASS	TM/DTM % OVERLAP	DOMINANT TRENDS		
		ELEVATION	SLOPE	ASPECT
1) Or/Ms	10.6
2) Or/Ms/Be	12.8
3) Bw	7.3
4) Bw/Po	17.0
5) Bw/Po/Ms/Or	9.3
6) Bw/Po/Pw	11.9
7) Pw/Ce	12.0
8) Swamp	18.3
9) Outcrop	9.0
10) Disturbed	20.8
11) Water	57.7

Bw *Betula papyrifera*
 Or *Quercus rubra*
 Ms *Acer saccharum*
 Pw *Pinus strobus*

Po *Populus tremuloides*
 Ce *Thuja occidentalis*
 Be *Fagus grandifolia*

Table 5.5: Vegetation community terrain trends.
 Relative elevation differences are illustrated by shaded areas in boxes, slope by sloping line from the horizontal, and aspect by arrow in 360 degree circle.

Or/Ms	Or/Ms /Be	Bw	Bw/Po	Bw/Po Ms/Or	Bw/Po Pw	Pw/Ce	Swamp	Out- Crop	Dist- urbed	Water
-----	-----	--	-----	-----	-----	-----	-----	-----	-----	---
TM1										
64.2	63.7	63.4	63.1	64.2	63.2	63.2	67.0	70.8	64.4	59.0
1.3	1.3	1.3	1.3	1.6	1.5	1.6	3.5	5.7	4.6	2.1
TM2										
28.1	27.3	26.5	27.5	27.6	26.5	25.8	28.5	31.2	23.4	19.1
1.0	0.8	1.1	0.9	1.2	1.2	1.3	3.1	3.7	2.8	1.1
TM3										
20.5	20.2	19.5	19.3	20.4	19.7	19.7	24.1	27.1	19.3	14.0
0.9	0.7	0.9	0.7	1.3	1.2	1.3	3.7	5.7	3.6	1.2
TM4										
139.6	125.1	119.0	124.6	123.2	106.3	85.0	76.2	100.3	21.3	11.6
5.1	5.5	12.4	7.1	9.9	6.8	10.8	16.7	19.5	10.3	1.2
TM5										
85.8	77.8	68.6	74.7	80.5	65.0	53.9	66.9	86.3	17.5	6.0
3.6	3.2	9.1	2.7	4.3	4.8	9.6	11.0	17.4	10.0	1.6
TM6										
23.0	21.3	19.6	20.8	22.5	19.0	17.1	22.5	30.5	8.6	4.2
1.6	1.6	2.1	1.6	2.2	2.0	3.0	5.7	7.8	4.2	1.1
Elevation										
67.1	88.4	49.8	68.7	59.9	63.0	47.7	51.1	88.8	31.2	29.7
8.1	11.2	12.8	5.8	12.3	2.8	5.5	10.6	18.6	6.1	0.5
Slope										
15.6	7.6	20.2	6.1	14.7	5.2	8.9	5.1	18.0	3.6	0.0
6.0	5.0	8.2	3.1	6.5	3.6	4.6	3.6	15.6	1.8	0.2
Aspect										
78.8	31.6	121.1	62.4	27.9	147.2	107.3	120.4	111.5	65.7	254.9
14.1	21.8	62.0	49.4	14.7	53.4	30.3	81.1	42.7	45.1	3.1

Table 5.6: TM/DiM overlap statistics. Mean and deviation by class.

Figure 5.19: Areas of TM/DTM overlap for Or/Ms class.

facing) (see figure 5.20).

5.2.2.3 Bw (White Birch)

This class of predominantly white birch occurs at low elevations (283 metres) on steep (18 degree) south facing slopes. Terrain influence is quite low at 7.3% and occurs predominantly along shorelines and stream channels. Average elevation is 263 metres. The aspect control is a result of much of the shoreline having a northeast-southwest orientation, which is bedrock controlled (see figure 5.21).

5.2.2.4 Bw/Po (White Birch/Trembling Aspen)

Occurring at a higher elevation (296 metres) but a lower slope angle (6 degrees) than the previous class, the DTM overlap follows a similar pattern to the Bw class. This corresponds to a general decrease in slope just above the steeper areas close to the shorelines. The southeast (61 degrees) aspect again corresponds to bedrock structure. The influence of terrain in the occurrence of this class is much greater than the previous classes, being 17 percent (see figure 5.22).

Figure 5.20: Areas of TM/DTM overlap for Or/Ms/Be class.

Figure 5.21: Areas of TM/DTM overlap for Bw class.

Figure 5.22: Areas of TM/DTM overlap for Bw/Po class.

**5.2.2.5 Bw/Po/Ms/Or (White Birch/Trembling Aspen/
Sugar Maple/Red Oak)**

The distribution of this class is similar to the Or/Ms/Be class. It occurs predominantly along the northeast (73 degree) facing slopes of north-northwest striking hills. The most obvious of these are along the west side of Mazinaw Lake. The difference between the Or/Ms/Be class and this one is the lower mean elevation of 293 metres. This class is also more widely distributed to the east of Mazinaw Lake. The degree of influence is similar at 13 percent (see figure 5.23).

5.2.2.6 Bw/Po/Pw (White Birch/Trembling Aspen/White Pine)

The influence of terrain on this class is 11.9 percent. The class has a different aspect control compared to the other classes; it has a westerly aspect (272 degrees), the slope is low (5.2), and the average elevation is 293 metres, slightly lower than the previous class containing birch and aspen. There is a descending sequence of elevation for the three classes which contain these two species of trees. Pure stands of white birch and trembling aspen are found at a mean elevation of 296 metres; lower down (293m.) red oak and maple are part of this plant community. At 272 metres the mix is birch, aspen, and pine. The distribution of the class is related to the structural trends in the study area, the major

Figure 5.23: Areas of TM/DTM overlap for Bw/Po/Ms/Or class.

occurrences being on the west slope of the ridge running the length of Mazinaw Lake and the northeast-southwest trending ridges on the east side of Mazinaw Lake (see figure 5.24).

4.2.2.7 Pw/Ce (White Pine/White Cedar)

This class has a high overlap of 12 percent. It is distributed in valleys and has an average elevation of 283 metres, slope of 10 degrees, and aspect of 187 degrees. It occurs primarily in the northeast-southwest trending valleys east of Mazinaw Lake (see figure 5.25).

4.2.2.8 Swamp

This class has a high overlap value of 18.3 % indicating a strong influence of terrain on its spatial distribution. It occurs at low elevations (mean 284) and slopes (mean 6.5). The northeast-southwest aspect trend is due to the dominance of the class occurring in valleys between parallel ridges.

4.2.2.9 Outcrop

As one would expect, rock outcrops have the highest elevation (mean 319 m.) and the greatest slope (22.4 degrees). The dominant aspect trend is southwest. This is a result of

Figure 5.24: Areas of TM/DTM overlap for Bw/Po/Pw class.

Figure 5.25: Areas of TM/DTM overlap for Pw/Ce class.

the topography bordering Mazinaw Lake where much of the outcrop occurs. The region of greatest outcrop, having a northeast-southwest orientation, corresponds to a major structural lineament running along the length of Mazinaw Lake. Overlap between the TM and DTM derived classes was 9 percent.

From this investigation it can be concluded that the distribution of the classes is influenced by the terrain from 7.3 to 18.3 percent. Elevation ranges from 283 to 305 metres, slope 6 to 13 degrees, and aspect 73 to 272 degrees.

5.2.3 Geobotanical Classes - Areas of Non-Overlap

The geobotanical classes are the areas of non-overlap between the vegetation classes and the corresponding DTM classes. These represent the distribution of the vegetation communities without those occurrences or areas directly attributable to terrain characteristics. Consequently the distribution of the vegetation communities is attributed to the geological-geochemical nature of the area.

5.2.3.1 Or/Ms (Red Oak/Sugar Maple)

This class occurs in 10 visually detectable concentrations as shown in figure 5.26 (see figure 5.33). The remaining areas of non-overlap are

Figure 5.26: Areas of non-overlap for Or/Ms class.

scattered over the study area. Large areas of complete absence occur around Mississagagon Lake, southeast of the Mazinaw Lake Arm, and in the northwest corner of the study area. Half of the areas of concentration occur in the southeast corner of the study area, while the remaining occur along the west and east side of Mazinaw Lake and north of Mississagagon Lake.

5.2.3.2 Or/Ms/Be (Red Oak/Sugar Maple/Beech)

The Or/Ms/Be class is widespread throughout the area. One exception is west of Mazinaw Lake where a crescent shaped area does not contain this class (see figure 5.27).

5.2.3.3 Bw (White Birch)

The same crescent shaped area occurs in this class as in the previous one. Three areas of concentration may be noted. South of the east arm of Mazinaw Lake, immediately west of the narrows separating Mazinaw Lake and Lower Mazinaw Lake, and immediately north of Kashwakamak Lake in the southeast (see figure 5.28).

5.2.3.4 Bw/Po (White Birch/Trembling Aspen)

The absence of this class also occurs in the semi-circular area to the west of Mazinaw Lake. One large area of

Figure 5.27: Areas of non-overlap for Or/Ms/Be class.

Figure 5.28: Areas of non-overlap for Bw class.

concentration occurs south of the east arm of Mazinaw Lake, where there is also a heavy concentration of the Bw class. The rest of the class is widespread across the study area (see figure 5.29).

**5.2.3.5 Bw/Po/Ms/Or (White Birch/Trembling Aspen
/Sugar Maple/Red Oak)**

Three areas of concentration can be identified, two east of Mazinaw Lake and a third in the region between Marble and Mississagagon Lake. This class also does not occur in the semi-circular area west of Mazinaw Lake (see figure 5.30).

5.2.3.6 Bw/Po/Pw (White Birch/Trembling Aspen/White Pine)

This class occurs over the whole study area but mostly in the northern two-thirds of the area. There are five large concentrations, three immediately west of Mazinaw Lake, and two on the east side (see figure 5.31).

5.2.3.7 Pw/Ce (White Pine/Cedar)

Twelve areas in which this class is concentrated can be identified in the study area. Eight occur approximately in the northeast quadrant. Two are west of Mazinaw Lake, and two others are in the southeast corner. A large area east of Mazinaw Lake does not contain this class. Fragments of this

Figure 5.29: Areas of non-overlap for Bw/Po class.

Figure 5.30: Areas of non-overlap for Bw/Po/Ms/Or class.

Figure 5.31: Areas of non-overlap for Bw/Po/Pw class.

class are scattered across the remaining area (see figure 5.32).

The mean and standard deviation statistics for each class are provided in table 5.7 for each of the TM bands and elevation, slope, and aspect. TM bands 4,5 and 7 provide the greatest spectral separation between the vegetation classes. Deviation is greatest in band 4.

5.2.4 BACKGROUND GEOBOTANICAL ANOMALIES

Background geobotanical anomalies were identified from the distribution of each of the vegetation community classes. These represent unexplained variances in the distribution of specific vegetation communities comprised of two or more tree species. Two criteria were used to identify the areas; 1) areas of concentration, and 2) areas devoid of the vegetation class.

5.2.4.1 Or/Ms

Ten small areas of concentration were identified and one large area where the class does not occur (see figure 5.33). All but one of the areas are east of Mazinaw Lake.

5.2.4.2 Or/Ms/Be

Figure 5.32: Areas of non-overlap for Pw/Ce class.

Or/Ms	Or/Ms /Be	Bw	Bw/Po	Bw/Po Ms/Or	Bw/Po Pw	Pw/Ce	Swamp	Out- Crop	Dist- urbed	Water
-----	-----	--	-----	-----	-----	-----	-----	-----	-----	-----
TM1										
64.0	63.8	63.3	63.1	63.9	63.6	63.4	66.0	71.5	67.4	58.4
1.0	1.2	1.1	1.1	1.2	1.2	1.1	2.5	4.7	6.1	1.3
TM2										
27.9	27.2	26.5	27.3	27.3	26.6	26.0	28.0	31.2	29.0	18.6
0.7	0.8	0.8	0.8	0.8	0.9	0.9	1.9	3.7	4.6	0.5
TM3										
20.6	20.1	19.5	19.2	20.0	19.6	19.7	23.0	27.7	24.4	13.7
0.6	0.6	0.7	0.6	0.9	0.9	0.9	2.5	5.3	6.7	0.6
TM4										
139.2	126.0	120.8	123.9	128.8	107.3	84.9	80.1	98.8	80.1	11.5
3.4	4.8	4.6	5.6	6.9	5.3	6.0	7.1	9.3	16.3	0.7
TM5										
85.2	77.7	70.6	74.8	80.7	65.7	56.0	67.4	86.3	70.4	5.7
2.5	2.6	2.5	2.4	2.8	3.3	5.3	5.7	9.1	16.5	1.0
TM6										
22.8	21.4	19.8	20.7	22.0	19.1	17.5	21.9	30.5	23.7	4.1
1.3	1.5	1.5	1.4	1.5	1.6	1.9	3.9	6.3	8.2	0.9
Elevation										
68.5	67.0	68.7	69.6	69.9	65.6	59.3	59.5	55.4	58.9	33.3
19.7	19.2	17.9	20.1	20.0	19.9	18.0	18.9	14.9	17.5	7.6
Slope										
11.1	9.6	7.7	9.4	9.3	8.3	7.2	6.7	8.8	7.4	4.9
9.2	8.3	6.2	8.2	8.3	7.4	7.2	7.1	7.1	7.4	5.5
Aspect										
72.3	96.1	93.0	96.8	87.1	98.6	108.9	105.0	86.5	101.2	100.3
52.9	64.9	66.5	66.9	62.4	68.5	76.8	79.0	64.2	78.0	67.0

Table 5.7: TM/DTM non-overlap statistics. Mean and deviation by class.

NTS 322000 m.E 4960000 m.N

Figure 5.33: Anomalous Or/Ms class distributions

NTS 322000 m.E 4960000 m.N

scale 1:100 000

337000 m.E 4965000 m.N

Figure 5.34: Anomalous Or/Ms/Be class.

Two areas were identified corresponding to areas of non-occurrence east and west of Mazinaw Lake (see figure 5.34).

5.2.4.3 Bw

Four areas of concentration and two of non-occurrence were identified (see figure 5.35). These occur in the northern portion of the area east and west of Mazinaw Lake. One exception occurs in the southeast corner.

5.2.4.4 Bw/Po

One area of concentration and one of non-occurrence were identified (see figure 5.36). These were located east and west of Mazinaw Lake.

5.2.4.5 Bw/Po/Ms/Or

Three areas of concentration and one of non-occurrence were apparent (see figure 5.37). Most of the area was again immediately west and east of Mazinaw Lake, with the exception of one area east of Marble Lake.

5.2.4.6 Bw/Po/Pw

Five large areas of concentration (see figure 5.38)

NTS 322000 m.E 4980000 m.N

Figure 5.36: Anomalous Bw/Po class distributions.

A map of the study area in the St. Lawrence and Saguenay Fjords. The map shows the coastline of the fjords, with several lakes and islands labeled. The lakes include Campbell L., Michel L., St. Lawrence L., Saguenay L., and St. Pierre L. The islands include St. Pierre, St. Lawrence, and St. Lawrence. The map also shows the Saguenay River and the St. Lawrence River. Sampling stations are indicated by numbers 1 through 10. The map is oriented with North at the top.

337000 m.E 4965000 m.N

226

NTS 322000 m.E 4980000 m.N

scale 1:100 000

337000 m.E 4965000 m.N

Figure 5.38: Anomalous Bw/Po/Pw class distributions.

were identified. A division may also be identified between the northern two thirds of the area and the southern third, which displays a marked decrease in the overall occurrence of the class.

5.2.4.7 Pw/Ce

Twelve areas of concentration were identified in the study area (see figure 5.39).

5.2.4.8 Combined Background Anomalies

Figure 5.40 represents the anomalous areas of all the vegetation communities with a few exceptions. The anomalies identified in the Pw/Ce class were not included since the concentrations of this class could be accounted for by the favourable growing conditions provided by the swamp lands. Similarly the distribution of the large areas occupied by the Bw/Po/Pw class were not extraordinary in the context of preferred environmental conditions.

5.2.5 Geophysical (Total Field Magnetic) Anomalies

Three areas of magnetic highs occur in the southern half of the study area (see figure 5.41). The highest values occur southeast of Kashwakamak Lake in the southeast corner of the

Figure 5.39: Anomalous Pw/Ce class distributions.

SCALE 1: 98679, 1: 98679 SIZE: 15.4KM, 15.4KM OFFSET: . KM, . KM
 FILE:MAGANOM.PIX DATE:19-APR-89
 RED: MAP :Encoded bitmap: 4
 GREEN: MAP :Encoded bitmap: 4
 BLUE: MAP :Encoded bitmap: 4
 Geobotanical Anomalies (PAGE)

Figure 5.40: Combined background geobotanical anomalies.

SCALE 1: 99679, 1: 99679 SIZE: 15.4KM, 15.4KM OFFSET: . KM, . KM
 FILE:MAGANOM.PIX DATE:19-APR-89
 RED: MAP :Encoded bitmap: 3
 GREEN: MAP :Encoded bitmap: 3
 BLUE: MAP :Encoded bitmap: 3
 Magnetic Anomalies (3 levels) (PAGE)

Figure 5.41: Total field magnetic anomalies.

study area. The magnetic high extends to the north as far as Mississagagon and Marble Lakes, and to the west nearly as far as Skootamatta Lake. This is in the metavolcanic sequence and carbonate metasediments. The highest values are in the dacitic metavolcanics.

A second magnetic high defines a region north of Mississagagon Lake extending longitudinally along the northeast-southwest trend of the bedrock. This follows along the contact between the early carbonate metasediments and the Mazinaw Lake granite. It trends toward the west end of Mississagagon Lake.

The third magnetic high extends from the west side of the study area in a southeast direction as far as the east side of Lower Mazinaw Lake. This coincides with the metavolcanic sequence. The magnetic highs define the areas occupied by rock types which are potential hosts of mineralization.

5.2.6 Geochemical (Till-Hg) Anomalies

Based on the statistical analysis documented in section 4.2.5.2, the GAP occurred between 79 and 98 with a value of 0.0848 (see figure 5.42, 5.43). Three sites had values above the GAP with values of 98, 120, and 150 ppm (see figure 5.43). A complete listing of the data and statistical analysis is

Histogram for Hg (Original observations)

Figure 5.42: Histogram of till geochemical data.

SCALE 1: 99679, 1: 99679 SIZE: 15.4KM, 15.4KM OFFSET: . KM, . KM

Figure 5.43: Till geochemical (Hg) anomalies.

provided in appendix B.

The three sites are located in the early carbonate and clastic metasediments, two in the area between Georgia and Kashwakamak Lakes, and the third south of Lower Mazinaw Lake. The location of these till anomalies is consistent with favourable lithologic conditions for gold mineralization.

5.2.7 Biochemical (Maple - Au,Zn,Ba,Mo) Anomalies

The statistical analysis performed on the biogeochemical data identified a number of values above the threshold between background and anomalous concentrations (see Appendix B). Table 5.8 is a summary of the largest adjusted GAP, GAP statistic, and number of site locations with values above the adjusted GAP. The threshold identified for molybdenum was

	Largest Adjusted GAP	GAP Statistic	No. Points > GAP
	-----	-----	-----
Zn	20.0 - 22.0	0.0646	27
Ba	2.0 - 2.2	0.0600	25
Mo	0.26 - 0.3	0.0877	43
	(2nd) 0.7		7
Au	1.3 - 1.5	0.0713	34

Table 5.8: Summary of biogeochemical threshold statistics.

readjusted to the second GAP at 0.7 resulting in 7 anomalous sites. This was done due to the distribution of the data, the bulk of which is above the first threshold identified.

5.2.7.1 Zinc Anomalies

Zinc anomalies are located along the east and west sides of Mazinaw Lake, south of Shabomeka Lake, between Mississagagon and Kashwakamak Lakes, west of Michell Bay, and southwest of Lower Mazinaw Lake (see figures 5.44, 5.45). These locations are associated with a variety of rock types. A concentration of 6 anomalous sites occurs between Kashwakamak and Mississagagon Lakes in the carbonate metasediments.

5.2.7.2 Barium Anomalies

Barium anomalies are located west of Mazinaw Lake, the east side of Mazinaw Lake at Mazinaw Rock, south of Shabomeka Lake, east of Lower Mazinaw Lake, west of Marble Lake, and between Kashwakamak and Mississagagon Lakes (see figures 5.46, 5.47). Similar to zinc, a grouping of the anomalies occurs at the latter location.

5.2.7.3 Molybdenum Anomalies

Molybdenum anomalies (figures 5.48, 5.49) are located

Histogram for Zn (original observations)

Figure 5.44: Histogram of zinc biogeochemical data.

SCALE 1: 98679, 1: 98679 SIZE: 15.4KM, 15.4KM OFFSET: . KM, . 1

Figure 5.45: Biogeochemical zinc anomalies.

Histogram for Ba (Original observational)

Figure 5.46: Histogram of barium biogeochemical data.

SCALE 1: 98679, 1: 98679 SIZE: 15.4KM, 15.4KM OFFSET: . KM, . KM

Figure 5.47: Biogeochemical barium anomalies.

Histogram for Mo (original observations)

Figure 5.48: Histogram of molybdenum biogeochemical data.

Figure 5.49: Biogeochemical molybdenum anomalies.

again between Kashwakamak and Mississagagon Lakes, as well as west of Mississagagon Lake and west of Mazinaw Lake. The locations of all but the site west of Mazinaw Lake occur in clastic metasediments.

5.2.7.4 Au Anomalies

Gold anomalies are located between Kashwakamak and Mississagagon Lakes, east and west of Lower Mazinaw Lake, west of Marble Lake and Mississagagon Lake; there are four locations along the east side of Mazinaw Lake, and one location west of Mazinaw Lake. The majority of the sites are located in early metavolcanics and metasediments (see figures 5.50, 5.51).

5.2.8 Integrated Anomalies

The magnetic data was divided into three anomaly levels based on the statistical distribution of the high values, as previously described. The background geobotanical anomalies indicating areas of vegetation occurrence or non-occurrence not consistent with the overall distributions made up another level. Geochemical values derived from the till sampling were identified as points rather than contoured areas, as were the anomalous biogeochemical values. The following expression describes the integration procedure for the different

Histogram for Au (Original observations)

Figure: 5.50: Histogram of gold biogeochemical data.

SCALE 1: 99679, 1: 99679 SIZE: 15.4KM, 15.4KM OFFSET: . KM, . KM

Figure 5.51: Biogeochemical gold anomalies.

MAGNETICS			GEOBOTANY		GEOCHEM.		BIOGEOCHEM.		
level	1	60	+	60	+	60	+	60	= 240
	2	40							(highest
	3	20							possible
									value)

The anomalies were assigned a digital number value as shown in the expression. Where all of the anomalies occur in the same location the resulting digital number value would be 240 on a scale of 0 - 255. Overlap of different combinations of anomalies would therefore result in different values. The lowest value would occur where only the lowest level of magnetic anomaly, 20, occurs. The highest digital value represents the greatest potential for mineralization based on the geologic evidence provided by the different data types. Included in these mineral potential maps are the lineaments interpreted from the Landsat data. The resulting additive images were transformed through a pseudo-colour look-up-table in order to display the levels of potential on a colour scale. The scale goes from blue at the low end through green, yellow, red, purple and white as the highest value with the different shades in between.

Three maps were produced, each being indicative of either gold, zinc-lead, or copper mineralization depending upon the biochemical elements included in the integration process.

Figure 5.52 illustrates the different anomaly types used to produce each potential map. Since the magnetics, geobotany, and geochemistry are used for each map, the results appear quite similar. The differences are

Figure 5.52 : Data anomalies integrated to provide evidence for and locations of, gold, zinc-lead, and copper mineralization.

based on the different point biogeochemical data points selected for each map (see figures 5.53, 5.54, 5.55).

5.2.8.1 Gold Potential

The locations of highest gold potential occur in the following areas:

- 1) Areas between Kashwakamak and Mississagagon Lakes;

SLAT: 99486.1: 99486 SIZE: 15.4KH, 15.4KH OFFSET: . KH. KH
 M.PIX CREATED: 2-NOV-88 TAPE ID: DATE: 27-FEB-89
 component of channel 5 using Psc segment 9
 component of channel 5 using Psc segment 9
 component of channel 5 using Psc segment 9 (PAGE)
 al Map from integrated anomalies.

Figure 5.53: Gold potential map (white=high, blue=low).

Figure 5.54: Zinc potential map (white=high, blue=low).

Figure 5.55: Copper potential map (white=high, blue=low).

- 2) A small area along the southern shore of Kashwakamak Lake;
- 3) North of Mississagagon Lake;
- 4) West end of Bon Echo Lake; and
- 5) 4 points east, west and south of Lower Mazinaw Lake.

5.2.8.2 Zinc Potential

The locations of highest zinc potential occur in the same first 4 locations identified for gold, and 3 locations east and west of Mazinaw Lake.

5.2.8.3 Copper Potential

The locations are again similar to those for gold but the highest potential is along the eastern boundary of the study area along highway 506.

5.2.8.4 Target Areas

The selection of target areas is accomplished based on comparing the evidence derived from the integrated anomalies and the geologic model of mineralization. In both the metasedimentary Pb-Zn-Au and metavolcanic sulphides, lithology is a controlling factor. The high potential areas in the lower right of the study area should be targeted for gold, zinc and copper since they are associated with calcitic

marble (gold occurring in quartz veins and stringers in the metasediments) as well as being in close proximity to the contact between marble and metavolcanics. The anomalous area north of Mississagagon Lake follows the metavolcanics and the contact between the marbles and granite intrusive to the north. This area would also represent a favourable target area for gold and metavolcanic sulphides. The lineaments trending in a northeast-southwest direction through the anomaly indicate more precisely the location of the contact between the different rock types. The high potential area to the west of Lower Mazinaw Lake is less favourable for follow up due to the predominance of intrusive rocks in the area.

When comparing the potential maps to the sites of known mineral occurrences (figure 2.10) in general it can be seen that the occurrences fall primarily within the medium to high potential areas. In particular, the Helena, Stead, Cook, and Mazinaw Base Metals occurrences correspond to areas of high potential. The Buffadison occurrence is one exception, falling within a low potential area. The Star gold mine is also questionable since it falls on the boundary between low and medium potential areas. A lineament does, however, cut through the location of the mine. Lineaments also cross the Cook and Helena occurrences. On a percentage basis 50% of the occurrences are in high potential areas, and 25% in both medium and low potential areas.

5.3 SUMMARY OF DECISIONS

The decisions made in the interpretation phase of the exploration model are of two types. The first relate to the interpretation of the geologic information, and the second to the significance of the information in either supporting or not supporting the model of mineralization.

Question: Do the interpreted lineaments and units from the enhancements indicate different lithotectonic regions?

Explanation: The definition in space of different lithotectonic units will aid in isolating areas for detailed investigation.

Inference(yes): Areas may be selected for detailed exploration methods.

This is important when the exploration activity begins at a scale of 1:250,000 or coarser. In the Mazinaw Lake example, the favourable area for mineralization could have been reduced to the southern half of the study area. Since the study area was relatively small, the entire area was studied but more sampling and detailed field examination were done in the favourable lithologies.

Question: On the basis of the supporting field investigations, do any of the litho-tectonic regions correspond to mafic volcanics in close proximity to clastic or chemical sediments?

Explanation: Trying to determine the genetic model

of mineralization.

Inference(yes): This supports the hydrothermal vein model.

Question: On the basis of the supporting field investigations, do any of the litho-tectonic regions correspond to volcanic rocks dominantly submarine in origin with calc-alkaline composition?

Explanation: Trying to determine the genetic model of mineralization.

Inference(yes): This supports the volcanogenic sulphide model.

Question: Are there faults or dominant structures in the area.

Explanation: Trying to identify more specific locations of mineralization.

Inference: These structures may represent channels for the transport of metalliferous fluids.

CHAPTER 6 - DISCUSSION AND CONCLUSIONS

The following chapter reviews the results of the Mazinaw Lake investigations within the context of the model for the integration of remote sensing into an exploration program.

6.1 The Role of Remote Sensing

The role remote sensing can play in an exploration program is best evaluated by examining the geologic information provided by the data. The following is a review of the geologic models and associated characteristics for the types of mineral occurrences in the area:

A) METASEDIMENTARY HOSTED Pb-Zn-Au

General Genetic Model: Hydrothermal Vein

Metallogenesis: Exhalative, associated with chemical precipitates and mafic metasediments (or) Isolated vent-type associated with the deposition of carbonates (or) distal lead-zinc deposits in carbonates (or) lead zinc associated with weathering and solution of older metal concentrations.

Metallotects: Mafic volcanics. Close proximity to clastic or chemical sediments.

Geological Model for Deposit

occurs in:

- 1) carbonate rocks
- 2) stratigraphically above metavolcanics
- 3) quartz veins in basaltic interflow metasediments;

- 4) dolomitic or calcitic marble stratigraphically close to the main volcanic succession in quartz carbonate veins.

B) METAVOLCANIC SULPHIDES

General Genetic Model: Volcanogenic sulphide

Metallogenesis: Deposits from meteoric or metamorphic solutions associated with metavolcanic units.

Metallotechs: Volcanic rocks dominantly submarine in origin. Calc-alkaline or tholeiitic in composition.

Geologic Model for Deposit:

occurs in:

- 1) basalt flows, andesite and rhyolite tuffs and flows, gabbro, peridotite;
- 2) rhyolite flows and tuffs and associated granite intrusions;
- 3) quartz diorite, diorite, dacite porphyry stocks, and adjacent andesite-dacite metavolcanics.

Table 6.1 outlines the type of evidence, and the evidence provided from the remote sensing data at the different exploration levels.

The reconnaissance level of interpretation of remotely sensed data provided evidence on structure and lithology. Of particular significance were the fold/fault structures trending northeast-southwest in the southeast portion of the study area. The contact between the metavolcanic, metasediment, and intrusive rocks also provided relevant geologic information pertaining to the geologic models for the

Level of Evidence -----	Type of Evidence Provided -----
Reconnaissance	<p>Structure .fold/fault features trending NE-SW in southeast portion of the area.</p> <p>Lithology .contact between metavolcanics/metasediments and intrusives</p>
Detailed	<p>Structure .more precise definition of structures.</p> <p>Lithology .more precise definition of lithologic contacts.</p> <p>Biogeo-chemistry .chemical anomalies reflected in the distribution of tree species.</p>
Prospect Evaluation	(possible use of high resolution airborne data for detecting metal induced stress - remote method of geochemical sampling)

Table 6.1: Type of geologic information provided from remote sensing data related to model of mineralization.

deposits. Geologic definition of the interpreted lines and polygons from the imagery were based on subsequent field investigation and published information.

The detailed level of investigation enabled more precise definition of the extent and location of structures and lithologic contacts since the data processing methods applied were calibrated through field verification to the conditions of the area under study. In addition, geologic information from the other geophysical geochemical and biogeochemical data provided complementary evidence to the anomalies defined from the remote sensing data.

Through the application of the geobotanical strategy, it was possible to define vegetation anomalies as a means of biogeochemical prospecting. The definition of local areas of anomalous distributions coincided with known mineral occurrences.

With the local nature of the anomalies which were defined at the detailed stage, it is most cost effective to follow-up at the prospect evaluation level with traditional ground sampling techniques. High resolution airborne multispectral data may be tried at this level to detect metal induced stress as a means of obtaining a precise target; however, the background anomalies did provide specific areas to focus

exploration efforts on by vegetation distribution, not stress.

The remote sensing data with follow-up field investigations provided geologic evidence in support of the models of hydrothermal vein and volcanogenic type mineralization. Precise targets were also obtained through geobotanical investigations using the satellite multispectral data.

6.2 Supporting Data Sets

Other geologic data sets used in this research provided geologic information complementary and additional to the information obtained from the remote sensing data (see figure 6.2). The magnetics aided in the definition of contacts between metavolcanics, metasediments and intrusions. The geochemical and biogeochemical data provided empirical data on metal concentrations for both pathfinder elements and the elements of economic interest such as gold and zinc

6.3 The Exploration Model

As discussed in chapter 1 the exploration model consisted of a primary and secondary level utilizing a geobotanical strategy to obtain geologic information in support of the model of mineralization.

Geophysics	Magnetics	.metavolcanic and metasedimentary lithologies and contact with granite intrusions
Geo- chemistry	Mercury	.possible associated Pb, Zn, Ag
Biogeo- chemistry	Gold	.possible Au and associated Zn, Cu, Fe
	Zinc	.possible Zn and associated Cu, Pb, Ag, Au
	Barium	.possible associated volcanogenic Zn, Cu, Pb
	Molybdenum	.possible associated Cu, Pb, Zn

Table 6.2: Supporting geologic information sources.

6.3.1 Primary Structure Level

The primary structure level of the model consists of the reconnaissance, detailed and prospect evaluation levels of exploration. This research has demonstrated the key role that remote sensing data can play in providing geologic information at the detailed level as well as the reconnaissance level, and for the identification of target areas. The specific locations identified at the detailed level indicate that the prospect evaluation phase should involve traditional methods such as trenching. This structured approach will eliminate individual expert biases but will allow for an experts' knowledge of an area to be incorporated into the decision making process.

6.3.2 Geobotanical Strategy

The geobotanical strategic approach behind the model was demonstrated to be effective in identifying anomalous areas on the basis of anomalous distributions of the vegetation communities. In applying this approach it was found that it was not actually necessary in the methodology to identify specific relationships between bedrock, surficial materials and vegetation, but rather to treat the vegetation communities as a biogeochemical data set and analyze them accordingly.

6.3.3 Secondary Structure Level

The secondary structure level discussed in section 1.4.1.2 consisted of 5 stages applicable to each of the primary levels. These were physical analysis, data acquisition, data analysis, data interpretation, and data integration. This was demonstrated to be an applicable approach. Of most importance is the recognition of the necessity to pass through the data interpretation stage for each of the data sets before entering into the data integration stage. Anomalies were extracted from each data set then arithmetically combined. This differs from other work in data integration which often attempts to identify areas of high mineral potential by integrating original data sets and weighting those according to their perceived importance to the model of mineralization (Bonham-Carter et al, 1988).

6.3.4 A Knowledge-Based Model

One of the objectives in testing this exploration model was to identify the key decisions made during each of the stages. This has been done at the end of each chapter. The ability to identify these decisions is key in providing the possibility for adapting this intelligent approach into a remote sensing exploration program expert system.

Decisions within the data acquisition phase focus on defining the nature of the terrain and the size of the area under investigation in order to identify the type of remote sensing data which is most appropriate to use.

Decisions on data processing vary most, depending on whether work is being done at the reconnaissance or detailed levels. Data processing requirements also vary depending on the availability of other geologic data sets.

The decisions made in the interpretation phase of the exploration model relate to the interpretation of the geologic information and its significance to the model of mineralization.

From these decisions it can be seen that several problems are being dealt with in the application of this exploration model. They are:

- 1) What geologic information is required?
- 2) What data types need to be acquired?
- 3) What data processing methods should be used?
- 4) What interpretations can be made?

This suggests the need for an integrated knowledge-based system consisting of four systems each addressing one of the problems listed above. The second, third and fourth problems

would require 2 paths, one for reconnaissance level, and a second for the detailed level. Figure 6.1 is a representation of the framework for the design of the integrated knowledge-base.

Figure 6.1: Integrated knowledge-based system design.

6.4 CONCLUSIONS

This research has contributed uniquely to the Earth Sciences and in particular exploration geology, through the

development of a structured approach for integrating remote sensing into an exploration program within the Canadian environment. With the development and testing of this model, a number of scientific contributions have been made. They are as follows:

. A Knowledge-Based Model for Integrating Remote Sensing into an Exploration Program. According to Tosaya (1988), there is a need for the development of an intelligent or structured approach for customizing a remote sensing exploration program. The model developed provides such a structured approach, designed to meet the needs of mineral exploration in vegetated environments.

. Development of the background Geobotanical Strategy or Method. Geobotany applied to remote sensing and mineral exploration has in recent years been actively researched. The approach where high resolution remote sensing data is used to detect mineral induced stress in vegetation, has failed to provide a practical approach for mineral exploration (as discussed in chapter 1). The background geobotanical method developed here as the strategic approach to the model, has provided a viable means of using the geobotanical concept to maximize the effectiveness for extracting geologic information from remote sensing data in vegetated terrains. In developing this method the following contributions have been made:

. Determining the influence of terrain in geobotanical modelling. By determining the terrain influence, geobotanical anomalies are more precisely defined since a major controlling factor in the distribution of vegetation, can be eliminated.

. Establishing geobotanical relationships. These relationships may subsequently be used as a guide in applying this methodology where similar geological and environmental conditions exist.

. Development of image analysis procedures for determining geobotanical anomalies. The unique image analysis methods developed, may be readily applied to other locations without

change.

. A methodology for the integration of geologic data sets to produce mineral potential maps. This method may be universally applied to a number of data sets where anomalies have been applied. This simple approach retains the full benefit of each dataset for defining geological anomalies.

The key to applying the exploration model is the geobotanical strategy. In the Canadian environment much of the earth's surface is covered by vegetation. Remote sensing detectors obtain energy reflected from the earth's surface; therefore, the signal is a function of the vegetation at the surface. By applying the geobotanical strategy, geological information can be obtained at a sufficiently detailed level to identify targets. This is a significant advance in the use of remote sensing in exploration geology where it is widely considered useful only at the reconnaissance level.

While this model provides a structured approach to applying remote sensing in an exploration program, there are still decisions not addressed in this thesis which need to be made by the exploration geologist. These relate to the unique conditions of an area in terms of the biophysical characteristics and the sensitivity of the vegetation to the underlying geology. This is of particular importance when, for example, the extent and location of a host lithology is to be mapped. While this may be considered a weakness, part of the

strength of the model is the universal nature in how the methods are to be applied. For example, in the reconnaissance level of the exploration program the same enhancements (contrast stretch, principal component, directional filtering, and unsupervised classification) may be applied to all areas; however, the specific input values into these enhancements will vary from area to area.

6.5 RECOMMENDATIONS

The amount of information obtained from remote sensing data is often site specific. Also, the types of tree species and relative concentrations vary over the Canadian landscape. As a result, the main recommendation would be to test this model at different locations in case adjustments are necessary.

The second recommendation would be to implement the model in a working knowledge-based system. The system should be designed so that additions may be made to it as more geobotanical information is acquired from experimentation and as remote sensing technology develops.

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APPENDICES

Appendix A: Field Photographs.

Appendix B: Biogeochemical and Geochemical Data and Analysis.

Appendix C: Background discussion on remote sensing.

Appendix D: Notes on presentation formats.

Appendix E: Selected portion of Ontario Geological Survey Map 2499 (scale 1:31,680).

APPENDIX A

Field Photographs

NTS 322000 m.E 4960000 m.N

scale 1:100 000

337000 m.E 4965000 m.N

Location of sites for accompanying photographs.

P1: (Site M1-3) View east along east-west trending lineament. Thin sandy soil (<50cm) over biotite schist bedrock. Vegetation includes beech (40%), maple (40%), and oak (15%). Shearing and alignment of minerals suggests movement in an east-west direction.

P2: (Site M3-36) Deeply weathered granitic schist, weathered yellow-red. Vegetation includes poplar (30%), birch (30%), pine (20%), maple (10%), cedar (10%). Thin veneer over bedrock - slope 30 degrees, aspect 212.

B.3 GAP statistical analyses.

ANALYSIS FOR Au

There are 74 samples. Searched above median on LY
The data were transformed by $\text{LN}(X-\text{ALPHA})$ with $\text{ALPHA}=-8.945946\text{E}-02$
Skewness before transformation= 1.788635 After=-3.194228E-02

The largest adjusted gap is between the values of
1.3000 and 1.5000

There are 34 stations above the gap

The gap statistic is 0.0713

The critical value (10 %) is 0.07377

ANALYSIS FOR Zn

There are 74 samples. Searched above median on LY
The data were transformed by $\text{LN}(X-\text{ALPHA})$ with $\text{ALPHA}=-.8221622$
Skewness before transformation= 1.158855 After=-1.466319E-02

The largest adjusted gap is between the values of
20.0000 and 22.0000

There are 27 stations above the gap

The gap statistic is 0.0646

The critical value (10 %) is 0.07377

P5: (Site M1-27)
Solution weathering
in dolomitic marble.
Very thin or no soil.
Vegetation cover cedar
(50%), maple (30%),
and beech (15%).

P6: (Site M3-26) View
north towards narrows
along eastern shore
of Lower Mainaw Lake.
Oak and birch occur
in rubble.

**P7: (Site M1-30) Sandy
glaciofluvial outwash
with cross-bedding
(approx. 8 to 10
metres thick).
Vegetation of birch,
poplar, and maple.**

**P8: (Site M2-12)
Contact between pebble
conglomerate schist
and marble (Whitefish
Rapids). Birch/poplar
vegetation with cedar
along the shorelines.**

P9: (Site M2-11)
Ridge - valley
succession with beech
dominant in valleys
and oak/maple on
ridges. Occurrence of
birch corresponds to
interpreted lineament
and probable contact.

P10: (Site M1-24)
Abandoned Au mine
(Helena) in early
carbonates. Thin
sand/silt layer over
bedrock. Surrounding
pit vegetation
includes pine, birch,
and maple.

APPENDIX B

BIOGEOCHEMICAL AND GEOCHEMICAL DATA ANALYSIS

Biogeochemical

- B.1 Original data values.**
- B.2 Summary statistics and histograms.**
- B.3 GAP statistical analyses.**

Geochemical

- B.4 Original data values.**
- B.5 Summary statistics and histograms**
- B.6 GAP statistical analysis.**

B.1 Original data values for Zn, Ba, Mo, and Au biogeochemistry.

Zn ppm	Ba ppm	Mo ppm	Au ppm
16.00	1.70	0.26	8.00
8.00	1.90	0.30	0.50
34.00	0.90	0.21	1.10
33.00	1.00	0.30	0.80
28.00	1.30	0.21	1.50
32.00	1.60	0.11	1.70
17.00	1.50	0.40	0.80
16.00	0.60	0.31	1.10
24.00	1.20	0.20	0.90
5.00	1.51	1.13	3.50
14.00	1.50	0.12	2.00
12.00	3.20	0.32	2.10
41.00	1.20	0.21	1.90
5.00	1.80	0.23	3.90
8.00	0.80	0.20	0.50
26.00	0.70	0.20	0.20
19.00	3.60	0.31	1.80
5.00	2.20	0.32	2.90
30.00	3.00	0.12	2.00
16.00	1.20	0.32	2.90
20.00	1.60	0.21	1.90
11.00	1.80	0.42	2.40
16.00	1.70	0.10	0.20
15.00	1.00	0.30	0.90
18.00	2.50	0.13	3.60
15.00	1.20	0.23	3.20
31.00	0.80	0.13	3.00
16.00	1.00	0.61	1.30
10.00	1.20	0.11	1.60
10.00	4.80	0.51	1.80
29.00	3.90	0.71	1.90
12.00	1.51	1.11	4.20
11.00	1.41	1.30	0.80
26.00	0.90	0.30	0.80
18.00	3.20	0.40	0.40
18.00	0.90	0.21	1.80
25.00	1.30	0.50	0.80
24.00	1.30	0.40	0.90
24.00	2.50	0.41	1.80
24.00	1.70	0.41	1.10
14.00	4.11	1.00	0.90
14.00	2.30	0.11	1.00
13.00	2.80	0.41	1.50
10.00	1.10	0.32	2.10
5.00	2.50	0.31	1.00
17.00	1.80	0.51	1.20
11.00	5.21	1.00	0.70
5.00	3.60	0.31	1.50
15.00	1.30	0.31	1.20
12.00	0.90	0.35	5.80

Zn ppm	Ba ppm	Mo ppm	Au ppm
15.90	0.60	0.11	1.10
22.00	5.00	0.71	1.10
9.00	2.40	0.20	0.70
19.00	1.60	0.40	0.80
46.00	3.00	0.20	0.20
44.00	1.30	0.11	1.20
19.00	2.00	0.10	0.40
20.00	3.10	0.10	0.80
24.00	1.30	0.11	1.00
10.00	0.80	0.40	0.20
55.00	3.20	0.56	6.10
53.00	3.50	0.37	7.00
53.00	1.50	0.30	0.90
22.00	1.40	0.40	0.90
11.00	2.00	0.30	0.20
44.00	6.60	0.23	3.70
35.00	4.60	0.41	1.60
14.00	1.90	0.22	2.80
14.00	2.30	0.30	0.70
10.00	1.70	0.10	0.90
29.00	1.00	0.10	0.80
19.00	1.00	0.31	1.20
10.00	4.50	0.42	2.30
42.00	0.80	0.16	6.40

9.2 Summary statistics and histograms for Zn, Ba, Mo, Au.

Biogeochemistry - Zn, Ba, Mo, Au
Mazinas Lake Study Area

+++VARIABLE: Au

Total observations = 74 Number above detection limit = 74

100% = 1.67

Mean	Variance	Standard Deviation	Coefficient of Variation
1.79	2.35	1.53	0.86

Confidence Limits	Lower	Upper
Mean	1.49	2.09
Variance	1.73	3.16

Minimum value: 0.20
Maximum value: 7.00

FREQUENCY DISTRIBUTION

69 values from 74 observations
Class interval = .1

Number	Class Interval	Frequency	Relative Freq. (%)	Cumulative Frequency	Relative Cum. Freq. (%)
1	0.00 -	0.10	0	0.00	0
2	0.10 -	0.20	0	0.00	0
3	0.20 -	0.30	5	7.25	5
4	0.30 -	0.40	0	0.00	5
5	0.40 -	0.50	2	2.90	7
6	0.50 -	0.60	2	2.90	9
7	0.60 -	0.70	0	0.00	9
8	0.70 -	0.80	3	4.35	12
9	0.80 -	0.90	8	11.59	20
10	0.90 -	1.00	7	10.14	27
11	1.00 -	1.10	3	4.35	30
12	1.10 -	1.20	5	7.25	35
13	1.20 -	1.30	4	5.80	39
14	1.30 -	1.40	1	1.45	40
15	1.40 -	1.50	0	0.00	40
16	1.50 -	1.60	3	4.35	43
17	1.60 -	1.70	2	2.90	45
18	1.70 -	1.80	1	1.45	46
19	1.80 -	1.90	4	5.80	50
20	1.90 -	2.00	3	4.35	53
21	2.00 -	2.10	2	2.90	55
22	2.10 -	2.20	2	2.90	57
23	2.20 -	2.30	0	0.00	57
24	2.30 -	2.40	1	1.45	58
25	2.40 -	2.50	1	1.45	59
26	2.50 -	2.60	0	0.00	59
27	2.60 -	2.70	0	0.00	59
28	2.70 -	2.80	0	0.00	59
29	2.80 -	2.90	1	1.45	60
30	2.90 -	3.00	2	2.90	62
31	3.00 -	3.10	1	1.45	63
32	3.10 -	3.20	0	0.00	63
33	3.20 -	3.30	1	1.45	64
34	3.30 -	3.40	0	0.00	64
35	3.40 -	3.50	0	0.00	64
36	3.50 -	3.60	1	1.45	65
37	3.60 -	3.70	1	1.45	66
38	3.70 -	3.80	1	1.45	67
39	3.80 -	3.90	0	0.00	67
40	3.90 -	4.00	1	1.45	68
41	4.00 -	4.10	0	0.00	68
42	4.10 -	4.20	0	0.00	68
43	4.20 -	4.30	1	1.45	69

Biogeochemistry - Zn, Ba, Mo, Au
Mazinnu Lake Study Area

***VARIABLE: Zn

Total observations = 71 Number above detection limit = 71

T01014 = 1.67

Mean	Variance	Standard Deviation	Coefficient of Variation
20.55	142.58	11.91	0.58

Confidence Interval	Lower	Upper
Mean	18.24	22.87
Variance	110.78	191.60

Minimum value: 5.00
Maximum value: 55.00

FREQUENCY DISTRIBUTION

71 values from 71 observations
Class interval = 1

Number	Class Interval	Frequency	Relative Freq.(%)	Cumulative Frequency	Relative Cum. Freq. (%)	
1	0.00 -	1.00	0	0.00	0	0.00
2	1.00 -	2.00	0	0.00	0	0.00
3	2.00 -	3.00	0	0.00	0	0.00
4	3.00 -	4.00	0	0.00	0	0.00
5	4.00 -	5.00	0	0.00	0	0.00
6	5.00 -	6.00	4	5.63	4	5.63
7	6.00 -	7.00	0	0.00	4	5.63
8	7.00 -	8.00	0	0.00	4	5.63
9	8.00 -	9.00	2	2.82	6	8.45
10	9.00 -	10.00	2	2.82	8	11.27
11	10.00 -	11.00	0	0.00	8	11.27
12	11.00 -	12.00	4	5.63	12	19.72
13	12.00 -	13.00	3	4.23	15	25.35
14	13.00 -	14.00	1	1.41	16	29.58
15	14.00 -	15.00	5	7.04	21	30.99
16	15.00 -	16.00	4	5.63	25	38.03
17	16.00 -	17.00	5	7.04	30	43.66
18	17.00 -	18.00	2	2.82	32	50.70
19	18.00 -	19.00	3	4.23	35	51.52
20	19.00 -	20.00	4	5.63	39	57.75
21	20.00 -	21.00	2	2.82	41	63.38
22	21.00 -	22.00	0	0.00	41	66.20
23	22.00 -	23.00	2	2.82	43	66.20
24	23.00 -	24.00	0	0.00	43	69.01
25	24.00 -	25.00	5	7.04	48	69.01
26	25.00 -	26.00	1	1.41	49	76.06
27	26.00 -	27.00	2	2.82	51	77.46
28	27.00 -	28.00	0	0.00	51	80.28
29	28.00 -	29.00	1	1.41	52	80.28
30	29.00 -	30.00	2	2.82	54	81.69
31	30.00 -	31.00	1	1.41	55	84.51
32	31.00 -	32.00	0	0.00	55	85.92
33	32.00 -	33.00	1	1.41	56	85.92
34	33.00 -	34.00	2	2.82	58	87.32
35	34.00 -	35.00	1	1.41	59	90.14
36	35.00 -	36.00	1	1.41	60	91.55
37	36.00 -	37.00	0	0.00	60	92.96
38	37.00 -	38.00	0	0.00	60	92.96
39	38.00 -	39.00	0	0.00	60	92.96
40	39.00 -	40.00	0	0.00	60	92.96
41	40.00 -	41.00	0	0.00	60	92.96
42	41.00 -	42.00	1	1.41	61	92.96
43	42.00 -	43.00	1	1.41	62	94.37
44	43.00 -	44.00	0	0.00	62	95.77
45	44.00 -	45.00	2	2.82	64	95.77
46	45.00 -	46.00	0	0.00	64	98.59
47	46.00 -	47.00	1	1.41	65	98.59

Biogeochemistry - Zn, Pb, Mo, Au
Maximus Lake Study Area

***VARIABLE: Ba

Total observations = 74 Number above detection limit = 74

1(10)% = 1.67

Mean	Variance	Standard Deviation	Coefficient of Variation
2.06	1.61	1.27	0.61

Confidence Limits	Lower	Upper
Mean	1.82	2.31
Variance	1.25	2.16

Minimum value: 0.60
Maximum value: 6.60

FREQUENCY DISTRIBUTION

74 values from 74 observations
(class interval = .1)

Number	Class Interval	Frequency	Relative Freq.(%)	Cumulative Frequency	Relative Cum. Freq. (%)
1	0.00 - 0.10	0	0.00	0	0.00
2	0.10 - 0.20	0	0.00	0	0.00
3	0.20 - 0.30	0	0.00	0	0.00
4	0.30 - 0.40	0	0.00	0	0.00
5	0.40 - 0.50	0	0.00	0	0.00
6	0.50 - 0.60	0	0.00	0	0.00
7	0.60 - 0.70	2	2.82	2	2.82
8	0.70 - 0.80	1	1.41	3	4.23
9	0.80 - 0.90	4	5.63	7	9.86
10	0.90 - 1.00	4	5.63	11	15.49
11	1.00 - 1.10	5	7.04	16	22.54
12	1.10 - 1.20	1	1.41	17	23.94
13	1.20 - 1.30	5	7.04	22	30.99
14	1.30 - 1.40	4	5.63	26	36.62
15	1.40 - 1.50	2	2.82	28	39.44
16	1.50 - 1.60	5	7.04	33	46.48
17	1.60 - 1.70	3	4.23	36	50.70
18	1.70 - 1.80	4	5.63	40	56.34
19	1.80 - 1.90	4	5.63	44	61.97
20	1.90 - 2.00	3	4.23	47	66.20
21	2.00 - 2.10	2	2.82	49	69.01
22	2.10 - 2.20	0	0.00	49	69.01
23	2.20 - 2.30	1	1.41	50	70.42
24	2.30 - 2.40	2	2.82	52	73.24
25	2.40 - 2.50	1	1.41	53	74.65
26	2.50 - 2.60	3	4.23	56	78.87
27	2.60 - 2.70	0	0.00	56	78.87
28	2.70 - 2.80	0	0.00	56	78.87
29	2.80 - 2.90	1	1.41	57	80.28
30	2.90 - 3.00	0	0.00	57	80.28
31	3.00 - 3.10	2	2.82	59	83.10
32	3.10 - 3.20	1	1.41	60	84.51
33	3.20 - 3.30	3	4.23	63	88.73
34	3.30 - 3.40	0	0.00	63	88.73
35	3.40 - 3.50	0	0.00	63	88.73
36	3.50 - 3.60	1	1.41	64	90.14
37	3.60 - 3.70	2	2.82	66	92.96
38	3.70 - 3.80	0	0.00	66	92.96
39	3.80 - 3.90	0	0.00	66	92.96
40	3.90 - 4.00	1	1.41	67	94.37
41	4.00 - 4.10	0	0.00	67	94.37
42	4.10 - 4.20	0	0.00	67	94.37
43	4.20 - 4.30	0	0.00	67	94.37
44	4.30 - 4.40	0	0.00	67	94.37
45	4.40 - 4.50	1	1.41	68	95.77
46	4.50 - 4.60	1	1.41	69	97.18
47	4.60 - 4.70	1	1.41	70	98.59
48	4.70 - 4.80	0	0.00	70	98.59
49	4.80 - 4.90	1	1.41	71	100.00

Biogeochemistry - Zn, Ba, Mo, Au
Mazinaw Lake Study Area

+++VARIABLE: Mo

Total observations = 74 Number above detection limit = 69

T(10)X = 1.67

Mean	Variance	Standard Deviation	Coefficient of Variation
0.36	0.06	0.25	0.70

Confidence Limits	Lower	Upper
Mean	0.31	0.41
Variance	0.05	0.09

Minimum value: 0.11
Maximum value: 1.30

FREQUENCY DISTRIBUTION

69 values from 74 observations
Class interval = .1

Number	Class Interval	Frequency	Relative Freq.(%)	Cumulative Frequency	Relative Cum. Freq. (%)
1	0.00 - 0.10	0	0.00	0	0.00
2	0.10 - 0.20	10	14.49	10	14.49
3	0.20 - 0.30	15	21.74	25	36.23
4	0.30 - 0.40	18	26.09	43	62.32
5	0.40 - 0.50	14	20.29	57	82.61
6	0.50 - 0.60	3	4.35	60	86.96
7	0.60 - 0.70	2	2.90	62	89.86
8	0.70 - 0.80	2	2.90	64	92.75
9	0.80 - 0.90	0	0.00	64	92.75
10	0.90 - 1.00	0	0.00	64	92.75
11	1.00 - 1.10	2	2.90	66	95.65
12	1.10 - 1.20	2	2.90	68	98.55
13	1.20 - 1.30	0	0.00	68	98.55
14	1.30 - 1.40	1	1.45	69	100.00

Gold

74 observations within the range from 74 total.

Histogram for Au (Original observations)

Zinc

74 observations within the range from 74 total.

Histogram for Zn (Original observations)

Barium

74 observations within the range from 74 total.

Histogram for Ba (Original observations)

Molybdenum

69 observations within the range from 74 total.

Histogram for Mo (Original observations)

B.3 GAP statistical analyses.

ANALYSIS FOR Au

There are 74 samples. Searched above median on LY
The data were transformed by $LN(X-ALPHA)$ with $ALPHA=-8.945946E-02$
Skewness before transformation= 1.788635 After=-3.194228E-02

The largest adjusted gap is between the values of
1.3000 and 1.5000

There are 34 stations above the gap

The gap statistic is 0.0713

The critical value (10 %) is 0.07377

ANALYSIS FOR Zn

There are 74 samples. Searched above median on LY
The data were transformed by $LN(X-ALPHA)$ with $ALPHA=-.8221622$
Skewness before transformation= 1.158855 After=-1.466319E-02

The largest adjusted gap is between the values of
20.0000 and 22.0000

There are 27 stations above the gap

The gap statistic is 0.0646

The critical value (10 %) is 0.07377

ANALYSIS FOR Ba

There are 74 samples. Searched above median on LY
The data were transformed by $LN(X-ALPHA)$ with $ALPHA = .2889865$
Skewness before transformation= 1.390111 After= $1.770995E-02$

The largest adjusted gap is between the values of
2.0000 and 2.2000

There are 25 stations above the gap

The gap statistic is 0.0600

The critical value (10 %) is 0.07377

ANALYSIS FOR Mo

There are 74 samples. Searched above median on LY
The data were transformed by $LN(X-ALPHA)$ with $ALPHA = 3.108648E-02$
Skewness before transformation= 2.018567 After= $6.846777E-03$

The largest adjusted gap is between the values of
0.2600 and 0.3000

There are 43 stations above the gap

The gap statistic is 0.0877

The critical value (10 %) is 0.07377

B.4 Original data values for Hg till geochemistry.

Date: 11-01-1988 Time: 14:00:23

Station ID	Hg PPM
M2-20	14.00
M2-30	15.00
M2-37	15.00
M2-23	18.00
M2-29	18.00
M2-43	22.00
M2-32	22.00
M2-35	25.00
M2-55	25.00
M2-49	25.00
M2-57	28.00
M2-14	32.00
M2-63	33.00
M2-45	33.00
M2-15	36.00
M2-39	36.00
M2-19	36.00
M2-56	36.00
M2-58	39.00
M2-7	40.00
M2-5	44.00
M2-12	47.00
M2-16	49.00
M2-4	55.00
M2-33	55.00
M2-22	58.00
M2-17	58.00
M2-50	58.00
M2-10	58.00
M2-8	62.00
M2-48	62.00
M2-25	62.00
M2-9	66.00
M2-21	66.00
M2-2	69.00
M2-46	73.00
M2-40	73.00
M2-11	73.00
M2-47	76.00
M2-21	98.00
M2-24	120.00
M2-28	150.00

B.5 Summary statistics and histogram for Hg.

FILE C:\CHEM\LISTPV
Mazoma Lake Study Area
Mercury

***VARIABLE: hg

Total observations = 42 Number above detection limit = 42

T(10)% = 1.68

Mean	Variance	Standard Deviation	Coefficient of Variation
49.52	798.60	28.26	0.57

Confidence Limits	Lower	Upper
Mean	42.19	56.86
Variance	574.97	1198.35

Minimum value: 14.00
Maximum value: 150.00

Hg

42 observations within the range from 42 total.

Histogram for Hg (Original observations)

B.6 GAP statistical analysis.

ANALYSIS FOR Hg

There are 42 samples. Searched above median on LY
The data were transformed by LN(X-ALPHA) with ALPHA=-5.447619
Skewness before transformation= 1.416673 After=-6.871044E-03

The largest adjusted gap is between the values of
76.0000 and 98.0000

There are 3 stations above the gap

The gap statistic is 0.0848

The critical value (10 %) is 0.11660

APPENDIX C

C.1 A Discussion on the Fundamentals of Remote Sensing

C.1.1 Fundamentals of Remote Sensing

C.1.1.1 Electromagnetic Radiation

C.1.1.2 Energy Interactions

C.1.2 Remote Sensing Systems

C.1.2.1 Non-Imaging Systems

C.1.2.2 Imaging Systems

C.1.2.3 LANDSAT

C.1.2.4 SPOT

C.1.2.5 RADAR

C.1 A DISCUSSION ON THE FUNDAMENTALS OF REMOTE SENSING

The following is a brief discussion on the fundamental principles of remote sensing and remote sensing systems. It is intended as additional background material for the reader if required. For more complete discussions on these topics the reader is referred to the books by Lillesand and Kiefer (1979) and Siegal and Gillespie (1980).

C.1.1 Fundamentals of remote sensing.

The definition of remote sensing in the context which it is normally applied, deals with the obtaining of information about a phenomenon through the analysis of data obtained by a device not in contact with the phenomenon. The source of data is electromagnetic energy emitted, scattered, and reflected from the phenomena under investigation. In a broader context the term may be applied to the use of force fields such as gravity or magnetics, or mechanical vibrations such as acoustical or seismic since these also involve the sensing of an object or phenomena from some distance. The accepted use of the term, however only deals with the use of electromagnetic energy from the visible, infrared and microwave wavelengths.

C.1.1.1 Electromagnetic Radiation

The region of interest in remote sensing is from the blue visible part of the spectrum at $0.4\mu\text{m}$ to the microwave wavelengths up to approximately 1 meter depending on the sensor. The information about an object is contained in the electromagnetic radiation passing from the target to the sensor.

The amount of radiation reflected or emitted will vary at different wavelengths. The sun is the source of energy reflected back to the sensor. The peak of the energy curve occurs in the visible portion of the spectrum. There is limited energy available from the sun in the microwave portion of the spectrum which has resulted in most microwave sensor systems being active in the sense of supplying their own source of energy. In the infrared portion of the spectrum atmospheric windows are relied upon since parts of this part of the spectrum are not suitable for sensing due to absorption of energy occurring due to water and carbon dioxide in the atmosphere.

C.1.1.2 Energy Interactions

The analysis and interpretation of remote sensing data

requires an understanding of the interactions of electromagnetic energy in the atmosphere and with earth surface features. Scattering and absorption of energy occurs in the atmosphere reducing the amount of energy available to interact with the features on the earth's surface. This becomes apparent when looking across a hilly landscape on a hazy day. The amount of scattered light increases the further the viewer looks away, thereby limiting the amount of reflected light from the earth's surface being received by the person's eyes. As a result little information can be interpreted by the brain about the terrain.

The electromagnetic radiation will either be absorbed, transmitted or reflected depending upon the material receiving the incoming radiation. For example, water generally appears blue to the viewer due to peak reflectance within the blue portion of the spectrum. In the reflected infrared portion of the spectrum the energy is absorbed. Sediment in glacial fed lakes appears green since the fine suspended particles result in energy being reflected in the green portion of the spectrum rather than the blue. The reflectance, transmittance and absorption of energy may become quite complex. If a person is sitting in the shade beneath a tree that person is still able to see well due to the continued reflectance of the electromagnetic radiation between the ground and the underside of the tree. With each reflection of this nature some energy will also be absorbed or transmitted. In a shallow lake where a certain amount of energy has been transmitted, it may subsequently be reflected from the bottom of the lake.

Another aspect to consider in terms of the application of remote sensing, is the variable appearance of a particular feature dependent upon the influence of other controlling factors. For example, bare sand occurring beside a stream and as channel bars will have quite a varied reflectance character depending on the amount of moisture in the sand, despite the homogeneity of the sand itself. In appreciating the natural environment in all its complexity, characteristic reflectance curves become suspect.

It becomes quite apparent that in order to analyze and interpret images, whether they are aerial photographs or multispectral satellite images, it is important to have an understanding of energy interactions.

C.1.1.2 Remote sensing systems.

Remote sensing devices (sensors) measure the intensity of electromagnetic radiation (EMR) emitted or reflected from a surface or object as a function of time, wavelength, space, geometry, including the angular orientation of the target with respect to the observer, and polarization of the radiation (Reeves, 1975). There is no single instrument capable of sensing all these factors. As a result the most suitable sensor must be decided upon for a particular application. The end result will involve a combination of sensors to achieve the range and amount of information required.

C.1.2.1 Non-Imaging Systems

Remote sensing systems may be broadly divided into imaging and non-imaging systems. The non-imaging systems are primarily used for experimental work to determine precise characteristics of the interaction of energy with specific targets. Spectroradiometers for example are electro-optical instruments which will provide a spectral response measurement over a range of wavelengths for a single target, the output being either numerical or graphical. This type of instrument is best used for investigating the specific characteristics of natural phenomenon, from which broader models may be developed to best apply remote sensing data and methods. In the southwestern United States this type of instrument is being used to identify rocks and minerals on the ground. The lack of vegetation and soils in the arid areas where this work is being carried out provide optimal conditions for using this type of technology for real time exploration field work. In this case, a knowledge-base of mineral spectra are stored in the instrument and measurements are compared directly with the database and an identification is made based on the comparison.

C.1.2.2 Imaging Systems

Imaging systems have been divided into photographic, electro-optical and radar scatterometer systems. The photographic systems which are most familiar to people consist of an enclosed chamber with a lens at one end and a light sensitive film at the other. The lens gathers the reflected energy and transmits it onto the light sensitive film in an orderly fashion. A shutter serves to regulate the amount and duration of EMR reaching the film. These types of remote sensing systems are generally mounted on airborne platforms and carried at high, medium, and low altitudes depending on the desired scale. Panchromatic and colour aerial photographs are produced in this way. The strength of these types of systems are the simplicity and inexpensiveness of the systems. They also

sense in the visible portion of the spectrum, making interpretation of the imagery somewhat simpler, since objects in the images reflect in the same way in which we see. When using data beyond the visible wavelengths, an understanding of how specific wavelengths behave with specific material types, is required.

Electro-optical imaging systems are most commonly used in remote sensing. These systems utilize an array of detectors which scan across portions of the earth's surface in a regular manner, producing an image from the raster display of the electrical responses of the detectors which are modulated by the amount of incident EMR at specific band widths and location over the spectrum. The advantages over photographic systems are the ability to readily transmit, record, process, and analyze the output signal since it is in an electrical form.

C.1.2.3 Landsat

The scan width of the Landsat scanner is 185 kilometres. There is an array of 24 detectors, 6 for each of the bands. The orbit is sun synchronous, progressing westward so as to cross the equator always at the same local time. There is, however, illumination variation due to the latitudinal and seasonal association with solar elevation angles. The Landsat 4 and 5 Thematic Mapper (TM) sensor is similar to the MSS scanner but has 7 narrow bands compared to the 4 relatively broad bands of the MSS.

Landsat 4 and 5 which have the TM sensor are at a lower orbit than the previous Landsats. This is one of the main contributing factors to the greater spatial resolution of 30 metres as compared to the 80 metre pixels of the MSS scanner. Resulting from this is a shorter orbit duration, greater number of orbits per day, and less time to cover the entire earth. Comparing the two sensors in terms of spectral and spatial resolution provides a useful insight into the potential application of each data type. The MSS has 4 bands in the visible and reflected infrared portion of the spectrum from green to mid-infrared. TM has 6 bands in the visible and reflected infrared range from blue wavelengths to the far reflected infrared at 2.2 microns. The TM sensor also has a band sensitive to thermal (emitted) infrared radiation in the 10.5 to 12.5 micron range. The thermal band has a lower spatial resolution of 120 metres as compared to the 30 metre resolution of the other bands. The final resampled pixel size for the MSS data is 59x79 metres. The higher spectral resolution of the TM sensor enables the detection of more subtle spectral variations at particular wavelengths since there is less averaging. This is particularly useful in studies with

vegetation as a key component. In terms of spatial resolution a 512x512 pixel scene of the TM data would cover an area of 15x15 kilometres (225 sq. kil.) and contain 262,144 pixels times the seven bands. The MSS would have the same number of pixels times 4 bands but cover an area 30x30 kilometres (900 sq. kil.) in size. The implication is that you can cover a larger area with the MSS for a given number of pixels. What is sacrificed however, is a significant amount of information. In project planning an early decision on what data to use is based on the size of the object which needs to be detected.

C.1.2.4 SPOT

Within the last couple of years the French earth observation satellite SPOT-1 was put into orbit. This spacecraft has two sensors on board. A multispectral visible-infrared scanner with 3 bands and 20 metre resolution, and a panchromatic scanner in the visible wavelengths with a resolution of 20 metres. Stereo images are made possible by revisit capabilities with the pointable sensor. The broad bandwidths of the multispectral scanner give it no advantage over the Landsat MSS and TM sensors. The advantage is in the spatial resolution of 20 metres. Any advantage gained by this is outweighed by the poor spectral resolution when compared to the TM data. The panchromatic 10 metre data adds a new dimension to space-based remote sensing. In effect, aerial photograph type images are produced digitally over larger areas for a single image.

C.1.2.5 Radar

The final sensor types to be discussed are the radar or microwave systems. Radar systems differ from the other remote sensing systems in that the sensor supplies its own energy source. There are passive microwave systems which rely on microwave energy reflected from the ground itself but these have seen very limited use for earth resource applications.

There are currently no satellite-based civilian radars. Data from the SEASAT radar is still used in geologic investigations, however, and provides a means for planning future radar systems. Since radar data may be collected under cloudy conditions a large data set was collected by SEASAT in its relatively brief period of operation. Several satellite based radars are planned for the next decade. These include Radarsat from Canada, ERS-1 from Europe and a satellite from Japan.

The most active use of Radar has been with airborne

systems. In 1962 and 1969 a large scale geological reconnaissance mapping project was undertaken using SLAR (side-looking airborne radar) imagery. This was over Eastern Panama, an area which previously had been unsuccessfully mapped due to constant cloud cover. It was found that the radar imagery aided in physiographic differentiation on a regional scale (MacDonald, 1980). Lithologies, structural and stratigraphic differences were identified. The first major radar survey in South America occurred in Venezuela in 1971. This project was the largest undertaken at that time. It greatly increased the mapping accuracy of the country and the knowledge of its geologic patterns (MacDonald, 1980). In 1971 a project called RADAM (Radar of the Amazon) was undertaken to obtain information on mineral resources, soils, hydrology, vegetation, and landuse and was used for the production of base maps (MacDonald, 1980). In 1980 the U.S. Geological Survey began a systematic airborne radar program to map the entire U.S. with Radar at a scale of 1:250,000. This is still being done.

The configuration of airborne radar systems is important for geologic investigations. The side-looking view allows for the illumination of the earth's surface with low controlled oblique angles from any desired azimuth. This makes it a versatile tool for the detection and mapping of geologic lineaments. It is the topographic relief and tonal anomalies which allow interpretation of lineaments on the imagery.

APPENDIX D

Notes on Presentation Formats

D.1 Histograms

D.2 Image Plots

D.1 Histograms

Histograms have been included in the text to provide the reader with a graphic representation of the data before and after various transformations. This is important in order to maintain an understanding of the exact nature of resulting images from the different image processing techniques. This understanding aids in the interpretation process.

All histograms, unless otherwise indicated, have the x-axis representing reflectance in digital numbers (DN) on a scale from 0 to 255. This range is standard for image processing systems which are largely 8 bit in architecture. The y-axis represents the number of occurrences or pixels at a given DN. If the pixel count is less than 10 then the actual number of pixels is given. Each star symbol represents 10 pixels.

Mean, median and standard deviation statistics have been calculated for each histogram and are presented immediately below the corresponding histogram.

D.2

All the images presented in the text have been plotted on a Tektronix 4696 ink jet plotter. A scale is written immediately below the images. This is calculated based on the pixel size and number of pixels in the image. Information below the scale refers to the image channels making up the image and their respective colour gun assignment.

APPENDIX E

**Selected Portion of Ontario Geological
Survey Map 2499 (scale 1:31,680)
(map photo-reduced)**

LEGEND

PHANEROZOIC

CENOZOIC*

QUATERNARY

PLEISTOCENE AND RECENT

- 11 gravel, sand, organic deposits
alluvium

UNCONFORMITY

PRECAMBRIAN*

LATE PRECAMBRIAN*

LATE METASEDIMENTS

FLINTON GROUP

LESSARD FORMATION†

- 12a Gneissous metapelite
quartzite

WILLOW CREEK FORMATION Gneiss

- 12b Gneissic schist, diorite-carbonate
rare schist, minor gneissic marble
12c Carbonate pebble conglomerate
gneissic schist, pelitic marble
12d Interbedded dolomite and calcitic
marble

5-3-0P CORNERS FORMATION

- 12a Muscovite schist, garnet-biotite
schist, quartzite
12b Quartzite
12c Quartzite pebble conglomerate
interbedded quartzite, pebbly
quartzite, micaceous quartzite
12d Pelitic conglomerate
12e Impure calcitic marble, calcareous
quartzite
UNCONFORMITY

FELSIC TO INTERMEDIATE INTRUSIVE ROCKS

SHOOTAMATTA STOCK†

- 14 Monzonite, syenite, quartz syenite,
or porphyritic syenite

MAZINAW LAKE GRANITE AND SMALL POTASSIC INTRUSIONS

- 13 Granite, granite porphyry

ELZEVIR AND MORTHBROOK BATHOLITHS AND SMALL SODIC INTRUSIONS

- 12a Granodiorite, trondhjemite
12b Granodiorite intrusive breccia
12c Quartz monzonite
12d Feldspar and quartz-feldspar
porphyry dikes, felsite dikes
INTRUSIVE CONTACT

INTERMEDIATE INTRUSIVE ROCKS*

- 11 Diorite, quartz diorite, diorite
intrusive breccia

MAFIC AND ULTRAMAFIC INTRUSIVE ROCKS*

- 10a Gabbro, peridotite, hornblende,
hornblende schist
10c Mafic and intermediate dikes
intrusive contact

EARLY METASEDIMENTS*

CARBONATE METASEDIMENTS

- 12a Dolomite, marble, calcareous
sand
12b Calcitic and subordinate interbedded
dolomite, marble, thin beds
and minor pelitic marble
12c Layered marble with numerous
mafic and intermediate sills and
dikes
12d Interbedded marble and calcareous

CARBONATE AND CLASTIC METASEDIMENTS

- 12a Interbedded dolomite, marble,
dolomitic siltstone, carbonate
siltstone, calcareous minor calcitic
marble

SULPHIDE-GRAPHITE METASEDIMENTS

- 12a Pyrite and/or pyrrhotite bearing
graphitic schist, black chert

CLASTIC INTERMEDIATE TO FELSIC METASEDIMENTS

- 12a Lithic calcareous siltstone, mudstone,
siltstone, calcareous minor calcitic
intermediate

CLASTIC MAFIC METASEDIMENTS

- 12a Mafic and intermediate clasts in
calcic siltstone

METAVOLCANICS*

RHYOLITIC METAVOLCANICS

- 14 Rhyolite, lapilli tuff, tuff breccia,
ash flow tuff, rhyolite, rhyolite porphyry
and granite porphyry dikes
and sills

DACITIC METAVOLCANICS

- 14a Basaltic andesite, andesite
14b Basaltic andesite, tuff, tuff breccia,
and tuff
14c Carbonate volcanic breccia
14d Basaltic andesite, porphyry dikes
and sills, small intrusions

ANDESITIC METAVOLCANICS

- 14a Andesite, basaltic andesite, andesite
breccia
14b Andesite tuff breccia, lapilli tuff,
mass flow deposits
14c Andesite, andesite porphyry dikes
and sills
14d Andesite agglomerate tuff breccia

BASALTIC METAVOLCANICS

- 14a Basalt flows, pillow lavas, flow
mounds, flow breccia, andesite
breccia, andesite porphyry dikes
and sills
14b Basaltic andesite, andesite flows,
breccia, andesite porphyry dikes
and sills, andesite breccia
14c Basaltic andesite dikes and
sills, small gabbroic intrusions

11m.c.

END

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FIN