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LANDSAT LINEAMENT STUDY OF THE
LAKE TEMISKAMING AREA (ONTARIO AND QUÉBEC)

by

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A Thesis submitted to the Faculty of Graduate
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of Arts
in Geography

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Abstract

A 1:1,000,000 lineament map of a 185 x 450 km area centred on Lake Temiskaming, Ontario has been produced using visual photogeologic interpretation and an analog edge enhancement technique. Five 1:125,000 lineament maps have been produced by interpreting computer-enhanced imagery using the "Landsat Geological Analysis Aid Package" of the Canada Centre for Remote Sensing, Ottawa, Ontario. Several major lineament trends have been detected through visual and statistical analysis.

The value of Landsat data and associated computer processing techniques for lineament detection has been evaluated. Terrain and system factors can affect lineament detectability on Landsat imagery. Computer processing techniques and repetitive interpretations may reduce the subjectivity involved in lineament interpretation.

Analysis indicates that the success of these techniques is highly controlled by the biophysical environment. Technical and methodological improvements to the "Landsat Geological Analysis Aid Package" are suggested.

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Table of Contents

	Page
Abstract	ii
Acknowledgements	iii
Table of Contents	iv-vii
List of Figures	viii-x
List of Tables	xi
Chapter 1 Introduction	1
1.1 Introduction	1
1.2 Thesis Goals	2
1.3 Landsat Applications to Geology and Seismology ...	2
1.4 Conclusions	7
Chapter 2 Study Region - Review of the Geological, Biophysical, Surficial and Seismological Characteristics	8
2.1 Study Area Location	8
2.2 Biophysical Environment	8
2.3 Geology	13
2.3.1 Major Structural Features	13
2.3.1.1 Lake Temiskaming Rift Valley	21
2.4 Surficial Geology	23
2.5 Seismicity	25
Chapter 3 Techniques of Image Analysis and Interpretation Methodology	28
3.1 Landsat and Geology	28
3.1.2 Landsat Characteristics	29
3.2 Interpretation	31
3.2.1 Visual Interpretation	33

	Page
3.2.1.1 PAS	34
3.2.1.2 Interpretation Methodology	39
3.2.2 Digital Analysis	39
3.2.2.1 Location of Digital Subscenes.....	39
3.2.2.2 Description of Digital Techniques Used in the "Landsat Geological Analysis Aid Package".....	42
3.2.2.2.1 Colour Composite	42
3.2.2.2.1.1 Contrast Stretch..	43
3.2.2.2.2 Textural Enhancement (Unsupervised Classification)...	48
3.2.2.2.3 Lineament Enhancement	56
3.2.2.2.3.1 Biomass Ratio	56
3.2.2.2.3.2 Spatial Filtering..	61
3.2.2.2.3.3. Linear Extraction..	61
3.2.2.3 Interpretation Methodology	61
Chapter 4 Lineament Maps - Analysis and Interpretation.....	66
4.1 Introduction	66
4.2 General (Visual) Interpretation of the Landsat Lineament Map	66
4.3 Digital Analysis	70
4.3.1 Comparison of Digital Data Sources	70
4.3.2 Evaluation of Digital Techniques.....	75
4.3.2.1 Comparison of Geology Map and Digital Lineament Map	75
4.3.2.2 Air Photo Analysis	77
4.3.3 Comparison of Visual and Digital Interpretation.....	82
4.4 Surficial Expression	84
4.4.1 Problems Associated With Lineament Interpretation Within the Study Area	87

	Page
4.5 Factors Which Affect the Detectability of Lineaments on Landsat Imagery	89
4.5.1 Terrain Factors	90
4.5.1.1 Surficial Cover	90
4.5.1.2 Nature of the Terrain	92
4.5.1.3 Vegetation	93
4.5.2 Cultural Factors	99
4.5.3 System Factors	100
4.5.3.1 Sun Azimuth Bias	100
4.5.3.2 Seasonal Imagery	103
4.5.3.3 Image Scale and Type	104
4.5.4 Perception	104
4.6 Conclusion	106
Chapter 5 Lineament Analysis	107
5.1 Introduction	107
5.2 Lineament Analysis	108
5.2.1 Statistics (Rose Diagrams)	108
5.2.1.1 Total Length vs Total Frequency Rose Diagrams	109
5.2.2 Lineament Trends	113
5.2.2.1 Grenville Province	113
5.2.2.2 Cobalt Embayment	127
5.2.2.3 Pontiac Gneiss Belt	127
5.2.2.4 Abitibi Volcanic Belt	127
5.2.2.5 Kapuskasing Belt	128
5.2.2.6 Opatica Belt	128
5.2.3 Lineament Origins	128
5.2.3.1 Circular Features	134
5.2.4 Lineament Density	134

	Page
5.2.4.1 Density, Definition	136
5.2.4.2 Lineament Density Maps.....	136
5.2.4.3 Interpretation	140
5.2.4.4 Comparison Between Density Measuring Approaches.....	140
5.3 Conclusion.....	143
Chapter 6 Summary and Conclusions	144
6.1 Summary	144
6.2 Evaluation of Interpretation Aids (Analog and Digital).....	145
6.2.1 Photographic Analysis System (PAS)	145
6.2.2 Digital Processing Techniques	146
6.3 Conclusions	150
6.4 Future Research	152
Glossary	153
Appendices.....	155
Bibliography	166

List of Figures

Figure		Page
2.1	Study Area Location	9
2.2	Forest Regions.....	12
2.3	Tectonic Subdivisions.....	14
2.4	Diabase Dike Swarms of the Canadian Shield	19
2.5	Tectonic Framework of the Grenville Province.....	20
2.6	Temiskaming Rift Valley	22
2.7	Surficial Geology	24
2.8	Seismicity of the Study Region	26
3.1a	Temiskaming Area - East-West PAS Edge Enhancement (Band 6 - Summer).....	35
3.1b	Temiskaming Area - North-South PAS Edge Enhancement (Band 6 - Summer)	36
3.1c	Temiskaming Area - East-West PAS Edge Enhancement (Band 6 - Winter).....	37
3.1d	Temiskaming Area - North-South PAS Edge Enhancement (Band 6 - Winter)	38
3.2	Methodology Flow Chart - Visual Interpretation.....	40
3.3	Raw Colour Composite (Bands 4, 5, 7) - Rib Lake Subscene - Photograph of the CRT.....	44
3.4	Data Histograms - Rib Lake Subscene	45
3.5a, b	Contrast Stretch	46-47
3.6	Breakpoint Graph	49
3.7	Contrast Stretch - Rib Lake Subscene - Photograph of the CRT	50
3.8	Contrast Stretch - Band 6 - Rib Lake Subscene - Versatec Printout	51

Figure		Page
3.9	Versatec Theme (water) Map - Rib Lake Subscene	54
3.10	Cluster Statistics - Unsupervised Classification - Rib Lake Subscene - Theme 4	55
3.11	Unsupervised Classification (6 Themes) - Rib Lake Subscene - Photograph of the CRT.....	57
3.12	Unsupervised Classification - Theme 4 - Rib Lake Subscene - Versatec Printout.....	58
3.13	Biomass Ratio (7/5) - Rib Lake Subscene - Photograph of the CRT	59
3.14	Biomass Ratio (7/5) - Rib Lake Subscene - Versatec Printout..	60
3.15	Vertical (1 x 5) High Pass Filter - Maxam Lake Subscene - Photograph of the CRT	62
3.16	Linear Extraction - Rib Lake Subscene - Versatec Printout...	63
3.17	Methodology Flow Chart - Digital Analysis	65
4.1	Landsat Lineament Map	67
4.1a	Prominent Lineament Trends on Geology - Aeromagnetic Maps ..	68
4.2	Rib Lake Subscene - Digital Lineament Map	71
4.3	Rib Lake Subscene - Digital Data Sources	72
4.4	Rib Lake Subscene - Lineaments Derived From Geology Maps....	76
4.5	Maxam Lake Subscene - Digital Lineament Map	78
4.6	Northeast Arm Subscene - Digital Lineament Map.....	79
4.7	Rib Lake Subscene - Lineaments Derived From Air Photo Analysis	80
4.8	Rib Lake Subscene - Surficial Expression of Lineaments	81
4.9	Rib Lake Subscene - Lineaments Derived From General Landsat Lineament Map (1:1,000,000 - Visual Analysis)	83
4.10	Tee Lake Subscene - Digital Lineament Map	95
4.11	Lake St. Amant - Digital Lineament Map	96
5.1	Grenville Province 10° Azimuth Class Trend Diagrams	110
5.2	Grenville Province 20° Azimuth Class Trend Diagrams	114
5.3	Cobalt Embayment 10° Azimuth Class Trend Diagrams	115
5.4	Cobalt Embayment 20° Azimuth Class Trend Diagrams	116

Figure		Page
5.5	Pontiac Gneiss Belt 10° Azimuth Class Trend Diagrams	117
5.6	Pontiac Gneiss Belt 20° Azimuth Class Trend Diagrams	118
5.7	Abitibi Volcanic Belt 10° Azimuth Class Trend Diagrams	119
5.8	Abitibi Volcanic Belt 20° Azimuth Class Trend Diagrams	120
5.9	Kapuskasing Belt 20° Azimuth Class Trend Diagrams	121
5.10	Opatoca Belt 10° Azimuth Class Trend Diagrams	122
5.11	Opatoca Belt 20° Azimuth Class Trend Diagrams	123
5.12	Summary of Major Lineament Trends	126
5.13	Lineament Density Contour Map (Total Frequency Per 20 x 20 km Grid Square)	137
5.14	Lineament Density Contour Map (Total Length Per 20 x 20 km Grid Square)	138
5.15	Lineament Intersection Density Map (20 x 20 Grid Square) ..	139

List of Tables

Table		Page
1.1	Advantages of Landsat Data for Mineral Exploration.....	5
2.1	Summary of the Biophysical Environment	10
2.2	Geologic Time Scale	15
2.3	Precambrian Time-Stratigraphic Classification in Relation to Orogenies of the Canadian Shield	16
2.4	Geology Summary Via Tectonic Subdivisions	17
3.1	Landsat Imagery	32
3.2	Image Processing Methods	41
3.3	Factors Affecting Plant Forms	52
4.1	Digital Data Sources - Rib Lake Subscene	73
4.2	Numerical Summary - Surficial Expression of Lineaments Rib Lake Subscene	86
4.3	Summary of the Surficial Expression of Lineaments from Digital Analysis (Emphasis on the Rib Lake Subscene).....	88
4.4	Areas of Low Lineament Density Within Digital Subscenes....	94
4.5	Identification of Textural Themes (Rib Lake Subscene)	98
4.6	Factors Which Affect the Detectability of Lineaments on Landsat Imagery	101
5.1	Grenville Province - Summary of Trend Statistics (10 ⁰ Azimuth Class)	111
5.2	Summary of Trend Statistics (20 ⁰ Azimuth Class) - Total Frequency	124
5.3	Summary of Trend Statistics (20 ⁰ Azimuth Class) - Total Length	125
5.4	Summary of Major Lineament Trends and Origins	129
5.5	Surficial Expression of Circular Features-Rib Lake	135
5.6	Interpretation of Total Length Contour Density Map.....	141
6.1	Analog Enhancements.....	146

Chapter 1

Introduction

1.1 Introduction

Over the last decade the mapping and study of linear geologic features (lineaments) of both local and regional significance have been progressing rapidly. Lineaments have long attracted the interest of field geologists but it was not until the advent of remotely sensed satellite imagery that the character and extent of these features have been realized. Although the origin and genesis of these features are not agreed upon, lineament maps do provide geologists with various types of information including clues as to the location of mineral deposits, information regarding the geologic structure of the earth's crust and a data source in which to decipher seismo-tectonic patterns (earthquakes).

Recently much emphasis has been placed on nuclear powered electricity generation as a viable energy alternative to fossil fuels. However, the disposal of radioactive waste remains a serious problem. Many options exist as to the method of disposal, one being burial within the earth's crust. In order to select a suitable burial site many requirements must be met (Appendix A). Knowledge of the earth's structure and crustal stability is a particularly important consideration. Lineament maps, by providing structural information, can be used as valuable tools in the selection of such a site.

The series of Landsat Satellites launched during the early and mid-1970's has provided geologists with an excellent, remotely sensed data source from which lineament maps can be constructed. In addition, both analog and digital methods of analysing Landsat data have been developing rapidly since the first launch. However, further research is required

in order to maximize the amount of structural information extracted from Landsat data, especially in glaciated and vegetated terrains.

1.2 Thesis Goals

This thesis, which assesses the potential value of using Landsat data for the detection of lineaments, forms a separate part of a broader geological and seismological study carried out by scientists from the Earth Physics Branch, Energy, Mines and Resources, Canada. The overall study is concerned with the selection of a nuclear waste burial site in a 100,000 square kilometer area centred on Lake Temiskaming, Ontario.

The primary goals of this thesis, listed in order of priority, are threefold:

1. To investigate the use of Landsat data and associated image processing techniques (digital - CCRS - "Landsat Geological Analysis Aid Package" and analog) in the study of structural and surficial lineaments for a selected area in northern Ontario.
2. To produce a map of lineaments (1:1,000,000) classified according to type and degree of expression of the entire study area as well as 5 subscene maps (1:125,000) derived from one Landsat image.
3. To analyse briefly the regional structural geology of the study area as derived from Landsat lineament data.

1.3 Landsat Applications to Geology and Seismology

The concept of the Earth Resources Technology satellite (now Landsat and hereafter referred to as such) was developed in the late 1960's by NASA (National Aeronautics and Space Administration) and USGS (United

States Geological Survey). Previously the geological value of orbital photographs had been verified from the Mercury and Gemini flights during the 1950's and 60's (Siegal, 1980). The three Landsat satellites, launched in 1972, 1975 and 1978 have been among the most successful unmanned spacecraft for gathering environmental data. Landsat imagery has been used for a wide variety of purposes ranging from land use categorization to environmental impact studies (Lillesand, 1979; Fox, 1979; Sabins, 1978).

Geologists have used Landsat data for a number of purposes including general geologic mapping, structural studies and mineral and hydrocarbon exploration. The first geologic use of Landsat imagery involved a simple comparison between a colour composite of Monterey Bay (San Andreas Fault, California) and the 1:250,000 scale geology map of California (Lowman, 1973). The detection of many previously unmapped large linear structures evident on the colour composite gave the first indication of the potential value of Landsat data for investigations of regional geologic structure. Since 1972 the value of Landsat in general geologic mapping and, to a lesser extent, geologic structural studies, has been shown to be substantial by studies carried out particularly in the U.S. (Rowan and Wetlauffer, 1975; Sabins, 1973; Lamar and Merifield, 1975).

The majority of studies dealing with structural geology and Landsat imagery has resulted in the production of lineament maps. During the early 1900's the American geologist Hobbs recognized the existence and significance of linear geomorphic features as the surface expression of zones of weakness or structural displacements in the crust of the earth. Hobbs (1904, 1912) defined lineaments as "the significant lines

of landscape which reveal the hidden architecture of the rock basement ... They are character lines of the earth's physiognomy" (Sabins, 1978:80). Over the years, and especially since the advent of small scale imagery from aircraft and spacecraft, a plethora of definitions for the term lineament has arisen (see Appendix B). In order not to contribute to the confusion and debate over the definition of lineament this author has decided to use the term lineament to broadly describe any linear to curvilinear feature expressed on Landsat imagery in continuous or discontinuous fashion. Appendix B presents a summary of the many possible expressions of lineaments on Landsat imagery.

Landsat imagery and data presented in the form of lineament maps have had direct applications to mineral exploration and seismic studies. Sabins (1978) has concluded that Landsat images have proven valuable for mineral exploration in three ways (see Table 1.1). Geologists and prospectors have long been aware of the fact that in many mineral districts mineral deposits occur both along major crustal lineaments and at points where these lineaments intersect. Lineaments and their intersection points represent logical targets for mineral exploration, having provided channels for the migration and emplacement of mineralizing solutions.

To a lesser extent, lineament maps have been useful in seismo-tectonic studies and it is for this application that the lineament maps in this thesis have been produced. Earthquakes are caused by the abrupt release of elastic stress that has built up within the earth's crust. Lineament maps may yield clues to the spatial distribution of earthquakes in that many authors (Gedney, 1976; Gedney and Van Wormer, 1973; Skaryatin, 1976; Vincent et al, 1978; Eggenberger et al, 1976)

Table 1.1

Advantages of Landsat Data for Mineral Exploration

1. Mapping of regional and local fracture systems that control ore deposits
2. Detection of surface alteration effects associated with ore deposits
3. Providing basic data for geologic mapping

Source: Sabins, 1978:277

have found that earthquake epicentres are frequently located within zones of lineaments or directly along major faults. More specifically, Gedney (1976) found that many of the large earthquake epicentres in the central portion of Alaska are located at the intersection of major lineaments.

The work of Overby and Rough (1968) lends additional support to the value of lineament maps in seismic studies. They compared joints, major lineaments and microfractures with the orientation of the stress field in oil and gas reserves. Results of their work indicated that structural lineaments may be reliable indicators of the orientation of the stress field. Therefore, lineament maps may provide an important insight into the spatial pattern of contemporary stress fields.

Although remote sensing data seems to have limited application for predicting specific earthquakes, it is useful for seismic risk analysis in which the geographic distribution, frequency and intensity of seismic activity is estimated (Sabins, 1978). This type of information would be essential for selecting the most appropriate site for the burial of radioactive waste.

Two methods of seismic risk analysis exist. The first involves the study of both instrumentally recorded earthquakes and historic records of earthquakes. However, this method is not altogether satisfactory since historic records of earthquakes are relatively short geologically (Japan - 2000 years, China - 3000 years) and display a rather erratic temporal distribution (Allen, 1975). These limitations make it extremely difficult to make confident extrapolations regarding future earthquakes. A second method proposed by Allen (1975) involves analysis of the geologic

record offered by the late Quaternary history in the form of active faults. Allen has demonstrated by studies in southern California, Turkey, Japan and China that in most seismically active areas there is clear surface evidence of major faults that have shown activity in Quaternary time. He maintains that surface faulting during large shallow earthquakes is more widespread than has been previously recognized and that the geomorphic effects of these movements and radiometric age dating of earlier events provide indicators of seismicity (Allen, 1975). Through use of the geologic record and the late Quaternary history in particular, many of the statistical shortcomings of the instrumental and historic records may be overcome. Through remote sensing analysis and supporting field studies the geologic record can be more completely unfolded both spatially and temporally.

1.4 Conclusions

Clearly lineament maps can be useful in seismo-tectonic studies by giving clues to stress patterns within the crust and by providing a spatial and temporal record of geologic structure. Structural features (lineaments) in turn can be correlated to individual epicentres as well as homogeneous tectonic units, thus providing a better overall picture of regional seismicity.

Chapter 2

Study Region - Review of the Geological, Biophysical, Surficial and Seismological Characteristics

2.1 Study Area Location

The northwest trending study area extends for approximately 450 kms. from Mattawa in the south to the Moose River in the north. The Landsat images, each 185 by 185 kms., provide complete coverage of the study area. Figure 2.1 F¹ illustrates the location of the study area and the 6 sites chosen for detailed analysis. These 6 Landsat subscenes were selected from the southernmost image (E-11110-15145). Each subscene measures approximately 40 by 30 kms. (512 by 512 pixels) and is oriented in a northeasterly direction corresponding to the satellite's orbital path.

2.2 Biophysical Environment

Two major forest regions are found within the study area. They are the Great Lakes/St. Lawrence type and the Boreal type (Rowe, 1972). Each of these major types is divided into various local classes which are associated with different topographies, soil and rock types and surficial deposits. Table 2.1 summarizes the major characteristics of each region while Figure 2.2 F shows the distribution of forest classes in the study area. The biophysical environment is an important consideration in lineament studies in that it influences the detectability and surficial expression of lineaments. This point will be discussed further in Chapter Four.

¹ all figures marked with a "F" are also located in the map folder

FIG.2.1 STUDY AREA LOCATION

Table 2.1 - Summary of The Biophysical Environment

<u>Class</u>	<u>Topography</u>	<u>Soils</u>	<u>Surficial</u>	<u>Tree Type</u>	<u>Geology</u>
<u>Boreal Forest</u>					
Northern Clay	nearly level to gently rolling topography (resulting from the presence of Glacial Lake Ojibway)	gray luvisols - developed on calcareous clays and modified tills, lowland/flats-peaty phase gleysols	lacustrine materials, spatially extensive deposits of water worked tills	black spruce - on gently rising uplands as well as lowlands; widespread sedge fens and sphagnumheath bogs - lowlands and poorly drained flats; extensive areas of spruce/cedar swamp; mixed wood (aspen balsam, poplar, balsam fir) - better drained sites; Jackpine - sandy sites (eskers and outwash plains)	Precambrian volcanic and granitic rocks
Hudson Bay Lowlands	flat, poorly drained	calcareous clays on marine flats, organic soils	marine clay, beach sand deposits ridges and strand lines	subarctic appearance; open woodland - black spruce and tamarack; muskeg patterned fens, linear string bogs	Paleozoic sedimentary bedrock
Missinibi-Caronga	higher elevation - rolling topography; located on drainage divide between the Great Lakes and Hudson Bay; numerous flats along river and lake sides	humoferric podzol	shallow till, some water modification of surface drift (Glacial Lake Ojibway-Sarlow)	mixed association of black spruce, balsam fir and white birch; vast areas of scrub filled forest (shrubs) - regeneration of burnt over or diseased areas	Precambrian granitic, volcanic and sedimentary rock
<u>Great Lakes/St. Lawrence Forest</u>					
Algonquin-Pontiac	rough irregular topography	soils are coarse in texture	thin glacial till, sand terraces glacio-fluvial deposits, localized drumlin and esker landforms, sporadic lacustrine flats and broad swamps	eastern white pine and red pine are or were predominate (forest fires/logging activity have caused depletion - replaced by white birch and trembling aspen); secondary species - yellow birch, maple, black spruce - upland sites	granites, gneiss/gneiss, metasediments

Table 2.1 - Continued

Class	Topography	Soils	Surficial	Tree Type	Geology
Sudbury/North Bay	lowlands and flats interspersed with rugged outcrops of bedrock, recent erosion has removed soil	humo-ferric podzols	water modified tills, lacustrine silts and sands, influenced by post-glacial lakes Nipissing and Algonquin	fire, cutting and pollution from mining have reduced many of the natural occurring species - replaced by hardy pioneer species (trembling aspen and white birch)	Precambrian rocks
Halleybury Clay	gently undulating plain - slopes northward from the tip of Lake Temiskaming	organic soils predominate (poor surface drainage), gray luvisols and humoferric podzols (well drained sites)	"Little Clay Belt", lacustrine clays (varves) and sand (glacial Lake Barlow)	transitional - close to Northern Clay Clans, black spruce (lacustrine flats) - reduced by cutting; burnt over areas - regeneration - white birch, trembling aspen, balsam fir; head of Lake Temiskaming - yellow birch, sugar maple, red oak	Temiskaming Rift Valley, Precambrian - volcanic rock, metasediments
Temagami	rugged, broken	sand, gravelly soils, humo-ferric podzols, slopes - organic (peat) soils - depressions	shallow till overburden, extensive areas of exposed bedrock	eastern white pine and scattered white birch, spruce trembling aspen, balsam fir, jack pine - sandy sites; black spruce, cedar, tamarack - poorly drained sites	Precambrian

Source: Rowe, 1972

FIG. 2.2

FOREST REGIONS

2.3 Geology

Ninety percent of the study area is underlain by the Canadian Shield, while the Hudson Lowlands underlie the northern ten percent. The Shield is divided into 7 tectonic units (provinces), 3 of which (Superior, Southern and Grenville¹) are represented within the study area (See Figure 2.3 F). Each province is distinguished by differences in internal structural trends, boundaries being drawn along major orogenic fronts or along major unconformities. Each province itself is divided into subprovinces on the basis of further differences in structure, metamorphic grade and deformational trends. Each subprovince contains folded Archean/Proterozoic strata termed "belts".

The rocks of the Precambrian Shield, either exposed or covered by glacial overburden, were formed in the Archean (2,390 m.y.) or Proterozoic (570 - 2,390 m.y.) Eons (see Table 2.2 for geologic time scale). Throughout these eons sedimentary, volcanic and plutonic rocks were formed, with volcanism being particularly active during Archean times (G.S.C. pub. - M40-40, 1974). In addition, the rocks of many parts of the shield have been faulted, folded and metamorphosed by periods of mountain building (orogenies) (see Table 2.3). Table 2.4 gives a simplified summary by tectonic unit (province and subprovince) of the rather complex geology of the study region.

2.3.1. Major Structural Features

Despite the complex tectonic and structural history of the region, it seems that only two structural features have shown recent seismic

¹Hudson Bay Lowlands (Phanerozoic Basin) is included in the Tectonic Map (Figure 2.3 F).

FIG. 2.3

TECTONIC SUBDIVISIONS

Geological Time Scale

Eon	Era	Period	Characteristic life	Total estimated time in years	
	Cenozoic	Recent Pleistocene	Man	1,500,000	
		Tertiary	Mammals and modern plants		
					Pliocene
					Miocene
	Mesozoic	Oligocene	Reptiles	65,000,000	
		Eocene			
		Paleocene			
		Cretaceous			
	Paleozoic	Jurassic	Amphibians	225,000,000	
		Triassic			
		Permian			
Carboniferous					
Late Precambrian (Proterozoic)	Paleozoic	Devonian	Fishes	570,000,000	
		Silurian	Higher invertebrates		
		Ordovician			
	Hadrynian	Cambrian	Primitive invertebrates and algae	880,000,000	
	Helikian			1,640,000,000	
Early Precambrian (Archean)	Apehbian			2,390,000,000	
				3,000,000,000 or more	

Table 2.2 Geologic Time Scale

Source: G.S.C. pub. M40-40/1974e

Table 2.3

*Precombrian time-stratigraphic classification
in relation to orogenies of the Canadian Shield
(by C. H. Stockwell)*

Eon	Era	Sub-Era	Orogeny (mean K-Ar mica age, m.y.)
Proterozoic	Hadrynian		
	Helikian	Neohelikian	Grenvillian (955)
		Paleohelikian	Elsonian (1370)
	Aphebian		Hudsonian (1735)
Archean			Kenoran (2480)

Source: Stockwell - Ch. 4 - Geology & Economic Minerals of Canada (1970)

Table 2.4. Geology Summary Via Tectonic Subdivisions

Province	Subprovince	Major Rock Types	Structure
Superior Province		altered volcanic & sedimentary rock of Archean Age & large bodies of granite (plutons) and related gneisses	easterly-trending structures (eugeosynclines); Archean rocks involved in Kenoran Orogeny; - 2480 m.y. (folding, shearing, metamorphism, intrusion of granite rocks); rocks intruded by several diabase dike swarms of various azimuths (Figure 2.4)
	Abitibi Belt	Greenstone Belt - volcanic rocks	Archean rocks folded along easterly trending axes and are cut by several eastward trending faults (Larder, Cadillac, Destor-Porcupine, - Kenoran orogeny)
	Pontiac Gneiss Belt	Metasedimentary Gneiss Belt - sedimentary - greywacke, arkose, quartz-feldspar gneiss	more highly metamorphosed and completely folded than rocks of the Abitibi Belt
	Opatica	Metasedimentary Gneiss Belt - meta-sediments and metavolcanic rocks	intruded by numerous northward trending diabase & gabbro (mafic igneous) dikes (Aqhebian age - 1700 m.y.)
Southern Province	Kapuskasing	volcanic and sedimentary rocks intruded by granite rocks - also includes belt of pyroxene bearing gneiss and alkaline elliptical masses	NE striking belt - includes a series of faults that strike in a similar direction, marked by major gravity and magnetic anomalies
	Cobalt Embayment (plate)	northern section - flat to gently folded sediments (conglomerate, arkose, greywacke) - lies unconformably on older Archean basement rocks; southern section - sediments conformably overlies older Huronian rocks	eastern section - Huronian rocks undeformed except adjacent to the major faults of the Temiskaming Rift Valley; western portion - moderately deformed by the Onaping Fault System

Grenville
Province

rocks of this province have undergone much more complex re-working (metamorphism and intense folding) than rocks in the Superior Province Grenville Orogeny - K-AR - 950 ± 150 m.y.; many dike swarms (Haydrian or younger), small scale irregular curved structures, basins and gneissic domes

quartzo-feldspathic gneiss; Wynne-Edwards (1972) has divided this Province into 7 major subdivisions, 3 of which have relevance to the study area:

- Grenville Foreland Zone (Superior Foreland Zone)
- Grenville Front Tectonic Zone
- Central Gneiss Belt (see Figure 2.5)

Hudson
Platform

Moose Basin - lowland - Precambrian basement complex overlain by gently tilted Paleozoic sedimentary rocks (Ordovician, Silurian, Devonian) - separated by shallow marine facies - succeeded by non-marine sediments of Mesozoic age (clay, sand)

Summarized from Douglas (1970) and Price and Douglas (1972)

Figure 2.4

Diabase Dike Swarms of the Canadian Shield

Source: Stockwell- Ch. 4 - Geology and Economic Minerals of Canada (1970)

activity - the Kapuskasing Belt and the Temiskaming Rift Valley.

2.3.1.1 Kapuskasing Belt (Structural Zone)

This zone has been involved in several tectonic events (Kenoran Orogeny - 2,500 m.y.: Hudsonian Orogeny - 1,800 m.y.) keeping it intermittently active for about 2,000 m.y. (Atomic Energy of Canada Ltd. - A.E.C.L. - Technical Rept. in preparation). Recent seismic activity (1980 - Cochrane earthquake, M-4.1) suggests that the Kapuskasing structural zone may be undergoing contemporary tectonic adjustment.

2.3.1.2 Lake Temiskaming Rift Valley

A prominent bedrock controlled feature that is central to the study area is the Temiskaming Rift Valley (Lovell and Caine, 1970) which consists of a series of northwest striking faults (Figure 2.6). It extends for approximately 250 kms. from Lake Temiskaming northwest to the Kapuskasing subprovince and is approximately 60 kms. wide between the Net Lake Fault near Temagami and the Quinze Dam Fault near Ville Marie, Quebec. This rift valley may be the northwest branch of the St. Lawrence Rift system which bifurcates near Mattawa, with one branch extending north through Lake Temiskaming and the other extending west through Lake Nipissing (Kumarapeli and Saull, 1966). The Temiskaming faults are characterized by long narrow trough-like valleys that indicate grabens or areas where blocks of the earth's crust have sunk between fault zones of parallel strike. It is possible that the magnitude 6.2 earthquake that took place near Tee Lake in 1935 occurred along one of these faults. This rift zone is younger than the Kapuskasing zone and it is believed (Kumarapeli and Saull, 1966, Kumarapeli, 1974, 1978) that most of the

Figure 2.6 Temiskaming Rift Valley

Source: Lovell and Cairne (1970)

activity has taken place during Phanerozoic time, with peak activity in the mid-Mesozoic that may be related to the opening of the North Atlantic Ocean (A.E.C.L. Technical Rept. - in preparation).

2.4 Surficial Geology

The most recent reworking of the surficial geology took place during the Wisconsin glaciation. The scouring action of the glaciers has left exposed areas of bedrock in predominantly the southern portion of the study area, while in other areas thick deposits of glacial drift, ranging from unsorted till to highly sorted glaciofluvial and lacustrine material, exist (Figure 2.7 F). Of particular relevance to the lineament analysis are eskers and linear string bogs and fens which occur in the central and northern portion of the study area.

In the southern area around Lake Temiskaming a thin discontinuous cover of ground moraine, consisting of sandy till and, large amounts of boulders and gravel and exposed areas of bedrock, predominates. In the central area, extending from the head of Lake Temiskaming to the region around Lake Abitibi, thick lacustrine deposits interspersed with ground moraine and sandy outwash deposits occur. The lacustrine deposits, consisting of varved and massive clay, silt and sand ("Little Clay Belt" and "Abitibi Clay Belt") were laid down by Glacial Lake Barlow-Ojibway, which receded approximately 7,900 years B.P. (Vincent and Hardy, 1979). Ground moraine, which represents the most widely distributed glacial deposit in the northern portion of the study area, consists of stone free or slightly stony clay till. Interspersed with this are rather extensive areas of lacustrine deposits. Surficially the

FIG 2.7

SURFICIAL GEOLOGY

24

- R Bare or thinly covered bedrock
- L Lacustrine sediments (lake or river sediments)
- M Ground Moraine
- C Clay
- R(C) Rock Knob and Clay
- OT Organic Terrain
- ↓ Glacial Striation (sense of direction known or inferred)
- ◆ Drumlinoid Ridges

TEMISKAMING AREA

Sources
Northern Ontario Engineering Geology Map Series
1:100,000 - G.S. Map 5000 et seq.
Ontario Department of Lands and Forests
Maps 5365 and 5465 (1:50,000) A.N. Boismoreau
Printed at 1967 - Geol. Map of Canada (1:500,000)
G.S. Map 1253 A
J.J. Veilleux (G.S. pers. comm., 1981)

Hudson Bay Lowlands can be characterized as a wet, marshy plain with many subdued glacial features and raised beaches.

2.5 Seismicity of the Study Region

Yang et al (1981), using seismic instrumental locations, historical seismicity and focal mechanism solutions, have delineated two distinct areas of seismic activity in eastern North America: 1) the Adirondack - Western Quebec zone trending northwesterly from the southeastern Adirondacks into western Quebec and 2) the Appalachian zone trending northeasterly from northern Virginia to New Brunswick (Figure 2.8).

The western Québec seismic zone, studied in detail by Forsyth (1981), is more relevant to the study area. Forsyth (1981) has concluded that most of the intraplate earthquakes of western Quebec are located near or within the boundaries of the northeastern part of a Grenville (1,000 m.y.) metasedimentary belt and near the junction of the rift structures following the Ottawa and St. Lawrence Rivers and Lake Champlain. Although most of the earthquakes have occurred outside the study region within terrain of Grenville age or older, a few major events (Temiskaming earthquake, M6.2 - 1935 - Temiskaming Rift Valley; Cochrane earthquake M4.1, 1980 - Kapuskasing Belt) have occurred within the study area.

Analysis of focal mechanism solutions, in situ stress measurements, geological observations (post glacial faults, pop-up structures) and the effect of stress on man-made structures has revealed that the maximum compressive stress within the Adirondack-western Quebec zone is horizontal and trends WSW (ENE) (Yang, et al, 1981; Sbar and Sykes, 1973, 1977). Sbar and Sykes (1973) have determined that in eastern North America intraplate earthquakes seem to occur in areas of high

Earthquake locations in northeastern United States and adjacent Canada for the period 1534-1959 [after Smith, 1962, 1966].

Figure 2.8. Seismicity of The Study Region
Source: Yang and Aggarwal (1981)

regional stress along zones of weakness (west Quebec being a major exception - Forsyth 1981) such as unhealed fault zones of late Paleozoic or younger age. This apparent relationship between earthquake activity and zones of crustal weakness may provide a means to assess the earthquake risk within crustal plates or, more specifically, within tectonic zones.

Chapter 3

Techniques of Image Analysis and Interpretation Methodology

3.1 Landsat and Geology

Most structural geology studies using Landsat data have focused on arid to semi-arid environments where surficial and vegetational cover is minimal. Much of the early optimism regarding the acquisition of geological information from Landsat data was based on studies in such environments where spectral signatures are closely related to the exposed bedrock. Much less research has been conducted on the structural geology of areas where bedrock is obscured by both vegetation and glacial overburden. The study area characteristic of extensive areas of south and central Canada, typifies such an environment. Due to the peculiar challenges posed by Canada's landscape, it has become necessary either to develop new methods and approaches to Landsat data interpretation or to reform existing methods.

Sabins lists the documented advantages of using Landsat data in geologic studies (1978:113). A number of these advantages are particularly relevant to this study. The synoptic coverage offered by Landsat imagery makes it much easier to recognize and evaluate spatial relationships among geologic macrostructures such as fault zones.

Moore and Gregory (1973) have determined that more geological information can be extracted by analysing imagery obtained during different seasons than if single season imagery is used. Considering the latitude of the study area, the lower sun angle present on winter imagery could particularly enhance lineaments with topographic expression by creating

noticeable shadows. Fall images could prove beneficial due to the process of fall senescence that heightens the reflective difference between broad-leaved deciduous and coniferous trees. Furthermore, defoliation of deciduous trees could provide increased exposure of bedrock and soils. Snow cover may either obscure or enhance lineaments. Snow and rain change the spectral characteristics of the surface and may obscure geological information. On the other hand, a thin residual cover of snow or ice may actually enhance lineaments and other surface features of low relief. Gregory and Moore (1973) have determined that a thin cover of snow may obscure terrain noise that results from variations in vegetation, water and soil to present a uniformly reflecting surface. Such a surface allows detection of even small variations in relief (≈ 30 m), especially in combination with the low angle of illumination present in winter images. However, summer imagery may be the best choice for digital textural enhancement because of maximum vegetational growth and resultant greater spectral range and contrast in the multispectral data.

3.1.2 Landsat Characteristics

Sabins (1978), Lillesand and Kiefer (1979) and Fox (1980) give a comprehensive review of the orbital and image characteristics of Landsat.

The Landsat satellite employs a multispectral line scanner (MSS) that collects data in 4 wavelengths (bands), 2 in the visible spectrum and 2 in the reflected infrared. The wavelength range for each band is as follows:

2

Band 4 (visible green)	.5 - .6 um
Band 5 (visible red)	.6 - .7 um
Band 6 (reflected infrared)	.7 - .8 um
Band 7 (reflected infrared)	.8 - 1.1 um

The instantaneous field of view (IFOV) of the detector results in a ground resolution cell of 79 x 79 m. Reflected energy is collected by an oscillating mirror and is focused through a dichroic grating which separates the reflected radiation from the emitted radiation. The reflected component is then directed through a prism which separates the energy into the desired spectral bands. An array of 24 detectors, 6 per band is placed in the correct geometric position behind the prism to receive the incoming radiation. This results in 6 contiguous scanned lines for each sweep of the oscillating mirror. The analog signal (intensity of reflection) from each line is sampled every 57 km by an onboard analog to digital (A to D) convertor resulting in a nominal pixel size of 57 x 79 m. The resulting raster of each Landsat image consists of 2,340 scan lines with 3,240 pixels per line, each containing four numbers representing the intensity of reflected energy received for each of the four bands sensed. Digital data can be transmitted in real time to surface receiving stations or stored on magnetic tape (CCT) for future computer processing.

Through discussions with CCRS staff, literature reviewed and personal experience Band 6 (.7 - .8 um, near infrared) imagery was judged to be the most appropriate for the highly vegetated terrain which characterizes the study area. Reflected infrared radiation is highly absorbed by water, thus providing a sharp contrast between land and water. Therefore Band 6

imagery would be especially useful for geological interpretation in areas where the drainage patterns are controlled by rock structure. Infrared radiation is also highly reflected by vegetation and differences in reflectance between vegetated and non-vegetated areas and between coniferous and deciduous areas are often evident on Band 6 imagery. Depending on the area, these differences may subtly or strongly enhance certain lineaments.

Table 3.1 lists the imagery used for this study along with relevant descriptive information.

3.2 Interpretation

There are two commonly used approaches to the interpretation of Landsat data for geological applications. One is based on visual interpretation which utilizes the fairly standard principles of photogeologic interpretation, while the other is based on computer processing of data in numerical format. This study integrates the two interpretation procedures. The entire study area was analysed by visual interpretation methods supplemented by use of the Canada Centre for Remote Sensing (CCRS) Photographic Analysis System (PAS), while selected areas were analysed digitally through use of the CIAS (Computer Image Analysis System) also located at CCRS.

To aid in the extraction of geologic information from the Landsat images a fairly new method or approach has evolved out of the CCRS geological liaison program ("Landsat Geological Analysis Aid Package"). This package of digitally produced Landsat interpretation aids has been used by a number of geologists in Canada with an encouraging degree of success (B. Bruce, oral communication). The use of such a package is still in the developmental stage and much additional testing and modification are required.

Table 3.1. Landsat Imagery

	<u>Frame I.D.</u>	<u>Date</u>	<u>Band</u>
Temiskaming	E-1822-15284-6	23/Oct/74	6
	E-1110-15145	7/Aug/75	6
	E-1534-15364-6	8/Jan/74	6
	E-1110-15145	7/Aug/75	4, 5, 7
Abitibi	E-20189-15332	30/July/75	6
	E-11309-15075	22/Feb/76	6
	E-1111-15200	8/Aug/75	4, 5, 7
Moose	E-20190-15384	31/July/75	6
	E-11292-15141	5/Feb/76	6
	E-20190-15384	31/July/75	4, 5, 7

Through consultation with Bill Bruce at CCRS, it was decided that these interpretation aids could be useful in the production of lineament maps for the purpose of analysing seismo-tectonic patterns that may be present within the study area. It was also hoped that experience gained during this study would assist in the evaluation and future development of the "Landsat Geological Analysis Aid Package". This could help other geologists to make greater use of the demonstrated capabilities for future studies in similar environments.

3.2.1 Visual Interpretation

Lineaments were first identified for the entire study area by direct visual inspection of the Landsat images (1:500,000 and 1:1,000,000). In addition the edge enhancement feature of the CCRS PAS (see Section 3.2.1.1) was used as an interpretation aid.

Although no specific restriction on length or width of lineaments was used, obviously a certain minimum observable length is dictated by the actual scale of mapping as well as the resolution of the sensing system. Keeping these factors in mind, a minimum length of 1 km. was generally used. The width of a lineament is also a variable characteristic and depends on whether the interpreted feature represents a single lineament or a cluster of lineaments. In some cases a linear lake varying in width from several meters to several kilometers may represent a large eroded fault zone. The skill and experience of the interpreter probably represents the best controlling factor for consistency of interpretation of minimum length and width.

3.2.1.1 Photographic Analysis System (PAS)

Image enhancement in this study was achieved by means of a density slicer (CCRS) modified to allow multispectral analysis of satellite and airborne photographic data. In simple terms, this system analyses optical densities of film transparencies. Input data consists of black and white or colour film in a format size up to 12 by 12 inches. Images are placed on a calibrated light table and a continuously scanning vidicon television camera is used to convert image densities into an electrical video signal which can be displayed on both black and white or colour television monitors (CRT) or recorded on video disk for subsequent analysis.

The production of colour composites and ratioed images is possible by combining individual bands that are stored on the video disk. Single band or ratioed images can be density sliced into a maximum of 32 levels, each coded in a different colour. One feature that was found to be particularly useful for lineament studies is an edge enhancement display which permits the detection and display of all locations on the image where the density gradient exceeds a specified threshold value (PAS Manual, CCRS). An analog computer circuit within the enhancement chassis calculates the relative photographic density of the transparency as well as the rate of change of the relative density across the picture. Grey areas on the enhanced picture represent areas of zero density change, white represents positive change and black represents negative change. Since density changes are measured along the horizontal axis only, the light table may be rotated to enhance features that trend in either a north-south or east-west direction. Hard copies of the displayed image may be obtained by either photographing the television monitors or by producing a grey level copy analogous to a digital binary map (Figure 3.1 a-d).

Figure 3.1a

Temiskaming Area - East-West PAS Edge Enhancement
(Band 6 - Summer)

Figure 3.1b

Temiskaming Area - North-South PAS Edge Enhancement
(Band 6 - Summer)

Figure 3.1c

Temiskaming Area - East-West PAS Edge Enhancement
(Band 6 - Winter)

Figure 3.1d

Temiskaming Area - North-South PAS Edge Enhancement
(Band 6 - Winter)

3.2.1.2 Interpretation Methodology

The visual interpretation procedure consisted of viewing the selected imagery from different directions and angles. Varying the look direction and angle by rotation of the imagery maximized the amount of lineament information extracted. One technique the author found useful, especially when viewing the edge enhanced products, was to shine a desk lamp on the image from various directions and angles. Although the lamp was an extra-neous source of illumination it seemed to enhance certain weakly expressed lineaments.

The actual interpretation procedure, which included a number of different phases, is summarized in Figure 3.2

3.2.2 Digital Analysis

Digital processing can be conveniently divided into three functional categories:

1. restoration;
2. image enhancement;
3. information extraction (Table 3.2).

Processing techniques used in this study fall into the second and third categories. The digital analysis techniques of the "Landsat Geological Analysis Aid Package" were applied to a summer image of the Lemiskaming area in order to enhance the imagery and to extract relevant lineament information. Output products included 35 mm colour slides obtained directly from the CRT display and Versatec electrostatic computer printouts.

3.2.2.1 Location of Digital Subscenes

Six subscenes (Figure 2.1 F) measuring 512 x 512 pixels ($\approx 40 \times 30$ kms)

Figure 3.2 Methodology Flow Chart - Visual Interpretation

¹ see Appendix C for description of classification system

Table 3.2. Image Processing Methods

1. Image restoration
 - a. Sixth-line dropouts
 - b. Sixth-line banding
 - c. Scan-line offsets
 - d. Atmospheric corrections
 - e. Geometric corrections
 - f. Synthetic stereo images
2. Image enhancement
 - a. Contrast enhancement
 - b. Density slicing
 - c. Edge enhancement
 - d. Spatial and directional filtering
 - e. Simulated normal color images
 - f. Digital mosaics
3. Information extraction
 - a. Band ratio images
 - b. Other ratio images
 - c. Multispectral classification
 - d. Change-detection images

Source: Sabins, 1978:240.

were selected from the Temiskaming image for detailed analysis using the "Landsat Geological Analysis Aid Package". Computer processing was undertaken at the Canada Centre for Remote Sensing, Ottawa on the CIAS (CCRS Image Analysis System). The subscenes were selected to surround the epicentre of the Tee Lake earthquake (1935). It is hoped that the production of digital lineament maps will contribute to the ongoing investigations of the surface manifestations of this earthquake. The Englehart subscene was selected because it is located in a different biophysical environment from the other 5 subscenes. This would enable the performance of digital techniques under varying terrain conditions to be assessed. It is hoped that a comparison of the results obtained by using photogeologic methods with those derived from the digital processing techniques would help to determine the most appropriate interpretation method to be selected for specific situations and environments.

3.2.2.2. Description of Digital Techniques used in the "Landsat Geological Analysis Aid Package"

3.2.2.2.1. Colour Composite

The first step was to photograph the raw subscene displayed on the CRT in colour composite form (Bands 4, 5, 7). On the colour composite image Band 4 (visible green light) is represented by a blue dye colour, Band 5 (visible red light) by a green dye colour and Band 7 (reflected infrared) by a red dye colour. It should be noted that the interpreter has complete control over the primary colours that are assigned to each band. Although different colour assignments were tested, the standard Band 4, 5, 7 composite provided the best representation of the scene for

the identification of vegetated, nonvegetated and cultural areas. The colour balance of the image can be altered by adjusting the master gain control located on the control panel of the CIAS. Figure 3.3 presents two photographs of the raw image of the Rib Lake subscene on which the differences in colour balance can be noted.

3.2.2.2.1.1. Contrast Stretch

As noted earlier, Landsat imagery is composed of discrete pixels. The pixels are organized by row and column in raster format to form an image. Each pixel, in addition to having a specific location in the grid, has an associated number (DN) for each wave band that is proportional to the amount of incoming radiation. The range of intensity values for each band can be represented graphically by a histogram in which the frequency of pixels is plotted against the intensity values (Figure 3.4). Few ground scenes have an intensity range (brightness) which utilizes the full sensitivity scale (grey scale, 0 - 256) of the Landsat detectors. In order to assist the visual discrimination of various ground units it is desirable to produce an image with an optimum contrast range. This can be achieved through the process of contrast enhancement which involves redistributing (stretching) the range of pixel intensity values over the entire range of the grey scale.

Many different contrast enhancement options exist (Figure 3.5, a, b). The one used in this study is termed a breakpoint linear stretch. Each band constituting the colour composite was subjected to this type of stretch in which the low values, representing primarily water, were assigned to the low (black) portion of the grey scale and the extremely high values

Figure 3.3

Raw Colour Composite (Bands 4, 5, 7)
Rib Lake Subscene - Different Gain Settings

(Photograph of the CRT)

Figure 3.4

Data Histograms - Rib Lake Subscene

Figure 3.5a
Contrast Stretch Enhancement

Source: CCRS-CIAS manual

Figure 3.5b
Contrast Stretch Enhancement

Source: CCRS-CIAS manual

were assigned to the high (white) portion. The remaining values were then linearly stretched to occupy the rest of the display range (Figure 3.6). Figure 3.7 represents the results of the contrast enhancement process. One can readily appreciate the differences in contrast when compared to the raw image. Figure 3.8 is reproduced from a Versatec printout of a Band 6 stretched image. The Versatec printouts function not only as a data source but also as a consistent base for the plotting of lineaments.

3.2.2.2.2. Textural Enhancement - Unsupervised Classification

Pattern and texture are two important elements of image interpretation, particularly with regard to geologic interpretation. Although the textural enhancement technique adopted here does not involve any new technology, it does require the adoption of a different perspective in the application and interpretation of the spectrally classified output. In vegetated terrains it is the vegetation itself which often establishes the basic character of surface reflectance (i.e. spectral signature). However, this basic signature is almost always modified by terrain factors which include slope/form, surficial materials/soils and aspect (Table 3.3). Employing this perspective the spectral classes obtained are more appropriately described as representing terrain spectra as opposed to strictly vegetation spectra. Interpreting these classes from a terrain point of view in addition to an exclusively spectral one permits inferences about possible geo-botanical patterns. A further advantage of this approach is that both spectral and spatial aspects of the resulting classification can be considered simultaneously.

(1)(2)(3)(4)---PREPROCESSOR CHANNEL NUMBER(S) TO WRITE WORKING LUT
 (5)---RETURN TO PREPROCESSOR LUT MENU
 (6)---GENERATE ANOTHER WORKING LUT
 INPUT UP TO FOUR NUMBERS >3

Figure 3.6. Breakpoint Graph

Figure 3.7

Contrast Stretch - Rib Lake Subscene

(Photograph of the CRT)

Figure 3.8

RIB LAKE BAND 6 CONTRAST STRETCH
VIDEO CHANNEL : 3 TOP LEFT (0, 0) BOTTOM RIGHT (511, 511)
DISTRIBUTION : EQUI-PIXEL INTENSITY LIMITS : 0 TO
SCALE 1 : 250000.00 PIXEL SIZE : 59.00 BY 79.00

Contrast Stretch - (Band 6) - Rib Lake Subscene

Versatec Printout

Table 3.3

Factors Affecting Plant Forms

A. Climatic	- moisture	} Seasonal/Latitudinal Patterns (Global/Regional)
	- light (solar insolation)	
	- temperature	
	- wind	
B. Geomorphic	- slope aspect	
	- slope steepness	
	- relief	
C. Edaphic	- soil texture and structure	} Macro/ Micro Scale
	- humus content	
	- presence or absence of horizons	
	- soil acidity/alkalinity/salinity	
	- soil organisms	
D. Biotic		

Source: A. N. Strahler, 1975

Spectral classes derived from this methodology provide the basis for two levels of interpretation. First, through field investigation, it can be determined whether or not the spectral classes correspond to identifiable terrain/vegetation or biophysical classes (Singhroy and Bruce, 1977). Although these spectral classes do not represent direct geologic information, certain geologic associations and controls may be inferred. Second, even though the spatial distribution of such classes is rarely continuous, to the eye of an experienced geologist/interpreter the pattern of distribution may reflect certain structural characteristics. For example, differential vegetation growth (different species and/or density) may occur along a fault zone due to differences in soil type, moisture and thickness that may exist between the fault zone and the surrounding area.

The classification procedure used to produce the spectral classes was unsupervised in that only the statistical properties of the image data (pixel intensity values) were used as the basis for classification. The computer itself, using a clustering algorithm, examines and divides the pixels into a prescribed number of classes based on natural groupings present in the pixel values sampled.

For each subscene the pixels representing water were interactively removed from the histogram and stored on a theme track within the computer (see Figure 3.9). The remaining parts of the images were then subjected to unsupervised classification which divided the image into 6 classes, the number of classes being determined by the author. Figure 3.10 shows a number of statistics pertaining to the individual clusters in 4 bands. Following this method, 7 classes (~~water~~ and 6 terrain classes)

Figure 3.9

RIBLUMM WATER MAP
TOP LEFT (0, 0) BOTTOM RIGHT (511, 511) DOT TEXTURE: COARS.
SCALE 1 : 250000.00 PIXEL SIZE : 59.00 BY 79.00
THEMES: 7

Versatec Theme (Water) Map

Rib Lake Subscene

*** CLUSTERING: MIGRATING MEANS (CUF02C) 18-SEP-80 19:39:57 ***

SIGNATURE FILE: RIBL.NDH
CLUSTER FILE: RIBL.MMS
ITERATIONS: 7 THRESHOLD: 1 CONVERGENCE CRITERION: 0.5
EUCLIDEAN DISTANCE MEASURE USED.

CLUSTER	VECTORS	PIXELS	CENTRES (ST. DEV.)		THEME
1	728	17332	9.5	5.7	11.2
			(1.59)	(1.89)	(1.19)
2	515	48200	9.4	5.4	13.8
			(0.77)	(0.90)	(0.92)
3	639	66324	9.4	5.4	16.4
			(0.81)	(0.98)	(1.02)
4	637	51099	9.5	5.4	19.5
			(0.82)	(0.99)	(1.01)
5	481	31298	9.5	5.4	22.2
			(0.70)	(0.77)	(0.97)
6	333	12385	9.5	5.3	25.0
			(0.60)	(0.56)	(1.18)

OPTIONS LIST <CR>, OR E(X)IT >

Figure 3.10

Cluster Statistics - Unsupervised Classification
Rib Lake Subscene

were established. Once again, output products consisted of 2 types; photographs of the CRT and Versatec printouts (Figures 3.11 and 3.12).

3.2.2.2.3 Lineament Enhancement

The following set of techniques were used to help enhance and isolate linear features present within the Landsat imagery.

3.2.2.2.3.1 Biomass Ratio

A ratio image is one in which the pixel intensity value from one band is divided by the corresponding intensity from another band. In order to enhance the vegetation component of the environment a Band 7 to 5 ratio was calculated for each subscene. A 7/5 ratio enhances vegetation by maximizing reflectance differences (variation in slopes of the spectral reflectance curves) between vegetation and other components of the terrain, specifically bare ground. Vegetation absorbs radiation quite strongly in Band 5 (chlorophyll absorption band) but reflects infrared radiation to a great degree; therefore by ratioing these bands vegetation can be effectively enhanced. A number of other advantages are inherent in ratio images, the prime one being that topographic shadowing effects and illumination differences are reduced. By minimizing topographic information, lineaments expressed primarily as a function of vegetational contrasts may be isolated and enhanced. Figure 3.13 is a photograph of a 7/5 ratioed image and Figure 3.14 is a Versatec printout of the same. The dark tones represent targets for which the denominator of the ratio is greater than the numerator. Conversely, the numerator is greater than the denominator for higher tones. Thus, for the 7/5 ratio, vegetated areas appear light while bare ground or unvegetated terrain appears dark to medium toned.

Figure 3.11

Unsupervised Classification (6 Themes)

Rib Lake Subscene

(Photograph of the CRT)

Figure 3.12

RIBL.UMM
TOP LEFT (0, 0) BOTTOM RIGHT (511, 511) DOT TEXTURE: COARSE
SCALE 1 : 250000.00 PIXEL SIZE : 59.00 BY 79.00
THEMES: 4 7

Figure 3.13

Biomass Ratio (7/5) - Rib Lake Subscene

(Photograph of the CRT)

Figure 3.14

RIBL.B10
VIDEO CHANNEL : 4 TOP LEFT (0, 0) BOTTOM RIGHT (511, 511)
DISTRIBUTION : LINEAR INTENSITY INTENSITY LIMITS : 0 TO
SCALE 1 : 250000.00 PIXEL SIZE : 59.00 BY 79.00

Biomass Ratio (7/5) - Rib Lake Subscene - Versatec Printout

3.2.2.2.3.2 Spatial Filtering

Each 7/5 ratioed subscene was subjected to a high pass spatial filter which enhances terrain objects that can exhibit high spatial frequency such as joints, fractures, dikes and faults. Both a horizontal (5 x 1) and a vertical (1 x 5) filter were utilized. The shape of the filter determines which lineaments are enhanced. Those trending perpendicular to the filter are enhanced while those trending parallel to the filter are suppressed. Figure 3.15 is an example of a high pass 1 x 5 vertical filter of the Maxam Lake subscene.

3.2.2.2.3.3 Linear Extraction

This procedure involved viewing the histogram of each filtered image on the display CRT and subsequently eliminating portions of the histogram in order to isolate the brightness ranges in which linear features are most clearly displayed. The effect that this procedure had on the appearance of the image can be witnessed directly by viewing the CRT. The operation has the additional value of simplifying the resultant image to a binary display (i.e. data vs no data). Approximately half of the data was first eliminated with progressively greater amounts of data being chopped until an image depicting clear linear spatial patterns was produced. Hard copies of the resulting images were obtained by producing Versatec printouts (Figure 3.16).

3.2.2.3 Interpretation Methodology

Both the slides (photographs) and the Versatec printouts for each data source were visually interpreted following procedures discussed in the

Figure 3.15

Vertical (1 x 5) High Pass Filter -

Maxam Lake Subscene

(Photograph of the CRT)

Figure 3.16

LINEARS EXTRACTION, RIBL.BIO, 5 X 1 #1
TOP LEFT (0, 0) BOTTOM RIGHT (511, 511) DOT TEXTURE: COARSE DA
SCALE 1 : 250000.00 PIXEL SIZE : 59.00 BY 79.00 MET
THEMES: 1

previous section. A final overlay was then produced which included all interpreted lineaments. Lineaments were classified and screened--those resulting from cultural features were eliminated by reference to other data sources such as topographic maps. Five classified maps at a scale of 1:125,000 each registered to the water theme map (Figure 3.9) were produced. A map was not produced for the Englehart subscene due to a lack of identifiable lineaments. Figure 3.17 presents a summary of the digital interpretation process.

Figure 3.17 Methodology Flow Chart - Digital Analysis

Chapter 4

Lineament Maps - Analysis and Interpretation

4.1 Introduction

This chapter consists of: 1) a general interpretation of the Landsat lineament map (Figure 4.1 F) derived by visual analysis procedures discussed in Chapter Three; 2) an analysis of the results of the digital techniques used to extract lineament data; 3) a discussion of the surficial expression of lineaments within one particular subscene; and 4) a discussion of the factors which have a dominant influence on the detectability of lineaments on Landsat imagery.

4.2 General Visual Interpretation of the Landsat Lineament Map

The general lineament map (Figure 4.1 F) comprising the entire study area displays a number of prominent lineament trends, the details of which will be discussed in Chapter Five. However, in order to assess the performance of the Landsat imagery for lineament detection, a brief discussion of the relationship between major trends present on the lineament map and existing geology and aeromagnetic maps is necessary.^{1*}

The major NW trending faults of the Temiskaming Rift Valley are well delineated on the Landsat lineament map as is the Kapuskasing Fault Zone which is characterized by a NE trending linear magnetic anomaly. The WNW trending Sudbury dike swarm branching from the Temiskaming Rift Valley and

¹ Geology Maps - Ontario Geological Survey - 1:253,440
Maps 2361, 2205, 2161, 2171, 2166

- Ontario Department of Mines - 1:1,013,760 - East Central
Sheet Map 2198

Aeromagnetic Map - Ontario Department of Mines - 1:1,013,760 - East Central
Sheet

* See Fig. 4.1a for location of dominant lineament trends discussed

FIG.41 LANDSAT LINEAMENT MAP

FIG. 4.1a - Prominent Lineament Trends on Geology & Aeromagnetic Maps

characterized by linear zones of magnetic highs, has also been detected on the Landsat imagery. The north striking Mattagami faults and dikes prominent on geology maps and marked by weak linear magnetic anomalies are strongly expressed on the Landsat imagery while the north trending Matachewan dike swarm located in the vicinity of Lake St. Pierre has also been detected, although not in its entirety according to the ODM geology and aeromagnetic maps. Many Landsat lineaments in this area may represent surficial lineaments (eskers, string bogs, fens). The eastward trending Destor-Porcupine and Pipestone fault zones and the NE trending Abitibi dike swarm (marked by a strong magnetic anomaly) are poorly demarcated on the Landsat imagery due to problems discussed in Section 4.4. In the vicinity of Lac Simard many NE trending lineaments have been detected. However, due to the lack of geology maps for this area, their origins are undetermined.

In addition to detecting the dominant trends present on geology and aeromagnetic maps of the area, many new lineaments, including circular features and extensions of existing faults and dikes, have been mapped according to their degree of surficial expression, first order representing lineaments strongly expressed and third order representing lineaments weakly expressed. Approximately one third of the Landsat lineaments have been verified as faults, dikes and lithological contacts by consulting geology maps.

In general terms all the dominant lineament trends present on the geology and aeromagnetic maps, with the exception of the Destor-Porcupine and Pipestone fault zones and the Abitibi and Matachewan dike swarms have been well delineated on the Landsat imagery. The dominant trends will be further analysed in Chapter Five.

4.3 Digital Analysis

The Rib Lake subscene (Figure 4.2 F) was selected for thorough application and evaluation of the full range of processing techniques discussed in Chapter Three. General examples drawn from a less rigorous analysis of the other 5 subscenes will be presented to demonstrate the broad applicability of the methodology and to support certain conclusions made.

4.3.1 Comparison of Digital Data Sources

Figure 4.3 F and Table 4.1 indicate the primary digital data source for each lineament present on the Rib Lake lineament map (Figure 4.2 F). It appears that in this subscene the water map, textural enhancement and a combination of digital data sources were the most useful in absolute terms (see Table 4.1 for definition of combination, absolute and relative categories). Although the combination category includes two or more digital data sources, by inspection of the lineament maps, the drainage pattern characterized by linear lake patterns (water map) would form part of the combination.

Large differences exist between the relative and absolute categories for the various data sources. (see Table 4.1). For example, by using the contrast stretch data source 39 lineaments were identified as opposed to 34 for the water map, although many of the lineaments identified were common to both sources. This latter situation occurs between other data sources. Although the high pass filter data source and the ratio data source permitted the identification of 27 and 14 lineaments respectively they were responsible for the detection of only 3 lineaments

-RIB LAKE SUBSCENE-
DIGITAL LINEAMENT MAP

Fig. 4.2

AIRL UNH WATER MAP
TOP LEFT ()
SCALE
TICKS: 1:201,612

- Mapped Fault
- - - - Mapped Dike
- - - - Landsat Lineament
- Lithological Contact
- L Low Density (see table 4.4)

RIB LAKE SUBSCENE
DIGITAL DATA SOURCES

Fig. 4.3

RIB LAKE WATER MAP
TOP LEFT (0.0.0)
SCALE 1:201,512
TRIPLEX

———— Combination of Data Sources
 - - - - - Water Map
 - - - - - Contrast Stretch
 - - - - - Ratio
 - - - - - High Pass Filter

Theme 1
 " 2
 " 3
 " 4
 " 5

Textural
Enhancement

Table 4.1 Digital Data Sources (Rib Lake Subscene)

Digital Data Source (Output)		# of Circular Features Detected		# of Lineaments Detected	
		Relative	Absolute	Relative	Absolute
Contrast Stretch		2	3	39	10
Water Map (Drainage)				34	30
Structural Enhancement	Theme 1			5	2
	Theme 2	1	1	14	6
	Theme 3			17	3
	Theme 4	1		16	7
	Theme 5			10	2
	Theme 6		1	11	3
Ratio 7/5		1		14	1
High Pass Filter (Vertical & Horizontal)				27	2
Combination of Data Sources			2		41
		Total 6		Total 107	

Definition of Terms:

Combination of Data Sources - includes 2 or more data sources

- Data source was used to detect "x" # of lineaments in combination with 2 or more data sources
- "x" # of lineaments found by 1 data source only
- e.g. the contrast stretch data source was used to detect 10 lineaments not found by any other data source (those 10 lineaments are unique to the contrast stretch data source)

(absolute category) not found by any other data source. This is as expected, especially with the high pass filter data source since it is an edge enhancement process and therefore shows similar effects to other data sources (e.g. textural enhancement, water map) that depict a strong spectral contrast between adjacent ground areas.

The high absolute total for the combination category obviously supports the premise that an integrated approach will yield the highest numbers of lineaments. In addition, lineaments in the combination category are given a higher probability of being real since they are detected on more than one data source.

The number of lineaments that can be identified from each data source separately is highly dependent on the nature of the biophysical environment. For example, the water map proved quite useful in the Rib Lake subscene due to the nature of the terrain which is characterized by thinly covered or exposed bedrock, rolling to quite irregular topography and a surface drainage system controlled by bedrock structure. In general all the subscenes with the exception of Englehart are characterized by this type of environment and thus the water maps were quite successful for the identification of lineaments. Postglacial drainage in the Englehart subscene has developed on a thick deposit of lacustrine clay and is probably little influenced by bedrock. As a result the water map was less useful in showing bedrock structural (drainage) features than the other data sources. The textural enhancement and ratio products were more useful in this subscene, although the majority of lineaments identified by those sources were cultural in nature (e.g. roads, field boundaries).

4.3.2 Evaluation of Digital Techniques

4.3.2.1 Comparison of the Geology Map and Digital Lineament Map

Thirty-two lineaments consisting of 24 faults and 8 dikes were mapped from the Ontario geological maps of the area¹ (Figure 4.4 F).

In contrast 107 lineaments and 6 circular features were mapped from the output of the digital analysis techniques (Figure 4.2 F).

Twenty-one of the 32 lineaments present on the geology map were identified in total or in part on the digital output. Seven lineaments not identified from the digital data are mapped as dikes on the geology map. These dikes do not show any topographic or drainage expression on the 1:125,000 and 1:250,000 topographic maps² studied and thus have minimal or no character on the Landsat imagery. Four mapped faults were also not detected by digital analysis. This could be a result of a lack of surficial expression or interpretive error. In fact the fault marked by a star on Figure 4.4 F when compared with the 1:250,000 topographic map of the area does show definite topographic expression; thus the exclusion of this feature was probably due to interpretive error.

The digital techniques have resulted in the detection of approximately 3 times as many lineaments as found on the existing geology maps. The geological origin of these lineaments cannot, however, be determined without extensive field checking. The fact that specific locations can be provided from the Landsat data would make this task relatively inexpensive compared with a field mapping program.

The conclusions discussed above are applicable to the remaining 5

¹ Ontario Geol. Map - Map 2361
Ontario Dept. of Mines - Map 2198

² NTS - 31M (1:250,000)
NTS - 31M/SW (1:25,000)

RIB LAKE SUBSCENE Fig. 4.4
LINEAMENTS DERIVED FROM GEOLOGY MAPS

RIB LAKE SUBSCENE
TOP LEFT (0.1 0.1)
SCALE 1:20,000
THICKNESS

- Fault
- - - Dike
★ Identification Mark (see section 4.3.2.1)

subscenes with the exception of Englehart. For the Maxam Lake subscene (Figure 4.5 F) fewer lineaments striking parallel to the Grenville Front were detected from the digital analysis aids than is indicated on geology maps. In the Northeast Arm subscene (Figure 4.6 F) many short segments of mapped faults were detected. Both these situations seem to be due to the lack of surficial (topographic) expression shown by these lineaments.

4.3.2.2 Air Photo Analysis

An air photo analysis¹ of the Rib Lake subscene was undertaken to evaluate the digital techniques for lineament identification. Figure 4.7 F shows lineaments found only on the air photos. Most of the lineaments found on the Landsat and associated processed imagery were also identified on the air photos, the only exception being those with no surficial expression (See Figure 4.8 F). Many more lineaments could be detected on the air photos than on the Landsat data although the majority of these features were fairly short (≈ 2 kms).

The difference in the number of lineaments identified from each data source may be explained by a number of factors. The higher resolution and larger scale of the air photos (≈ 1 to 2 m, 1:36,000/1:50,000) compared with that of the Landsat digital data (79 x 79 m, 1:125,000) meant that a greater number of very narrow and/or short lineaments could be detected through air photo analysis.

Many thin white lines were identified on the air photos just south of Rib Lake. These white lines correspond to very narrow cleared areas

¹ two sets of B/W air photos were used
A. October 19/70 - 1:36,000, Roll #22092 - Prints 5 to 59
Roll #22091 - Prints 110 to 155
B. May 16/80 - 1:50,000, Roll #25419 - Prints 48 to 63
Roll #25418 - Prints 2 to 10, 30 to 37
obtained from N.A.P.L. (National Air Photo Library), Ottawa

-MAXAM LAKE SUBSCENE-
DIGITAL LINEAMENT MAP

Fig. 4.5

MAX. UTM WATER MAP
TOP LEFT (0, 0)
SCALE
1:201,812

- Mapped Fault
- - - Mapped Dike
- - - Landsat Lineament
- Lithological Contact
- - - - - Grenville Front

-NORTHEAST ARM SUBSCENE- Fig. 4.6
DIGITAL LINEAMENT MAP

RTA URM WATER MAP
TOP LEFT (9, 9)
SCALE 1 : 201,612
THEME:

- Mapped Fault
- - - Mapped Dike
- - - Landsat Lineament
- Lithological Contact
- - - Grenville Front
- L Low Density (see table 4.4)

RIB LAKE SUBSCENE
LINEAMENTS DERIVED FROM AIR PHOTO ANALYSIS (B/W)

Fig. 4.7

RIB LAKE WATER MAP
TOP LEFT (0. 0. 0.)
SCALE
1:201,612

Lineaments

RIB LAKE SUBSCENE
SURFICIAL EXPRESSION OF LINEAMENTS

Fig. 4.8

RIB LAKE WATER MAP
TOP LEFT (0, 0)
SCALE 1:201612
TRIMED

——— Combination (Topography/Drainage)	——— Drainage
——— Ridge, Hill	No Expression
——— Valley	T Exceptionally Strong Textural Enhancement (see section 4.4)
	1-6 Circular Features (see table 5.5)

running through predominantly vegetated terrain. In some places these lineaments were topographically expressed as ridges that appeared to truncate other ridges orthogonally. The width of these lineaments averaged approximately 40 - 50 meters and therefore would not be resolvable on Landsat imagery. Under certain circumstances features smaller than the nominal resolution cell can be detected if contrast differences between the observed features are at an optimum. In this case a high contrast was observed on the air photos between these lineaments and the surrounding terrain; however, the photos were taken in the spring whereas the Landsat imagery, analysed digitally, was taken in the summer (August). Therefore these lineaments may not be detectable on the summer imagery due to full growth of foliage resulting in lower contrast between the lineament and the surrounding area.

The orientation of lineaments in respect to the sun azimuth may also affect their detectability on Landsat imagery. The final factor that should be considered in explaining the difference in lineament numbers is interpretative error (perception difficulties). These last two factors will be discussed in Section 4.5.3 and 4.5.4.

4.3.3 Comparison of Visual and Digital Interpretation

Visual interpretation of the Landsat imagery (Figure 4.9 F) derived from 1:1,000,000 Landsat lineament map) yielded 35 lineaments including one circular feature. The major NW trending faults are common to both the visual (Figure 4.9 F) and digital maps (4.2 F) and the general lineament trends are quite comparable. However 10 of the 35 lineaments, including the circular feature, found by visual interpretation

RIB LAKE SUBSCENE

Fig. 4.9

LINEAMENTS DERIVED FROM GENERAL LANDSAT
LINEAMENT MAP (1:1,000,000-VISUAL ANALYSIS)

RIB LAKE WATER MAP
TOP LEFT (0, 0)
SCALE 1:201,612

- Mapped Fault
- - - Mapped Dike
- - - 2nd Order } Landsat Lineaments

2

were not found by digital interpretation procedures. Of these 10 lineaments not found, 6 are mapped as third order lineaments, 3 as second order and 1 as both second and third order. In addition, 2 lineaments that are quite short on the digital map appear to form part of a much longer lineament on the map derived by visual interpretation.

The reason for this lack of detection may be twofold: 1) a mislocation or omission of a lineament may have occurred in reduction of the 1:500,000 Landsat enlargements to the 1:1,000,000 base map, or 2) these lineaments may have been more clearly identified on the fall and winter images used for the visual analysis and were less obvious on the summer image (which was subjected to digital interpretation).

Once again the digital techniques have enabled the identification of approximately three times as many lineaments than did the visual interpretation alone. It is also interesting to note that the lineaments found by visual interpretation (Figure 4.9 F) are nearly equivalent in number and location to the faults on the geology map (4.4 F). A comparison of these two maps shows that the major NW trending faults are common to both, although the map based on visual analysis shows fewer lineaments in the southern portion because dikes present in that part lack surficial expression. Three rather prominent lineaments of unknown structural significance (second order) in the northern half of the sub-scene were detected visually but do not appear on existing geology maps.

4.4 Surficial Expression of Lineaments

The most important aspect in the interpretation of lineaments is the surficial expression of these features. Knowledge of how lineaments are

expressed on the ground can help an interpreter to assess the applicability of the digital analysis aid package for specific biophysical environments. Although all lineaments on Landsat data are tonal in nature resulting from spectral contrast, Figure 4.8 F and Table 4.2 (deduced from topographic and surficial geology maps and air photo analysis)¹ indicate that over 90 percent of the lineaments detected show some form of topographic expression, either by ridge, valley, crest lines or a combination of the three. Likewise, the expression of lineaments in drainage patterns has been considered as a separate category but, in reality, drainage is inherently controlled by topographic relief (e.g. river valley, topographic relief along a series of linear lakes, differential erosion along lithological contacts, faults, dikes, joints). Many lineaments in the Rib Lake Subscene were expressed most strongly on a textural basis (e.g. differential vegetation reflectance); however topography through its effect on drainage and thus vegetation is a controlling factor on detectability. Virtually all the lineaments showing exceptionally strong textural expression (lineaments marked with a "T" on Figure 4.8 F) consisted of differential vegetation growth along a ridge or valley. Furthermore, depending on the orientation of the ridge to the sun azimuth, differential shadowing was also responsible for the highlighting of certain lineaments.

Six lineaments showed no appreciable surficial expression, at least on the topographic maps and air photos analysed.² Several of these

- geology and topographic maps, air photos - listed previously
- surficial geology maps - Ontario Dept. of Lands and Forest - 5465
- Northern Ontario Engineering Terrain Study Maps 5024

² sections of other lineaments also showed no appreciable surficial expression (see Section 4.3.2.2)

Table 4.2
Numerical Summary - Surficial Expression of
Lineaments - Rib Lake Subscene

Surficial Expression		# of Lineaments
Combination (Topographic/Drainage)		32
Ridge/Hill	Topographic	35
Valley		11
Drainage		29
No Expression		6

lineaments were identified from the textural data (themes 1, 2, 3, 4, 6) while the remainder were derived from a combination of data sources. A number of possibilities as to the origin of these lineaments exist. Firstly, they could represent artifacts or false lineaments that may arise from digital processing; secondly, they could simply be a result of improper interpretation (perceptual biases); or thirdly, they may represent real features. The surficial expression of these lineaments may be evident on other supportive data sources. Perhaps a set of winter or summer air photos would reveal the surface expression of these lineaments since only fall and spring photos were used in the surficial analysis. Finally, due to differences in scale, resolution and processing between Landsat imagery and air photos, a specific lineament may be distinguished more easily on one than the other.

A summary of the surficial expression of lineaments derived from digital analysis (with emphasis on the Rib Lake subscene) is presented in Table 4.3.

4.4.1 Problems Associated with Lineament Interpretation within the Study Area

In the study area which has been heavily glaciated, it is not easy to ascertain whether the mapped lineaments represent true structural features or linear features formed by glacial erosion or deposition. If one assumes that the structural information obtained from the Ontario geology map series is valid, then the problem is diminished. However, the validity of such maps, especially if the information was obtained by geophysical techniques as opposed to field sampling, is questionable.

Table 4.3 - Summary of the Surficial Expression of Lineaments Derived From Digital Analysis (Emphasis on the Rib Lake Subscene)

- * - these types of lineaments were not evident in the areas analysed digitally
- they may be more common in the northern portion of the study region where many lineaments were expressed on a textural (vegetational) basis.

In the southern portion of the study area, where thinly-covered or exposed bedrock predominates, individual lineaments and groups of parallel trending lineaments are highlighted by the drainage system. Therefore one must determine whether the drainage system is structurally controlled or glacially controlled. A corollary to this situation is that the bedrock structure may have controlled the direction of localized glacial movement. Thus the scouring and erosive action of the glacier would serve to accentuate certain lineaments of basically structural origin. In the central to northern portion of the study area, which is covered by thick lacustrine and till deposits, the problem is compounded. In this area there is often no visible relationship between the drainage pattern and lineament trends.

By comparing lineament trends to glacial features that give some indication of the direction of ice movement (such as striations, drum-linoid ridges and eskers) one can at least separate possible structural trends from glacial trends, unless the two are coincident. In a statistical sense the effects of glaciation may tend to over-represent structural trends that are coincident with glacial trends as well as obscure structural trends orthogonal to the ice movement.

Areas in the study area where field analysis is required to verify the structural origins of lineaments due to the coincidence of possible glacial and structural trends have been noted in Table 5.4.

4.5 Factors Affecting the Detectability of Lineaments on Landsat Imagery

4.5.1 Terrain Factors

Three important parameters - vegetation, surficial cover and terrain type - affect the detectability of lineaments on Landsat imagery. Vegetation and surficial cover may act to obscure the underlying geological structure whereas terrain type has important ramifications on the expression or lack of expression of lineaments. The masking effect of surficial cover and terrain type are manifested as areas of low density on both the general lineament map (Figure 4.1 F) and the digitally produced lineament maps.

4.5.1.1 Surficial Cover

Visual comparison of the surficial geology map (Figure 2.7 F) with the general lineament map (Figure 4.1 F) reveals that definite areas of low lineament density correlate well with areas of lacustrine (clay) deposits. The major areas of low lineament density correspond to the "Little Clay Belt" north of Lake Temiskaming and the extensive "Abitibi Clay Belt" located further north. This apparent correlation can be interpreted in one of two ways: either (1) there is simply a low density of structural lineaments in these areas or (2) the surficial cover tends to conceal underlying structural lineaments. In the latter case, the probability of the mapped lineaments being of only glacial origin may be greater.

Visual analysis of existing geology maps of these areas generally indicates that there are more faults than would be suggested by the Landsat interpretation. This is especially evident in the area from Night Hawk Lake to McDiarmid Lake.¹ On the Ontario geology map sheet of the area

¹See Fig. 4.1a

(Timmins - Kirkland Lake - map 2205) two major eastward-trending fault zones - ~~Destor~~-Porcupine and Pipestone faults - as well as several NW trending faults have been mapped. These faults have not been detected on the Landsat lineament map in their entirety. The Landsat map indicates a paucity of lineaments in this area with well over 90 percent of the features mapped as short, third order lineaments. A few of the second order lineaments, especially the eastward trending ones located approximately 10 kms south of Lake Abitibi, may be related to the prominent fault zones listed above. Likewise the east-northeast trending second and third order lineaments present in the northern portion of the Little Clay Belt may represent structural activity associated with the Larder Lake fault zone.

Lineament density, as indicated on the Landsat map, appears to increase rather dramatically as one progresses from areas of thick lacustrine deposits to thinly covered or exposed bedrock. In some cases, the change occurs quite noticeably along the boundary of the two surficial units. This is the case south of Larder Lake where a series of lineaments of strong topographic expression have been mapped. The ridge and valley topography in this area may have acted as a barrier which exerted some control over the deposition of the two surficial units.

In the vicinity of Night Hawk Lake a noticeable difference in lineament density between the two surficial units is evident. Geology maps indicate that there are approximately 75 percent more faults within the area of thinly covered or exposed bedrock than the area of lacustrine deposits. Therefore, in this area the differences in density may be a

result of differences in real lineament numbers. However this in turn may be tempered by the fact that thick surficial cover may also affect other techniques (geophysical, ground surveying, outcrop mapping) used to collect geological data. Therefore a greater number of lineaments may be present in these low density areas than indicated on the geology maps.

South of the Abitibi Clay Belt (Larder Lake Fault Zone) lineament density is fairly high in the extensive area of thinly covered or exposed bedrock, where topographic expression of lineaments is more pronounced.

The area north of the Abitibi Clay Belt also exhibits low lineament density. Ground moraine and lacustrine deposits predominate, which may again conceal underlying lineaments. However, this area which includes extensive areas of marsh and organic deposits is much flatter with little topographic variability. Third order and surficial lineaments predominate and the glacial or structural origin of these features, as discussed earlier, is not easily ascertained. The actual nature of the terrain in this area may determine the detectability of lineaments on Landsat images. This point will be investigated further in the next section.

4.5.1.2 Nature of the Terrain

The effect of terrain type on lineament detectability was suggested by analysis of the digital lineament maps. All the subscenes with the exception of Englehart are located on areas of thinly covered or exposed bedrock and rolling terrain. Therefore in these areas surficial cover

is not a limiting factor in lineament detectability.¹ However, low density areas which can be related to specific terrain conditions as opposed to broad scale differences in surficial cover, are present within some of these subscences. Through visual analysis, areas of low density, summarized in Table 4.4, were found to correspond with relatively flat, marshy (organic) terrain. These low density areas can once again be interpreted as having an inherent lack of structural lineaments and/or the lineaments that may be present are not detectable due to the nature of the terrain (i.e. very little topographic expression).

4.5.1.3 Vegetation

Although vegetation often obscures underlying geologic structure, in some cases it can reflect structure and to a much lesser extent lithology. For example, differential vegetation growth could occur along a diabase dike that cuts through a homogeneous granite terrain. The relationship is one in which the dike, being of a different rock type, results in the formation of a slightly different soil type from the surrounding granite bedrock. The difference in soil type and possible soil moisture content could result in vegetation of a different density and/or composition. However, this is a very general relationship that may be easily disrupted by other environmental factors such as the effects of glaciation (glacial overburden and transported soils). Furthermore, the diabase dike, depending on the nature of the terrain, would likely display negative or positive relief. Analysis of the Rib Lake subscene showed that the textural enhancement procedure was useful for the isolation and

¹The Englehart subscene, for which no lineament map was produced due to a lack of detectable lineaments, is located within the flat lying "Little Abitibi Clay Belt". In this case low lineament density may be a result of the thick surficial cover as well as the general nature of the terrain.

Table 4.4 - Areas of Low Lineament Density Within Digital Subscenes

Subscene	Location of Low Density Area	Terrain Type	Geological Interpretation
Tee Lake	Fig. 4.10 (F) - L	- low plain - organic deposits	- lack of structural lineaments or terrain conditions (lack of topographic expression) responsible for low lineament density
Maxam Lake	Fig. 4.5 (F) - L	- till/clay plain interspersed with bedrock knobs	- surficial cover may obscure lineaments
Northeast Arm	Fig. 4.6 (F) - L	- flat to gently rolling organic terrain	- low density in these areas may be due to lack of structural lineaments since geology maps show very little structural features (faults, dikes, etc.)
Lake St. Amand	Fig. 4.11(F) - L	- clay plains/flat marshy terrain interspersed with areas of bedrock - agricultural activity	- agricultural activity (fields) - may obscure structural lineaments as well as creating new cultural lineaments (e.g. field boundaries)
Rib Lake	Fig. 4.2 (F) - L	- very small area of flat, marshy terrain	-
Englehart *	Entire subscene	- area located within "Little Clay Belt" - flat terrain interspersed with marshy areas - agricultural activity - rectangular grid pattern of roads	- of the few lineaments identified, all exhibited strong topographic/drainage expression (i.e. ridges that rise above clay plain or valley which has cut deeply into the lacustrine deposits) - surficial cover and agricultural activity may obscure structural lineaments - geology maps indicate a lack of structural lineaments

* a lineament map of this subscene was not produced due to a lack of lineaments detected

-TEE LAKE SUBSCENE-
DIGITAL LINEAMENT MAP

Fig. 4.10

TPPL UTM WATER MAP
TOP LEFT (0, 0)
SCALE 1:201,612
TRIM: 1

- Mapped Fault
- - - Landsat Lineament
- Epicentre Area (Tee Lake Earthquake -1935)
- Lithological Contact
- L Low Density (see table 4.4)
- 1 Circular Feature (see section 5.2.3.1)

- LAKE ST. AMAND SUBSCENE -
DIGITAL LINEAMENT MAP

Fig. 4.11

STARK, UPR WATER MAP
TOP LEFT (0. 0)
SCALE 1 : 201,612
THICKEN

detection of certain lineaments, but as was discussed in Section 4.4 these features were strongly expressed in the topography. In flatter areas, (i.e. Englehart subscene) however, certain lineaments may be expressed entirely by vegetational differences without any notably topographic control. In this type of terrain the textural enhancement procedures may provide a relatively more important data source, as was found to be the case in the Englehart subscene.

Although the textural procedure was successful in highlighting certain lineaments, another consideration is the degree to which textural themes (complexes) correlate with actual lithological units. Through air photo analysis and topographic and vegetation map analysis¹ an attempt was made to characterize the separate textural themes present in the Rib Lake subscene (Table 4.5). It should be noted that no field checking was possible. However, such identification is not important insofar as the operational value of the textural product is concerned. Thus, no attempt has been made to establish quantitative estimates of accuracy for these classes. A brief visual comparison of the theme maps (unsupervised classification) and the geology map suggests that there is no simple correlation between the two variables. This is expected since, as was discussed in Chapter 3, vegetation which is primarily responsible for surface spectral signatures is influenced by a number of terrain factors in addition to bedrock geology. In certain exceptional cases certain themes did correlate with a lithological unit (see Chapter 5).

¹ - air photos - listed previously
 - topographic maps - Haileybury 31M/SW, 1:250,000 - Ville Marie - 31M
 - Forest Stand Maps (Ontario Natural Resources - see bibliography)

Table 4.5 - Identification of Textural Themes (Rib Lake Subscene)

Themes	Vegetation Type	
1	Pure Coniferous Stands (eg. cedar, black spruce) Wetlands	
2/3	Mixed (greater % coniferous)	} Slope/Aspect - Differential shadowing can cause variable classification
4/5	Mixed (greater % deciduous)	
6	Pure Deciduous Stands and Short Grass Meadows	
7	Water	

4.5.2 Cultural Factors

The landscape of the Englehart subscene is dominated by cultural features. Such features as roads and field patterns add further confusion to the lineament interpretation process and are usually not included in a lineament map. However, cultural features (transportation routes, settlement patterns) often reflect historic settlement patterns which in turn may have been affected by environmental conditions such as terrain, topography, drainage patterns and geologic structure. Although this is not the case in the Englehart subscene, for settlement patterns generally follow a regular grid pattern, careful analysis of other data sources is needed when filtering cultural lineaments. The textural enhancement procedure particularly highlighted field boundaries displaying differential vegetation growth. Furthermore, the textural themes produced for this largely agricultural subscene are based on entirely different vegetation complexes than the other subscenes. This means that textural/structural relationships that were valid in other subscenes cannot be applied satisfactorily to the Englehart subscene. This observation is not surprising, given the widely different biophysical environment.

Other factors that would tend to complicate application of digital techniques are burnt over and cut over areas. Logging activity in the central and northern portions of the study area has produced a pattern of cultural lineaments (logging roads and linear boundaries between cut over and heavily vegetated areas) that was found to be visually confusing. These features were highlighted especially in the output from the PAS system. Based on the analysis of the Englehart subscene these types of lineaments

would also be highlighted by the digital processing techniques, thus creating difficulties in interpretation.

Burnt over areas would also create complications in the interpretation of especially the textural digital data. For example, the simple relationship suggested in Section 4.5.1.3 between a diabase dike, its associated soil type and the resulting vegetation may be obliterated as a result of a forest fire. Following the fire early vegetation regrowth is often in the form of scrub species that are able to survive on a burn site regardless of differences in rock and soil type. Thus the vegetational/structural assumptions that form the basis of the textural enhancement procedure would be severely weakened.

The environmental and cultural factors that have affected the detectability of structural lineaments in the areas analysed digitally and the effect these have on geological interpretation are summarized in Table 4.6.

4.5.3 System Factors

4.5.3.1 Sun Azimuth Bias

One factor that is of particular importance to lineament studies is the sun azimuthal bias. Lineaments that are subparallel to the azimuth of the sun are only weakly enhanced by shadowing; however, when the azimuths are perpendicular the enhancement is at a maximum (Gregory and Moore, 1973). In addition, lineaments that strike parallel to the MSS scan lines may also be overlooked (Gregory and Moore, 1973). These biases inherent in Landsat imagery must be recognized when evaluating trend statistics derived from rose diagrams. Strict quantitative interpretation must be approached with caution. This, however, does not

Table 4.6 - Factors Which Affect the Detectability of Lineaments on Landsat Imagery

Factors Affecting Detectability	Effect on Lineament Detection	Geological Interpretation
A) Environmental Conditions		
Surficial Cover	<ul style="list-style-type: none"> - may obscure structural lineaments - surficial lineaments may predominate - drainage pattern will not reflect underlying bedrock 	<ul style="list-style-type: none"> - lack of lineaments may be a result of: 1. surficial cover (obscuring effect) 2. lack of structural lineaments - confusion between surficial and structural lineaments*
Flat Marshy Terrain	<ul style="list-style-type: none"> - lack of topographic expression makes lineaments more difficult to detect - organic terrain may obscure lineaments 	<ul style="list-style-type: none"> - confusion between surficial and structural lineaments
Vegetated Areas	<ul style="list-style-type: none"> 1. vegetation may obscure lineaments 2. lineaments may be highlighted by vegetation (textural enhancement) - textural enhancement can enhance both continuous and discontinuous linear textural patterns that may reflect underlying geologic structure 	<ul style="list-style-type: none"> - confusion between surficial and structural lineaments
Areas of Thinly Covered or Exposed Bedrock	<ul style="list-style-type: none"> - topographic expression - prime mode of lineament expression (differential shadowing, textural enhancement) - drainage pattern often reflects bedrock structure 	<ul style="list-style-type: none"> - less confusion between surficial and structural lineaments

* areas of thick surficial cover and flat terrain also present difficult conditions for structural mapping using other techniques (eg. ground mapping procedures)

Table 4.6 - Factors Which Affect the Detectability of Lineaments on Landsat Imagery

Factors Affecting Detectability	Effect on Lineament Detection	Geological Interpretation
Cut (Logging) and Burnt Over Areas	<ul style="list-style-type: none"> - may effect relationship between vegetation and geology - present confusing signatures 	
Cultural Lineaments	<ul style="list-style-type: none"> - present confusing signatures 	<ul style="list-style-type: none"> - filtered except in cases where road, rail is coincident with a structural lineament
Agricultural Areas	<ul style="list-style-type: none"> - may obscure structural lineaments - presents confusing signatures (field boundaries) 	
B) System Parameters		
Sun Azimuth	<ul style="list-style-type: none"> - suppression of lineaments parallel to sun azimuth 	
Scan Lines	<ul style="list-style-type: none"> - scan lines - false lineaments 	

preclude the value of rose diagrams for comparing regional trends on a relative basis. The directional bias is inherent in the illumination source and has been recognized with Landsat data due to the stable illumination standard as compared with aerial photographs. Although no mathematical method for correcting this bias is known, one method of reducing the effect on Landsat data is by viewing seasonal imagery with differing solar azimuths and minor scene position differences (Moore and Gregory, 1973). Another method would involve the comparison of Landsat imagery to another form of remotely sensed data in which the sun azimuth is not a controlling factor in the image geometry and radiometry (ie. radar imagery).

4.5.3.2 Seasonal Imagery

Summer, winter and fall imagery were used in this study not only to help counteract the sun azimuth bias problem but also to enable the maximum amount of lineament information to be obtained. It was found that the most useful seasonal image is dependent on the type of biophysical environment that is being analysed. For example, the winter images yielded the most lineaments in topographically rugged areas of thinly covered or exposed bedrock. In these areas increased lineament enhancement was a result of the lower sun elevation (shadow enhancement) and the highlighting of the drainage system by snow, thus increasing the visual contrast between lineaments and the surrounding terrain. In flatter areas covered by thick glacial deposits the winter images did not offer a substantial advantage over the summer images. In some cases, especially in the northern portion of the study area where vegetational lineaments predominate, the summer colour composite and Band 6 image yielded a greater

number of lineaments due to maximum tonal contrast. Gregory and Moore (1973) have found that images from different seasons provide both supporting and unique information useful for geological purposes. In order to obtain the maximum amount of lineament information, seasonal imagery of the same area should be used.

4.5.3.3 Image Type and Scale

Paper enlargements of Band 6 imagery at a scale of 1:500,000 formed the major lineament data source for the visual analyses. This imagery format which proved quite satisfactory for the detection of lineaments was chosen primarily on the basis of cost (\$25.00) and ease of handling. However, 1:250,000 colour composite and Band 6 transparencies would probably facilitate the detection of a greater number of lineaments. Although the resolution cell (pixel) of Landsat imagery is fixed the larger scale transparent enlargements would make it much easier to identify and map smaller to medium sized lineaments than was the case in the present study. Furthermore, the use of DICS (Digital Image Correction System) tapes, which can be overlaid directly on NTS maps as well as geological and geophysical maps, is recommended to simplify the process of transferring detail from image to map.

4.5.4 Perception

Inherent in all lineament studies is the problem of perception. A great deal of subjective interpretation is involved in the analysis of imagery for lineament information, a feature which has been the subject of considerable study (Podwysocki et al., 1978, Burns et al., 1977, 1978, Martin-Kaye et al., 1979).

Podwysocki et al. point out the subjectivity and variability involved in mapping linear features from Landsat data by different interpreters, particularly in low relief terrain. Results in which a very low amount of agreement between the results of different interpreters, or by one interpreter on different occasions, have been obtained by Burns et al. (1977). They concluded that even with very clear and well defined imagery there are stochastic processes (random errors in recognition, mental and visual activity) as well as manual errors in marking the annotations that ensure that no two annotations are identical.

Two approaches to dealing with the problem of perception exist. Burns et al (1978, 1977) have attempted to devise perception models that describe the results of a photointerpreter annotation of discrete features on an image as well as stochastic processes in the observer. Podwysocki et al., on the other hand, have proposed a number of automatic enhancement techniques (filtering - digital and edge enhancement-analog) which may help to eliminate some of the operator variability. Although digital processing techniques do not result in final interpreted lineament maps - for the interpreter must still visually analyse the digital output - they do help to extract and enhance lineament data, thus facilitating visual interpretation. A more appropriate term for this procedure may be computer assisted interpretation as opposed to actual digital computer interpretation.

In order to deal with the perception problem, I used, in addition to digital processing techniques, a method of multiple interpretations. With regard to the digital data, each subscene was interpreted once and

then left for a period of approximately six weeks, after which each was interpreted a second time. In the case of the Rib Lake subscene, a total of three interpretations were undertaken. The visual interpretation process (1:1,000,000 lineament map) involved a four-week period in which each data source (images and edge enhanced products obtained from the PAS) was subjected to a detailed interpretation and followed a few days later by a sample checking procedure. Although many lineaments were common to successive interpretations, a smaller number of lineaments unique to individual interpretations were also evident. In all cases the lineaments, whether unique or common, were plotted on the base map.

The digital output products, being the most easily interpreted generally displayed lineament patterns clearly. The edge enhanced photographs produced from the PAS were the most difficult to interpret in that they were often fuzzy and specific lineaments were hard to identify due to background noise (see Section 6.2.1 and Figure 3.1)

4.6 Conclusion

Results from the visual and digital analysis indicate that Landsat data and associated processing techniques have been useful for the detection of lineaments in glaciated and vegetated terrain. Specific conclusions regarding limitations and advantages of Landsat imagery and digital processing techniques will be discussed in Chapter 6.

Chapter 5

Lineament Analysis

5.1 Introduction

The primary goal of this thesis as outlined in Chapter 1, is a detailed analysis of Landsat imagery and associated computer processing techniques for lineament detection. However, within the entire framework of the seismo-tectonic study being conducted by the Earth Physics Branch (E.M.R.), a more detailed geological and statistical analysis of the lineaments is beneficial in order to possibly assist in establishing a relationship between the tectonic history and stress field within the study region. The analysis is by no means exhaustive; no attempt has been made to establish the tectonic history of the study region based on the lineament data. Dominant lineament trends have been identified by statistical and visual methods, the possible origins of these lineaments are discussed and lineament density within the southern half of the study region is analysed. In addition, the data collection techniques used to produce the statistics (i.e. rose diagrams) and contour density maps are analysed. For more details on the results of the various disciplines involved, including descriptive geology, geophysical characteristics, tectonic history and general stress patterns, the reader is advised to consult a summary A.E.C.L. report (in preparation) produced by the Earth Physics Branch (E.M.R.) of the entire project.

5.2 Lineament Analysis

5.2.1 Statistics - Rose Diagrams

Each lineament was digitized using the Horizon mini-computer and a Summagraphics ID digitizer located in the Geography Department at Carleton University. The digitization process generated for each lineament: 1) total length in kilometers; 2) mean azimuth in degrees (-90° (west) to 90° (east), north = 0°); and 3) a numerical identification code. The codes included all lineaments (0), first order lineaments (1), second order lineaments (2), third order lineaments (3), and a fourth category (4) which included lineaments that correspond to faults and dikes on available geology maps. Circular features were not considered in the analysis, although curvilinear features were digitized for their individual total length and their average azimuth direction.

The lineament data thus collected was then sorted via frequency into 10 and 20 degree azimuth classes by another computer program (STATS). This program also calculated various statistics including total length, average length and standard deviation per specified azimuth class (see Appendix D for a copy of computer programs used as well as a sample of the data obtained).

Separate rose diagrams showing total frequency and total length of lineaments per 10° and 20° azimuth classes were produced for each tectonic unit with the exception of the Hudson Bay Lowlands and the Quetico subprovince, such exception being due to the low number of lineaments within these tectonic and physiographic units. For the Kapuskasing subprovince only 20° azimuth class rose diagrams were produced, once again due to the low number of lineaments.

Although all lineaments (code 0) were used in the compilation of the rose diagrams, the "STATS" program is capable of producing statistics pertaining to the individual codes listed previously, thus enabling separate rose diagrams to be produced for first order, second order, third order and mapped faults and dikes. This could be useful for a more detailed or analysis of localized trends than was necessary to achieve the objective of this thesis.

5.2.1.1. Total Length Versus Total Frequency Rose Diagrams

Ten degree azimuth class rose diagrams calculated from total lineament length and total frequency for the Grenville Province are shown in Figure 5.1. Table 5.1 is a summary of lineament trend statistics for the Grenville Province. Although both types of rose diagrams (Figure 5.1) show approximately the same dominant trend and secondary trend directions, some minor differences do exist. The rose diagram calculated from total frequency indicates that the dominant trend strikes -40° to -50° whereas the rose diagram calculated from total length indicates the dominant trend direction to be -60° to -70° . The azimuth degree interval of -40° to -50° contains the highest number of lineaments (30) but the total length of all lineaments is only 212 kms; therefore this would register as a secondary trend when considering the rose diagram calculated from total length. Conversely, the -60° to -70° trend, although containing one less lineament than the -40° to -50° trend, registers a total length of 374 kms. The difference is simply that the -60° to -70° trend contains on average longer lineaments than the -40° to -50° trend. This is reflected also in the mean and standard deviation. This problem is further illustrated,

Figure 5.1. Grenville Province 10^0 Azimuth Class Trend Diagrams

177

Type	Dominant Trends	Frequency	Secondary Trends	Frequency
Total	-40 to -50°	30	-30 to -40°	20
Frequency	-60 to -70°	29	-70 to -80°	20
	-50 to -60°	24	0 to -10°	18
			30 to 40°	17
			60 to 70°	17
			-20 to -30°	16
			-80 to -90°	10

Type	Secondary Trends	Total Length (km)	Average Length (km)	Standard Deviation	Secondary Trends	Total Length (km)	Average Length (km)	Standard Deviation
Total	-60 to -70°	374.5	12.9	15.0	-80 to -90°	219.6	21.9	28.7
Length	-50 to -60°	287.0	11.9	10.3	-40 to -50°	212.2	7	7.8
	-70 to -80	276.3	13.8	13.6	-30 to -40°	160.6	8.0	4.6
					0 to -10°	157.5	8.7	7.6

albeit to a greater extreme, by the -80° to -90° trend which only contains 10 lineaments (total length equals 219 kms, average length equals 21 kms, standard deviation equals 28). The high standard deviation indicates that a few very long lineaments are present in this azimuth interval. Therefore, two situations may exist that could have ramifications on structural interpretation. An azimuth class may give rise to a high lineament rating on frequency but a relatively low rating on length.

The interpretation of structural trends must be somewhat tempered by the above consideration. One must not jump to the immediate conclusion that the -40° to -50° trend is structurally more important than the -80° to -90° trend. It may be logical to assume that perhaps the lineaments in the -40° to -50° interval, being more numerous but shorter, represent features of lesser structural significance (i.e. joints) than the longer lineaments that comprise the -80° to -90° trend. In fact, by examining the lineament map (Figure 4.1) it can be seen that the lineaments that strike -80° to -90° are quite long faults as opposed to the second and third order and to some extent shorter faults that comprise the -40° to -50° trend. Although one cannot really determine which trend is structurally more significant without extensive field investigations, this aspect of the trend interpretation must be considered. Another factor that should be kept in mind during trend analysis is that the lineaments represent strictly Landsat derived features and due to problems discussed in Chapter 4 cannot be considered to represent the total structural milieu.

The same considerations apply to the 20° azimuth class rose diagrams,

although to a lesser degree due to the broader class interval. These rose diagrams, by combining some of the rather irregular maxima and minima present in the 10^0 azimuth class rose diagrams, display a more general and smoothed view of the lineament trends. Furthermore, they are easier to interpret in a visual sense since they provide a marked enhancement of dominant trends. Therefore, only these rose diagrams will be summarized in tabular form (Table 5.2 and 5.3). The construction of both types of rose diagrams, one based on total frequency and one based on total length per azimuth interval, will give a more complete and precise picture of general lineament trends.

5.2.2 Lineament Trends

Lineament trends are summarized in three forms. Figures 5.1 to 5.11 present 10^0 and 20^0 azimuth class rose diagrams for each tectonic unit, Tables 5.2 and 5.3 summarize the dominant and secondary trends present on the 20^0 azimuth class rose diagrams while Figure 5.12 displays the dominant trends in map form.

5.2.2.1 Grenville Province

By inspecting the rose diagrams (Figure 5.2) and general lineament map (4.1 F) a fairly strong NW to WNW (-30^0 to -70^0) (-70^0 to -90^0) trend is evident which consists primarily of faults in Ontario and first and second order lineaments in Quebec. Two secondary trends are also evident; one in Quebec striking NNW (-10^0 to 0^0) consisting of first order lineaments and the other striking NE (30^0 - 70^0) paralleling the Grenville Front consisting of mapped faults and second order lineaments.

Figure 5.2. Grenville Province 20° Azimuth Class Trend Diagrams

Figure 5.3. Cobalt Embayment 10° Azimuth Class Trend Diagrams

Figure 5.4 Cobalt, Embayment 20° Azimuth Class Trend Diagrams

5.5 Pontiac Gneiss Belt 10° Azimuth Class Trend Diagrams

Figure 5.6 Pontiac Gneiss Belt 20° Azimuth Class Trend Diagrams

Figure 5.7. Abitibi Volcanic Belt 10^0 Azimuth Class Trend Diagrams

Frequency Interval = 10

Length Interval = 50 km

Figure 5.8. Abitibi Volcanic Belt 20° Azimuth Class Trend Diagram

Figure 5.9. Kapuskasing Belt 20° Azimuth Class Trend Diagrams

Figure 5.10. Opatica Belt 10° Azimuth Class Trend Diagrams

Figure 5.11. Opatoca Belt 20° Azimuth Class Trend Diagrams

Table 5.2 - Summary of Trend Statistics (20° Azimuth Class) - Total Frequency

Tectonic Unit	Dominant Trends	Frequency	Secondary Trends	Frequency
Grenville Province	-50 to -70°	53	30 to 50°	31
	-30 to -50°	50	-70 to -90°	30
			-10 to 10°	29
			50 to 70°	29
Southern Province				
Cobalt Embayment	-10 to 10°	61	10 to 30°	45
	i.e. (-10 to 0°)		-30 to -50°	43
	0 to 10°		30 to 50°	42
			-50 to -70°	37
Superior Province				
Pontiac Gneiss Belt	10 to 30°	36	30 to 50°	21
			50 to 70°	20
Abitibi Volcanic Belt	-10 to 10°	86	50 to 70°	55
			-10 to -30°	49
			30 to 50°	44
Opatica Belt	-10 to 10°	66	-10 to -30°	53
			-30 to -50°	28
Kapuskaing Belt	30 to 50°	13	70 to 90°	8
	10 to 30°	13		
	-10 to 10°	12		

Table 5.3 - Summary of Trend Statistics (20° Azimuth Class) - Total Length

Tectonic Unit	Dominant Trends	Total Length (km)	Average Length (km)	Standard Deviation	Secondary Trends	Total Length (km)	Average Length (km)	Standard Deviation
Grenville Province	-50 to -70°	661.5	12.4	13.1	-10 to 10°	218.4	7.5	6.2
	-70 to -90°	495.9	16.5	20.3	30 to 50°	203.9	6.5	3.9
	-30 to -50°	372.9	7.4	6.7				
Southern Province								
Cobalt Embayment	-30 to -50°	595.8	13.8	17.9	10 to 30°	346.4	7.6	3.9
	-50 to -70°	560.1	15.1	15.1	30 to 50°	276.4	6.5	3.9
	-10 to 10°	491.9	8.0	7.5				
Superior Province								
Pontiac Gneiss Belt	10 to 30°	626.7	17.4	15.8	50 to 70°	172.7	8.6	6.0
					30 to 50°	152.0	7.2	4.5
Abitibi Volcanic Belt	-10 to 10°	841.1	9.7	8.1	-10 to 30°	605.3	12.3	10.3
					50 to 70°	392.9	7.1	4.2
					-30 to -50°	369.8	11.2	10.6
Opatica Belt	-10 to 10°	723.3	10.9	9.3	-10 to 30°	452.5	8.5	8.0
					-30 to -50°	252.2	9.0	5.1
Kapuskasing	30 to 50°	178.4	13.7	17.1	10 to 30°	91.3	7.0	4.5

FIG. 5.12
SUMMARY OF MAJOR LINEAMENT TRENDS

5.2.2.2 Cobalt Embayment

The dominant and secondary trends within this subprovince are quite similar to the trends present in the Grenville Province. The major difference is that the northward trend (-10° to 10°) is more dominant.

The total frequency rose diagram (Figure 5.4) shows the dominant trend to strike roughly northward whereas the total length rose diagram indicates a NW (-30° to -70°) dominance. The NW trend, although containing fewer lineaments than the northward trend, does contain on average longer lineaments, thus resulting in a high total length value. The -30° to -50° trend may have an unrepresentatively high mean (13.8 km) as evidenced by the high standard deviation (17.9). The Montreal River and Cross Lake Faults, both of which strike -30° to -50° and are quite long, are responsible for the high standard deviation. The majority of lineaments are slightly less than the average length listed.

5.2.2.3 Pontiac Gneiss Belt

The dominant lineament trend which consists primarily of first and second order lineaments strikes in a NE direction (10° to 30°) (Figure 5.6).

5.2.2.4 Abitibi Volcanic Belt

The dominant trend is northward (-10° to 10°) with secondary trends striking NW and NE (Figure 5.8). Generally the northward trend consists of mapped faults, second order lineaments and to a lesser extent surficial lineaments (eskers). The secondary NE trend consists of second order and third order lineaments which are prevalent in the eastern portion of the subprovince. The NW trend consists of mapped faults and second order lineaments.

5.2.2.5 Kapuskasing Belt

The major lineament trend in this subprovince is in a NE direction. The total frequency rose diagram indicates the dominant trend direction to be -10° to 30° ; however, the total length rose diagram narrows this range to 30° to 50° (NE) (see Figure 5.9). Although the 30° to 50° azimuth interval has the same number of lineaments (13) as the 10° to 30° and -10° to 10° intervals, its total length figure (178.4 km) is about twice as large. Included in this trend direction is a long lineament (≈ 70 kms) that is mapped partially as a fault and partially as a second order lineament on the general lineament map (Figure 4.1 F). This feature is responsible for the high value of both the average length (13.7 km) and standard deviation (17.1).

5.2.2.6 Opatika Belt

A strong NW to northward striking trend (-10° to 10°) consisting of primarily third order and surficial lineaments is evidenced by inspecting the lineament map (Figure 4.1 F) and rose diagrams (Figure 5.11).

5.2.3 Origins

Table 5.4 presents a summary of the possible origins and interpretation problems associated with the dominant lineament trends.

In the Grenville and Cobalt tectonic units the possible relation of major trends to the Temiskaming Rift Valley, the Nipissing Branch of the Ottawa Rift Valley (graben) and the Grenville Front is based purely on the spatial location of certain lineament trends in relation to

Table 5.4 - Summary of Major Lineament Trends and Origins
(Identification Numbers - See Fig. 5.12)

Tectonic Unit	Trends	Origin	I.D. #'s	Interpretation Problems
Grenville Province	NW -30 to -70°	Temiskaming Rift Valley	1	
	WNW -70 to -90°	Nipissing Branch of the Ottawa Graben	2	
	NE 30 to 70°	Grenville Front	3	Glacial/structural origin?
Southern Province				
Cobalt Embayment	NW -30 to -50°	Temiskaming Rift Valley	1	
	WNW -50 to -70°	Diabase Dikes (Sudbury)	4	-Dikes dissect many N to NE trending lineaments as well as a NW striking fault belt south of Diamond Lake -Many dikes appear to originate from major faults that may be associated with the Temiskaming Rift Valley
Superior Province	NNW-NNE -10 to 10°	Associated with similar trend in the Abitibi Volcanic Belt (see #7)	5	-Glacial/structural origin
Pontiac Gneiss Belt	NE 10 to 30°	Possible fault zone/joints (see written description Section 5.2.3)	6	-Glacial/structural origin -Chagnon (1968) - concluded that bedrock geology exerted the strongest control on lineament orientation and that glaciation had an accentuating effect only
Abitibi Volcanic Belt	NNW 0 to -20°	Fault Zone	7	-glacial/structural origin
	NE 50 to 70°	Fault Zone/Dike Swarm (Abitibi)	8	
Kapuskasing Belt	NE 30 to 50°	Fault Belt	9	

Table 5.4 - Summary of Major Lineament Trends and Origins
(Identification Numbers - see Fig. 5.12)

Opatca	NNW-NNE -10 to 10°	- surficial lineaments and third order -possible dike swarm (Matachewan)	10	Glacial/structural origin
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major geologic features and the directional information as evidenced by the rose diagrams.

The Rib Lake subscene (Figure 2.1) is located within the Cobalt Embayment. The most prominent structural features are a series of NW trending faults corresponding to the Temiskaming Rift Valley. Visually the dominant lineament trend as evidenced on the digital derived map (Figure 4.2 F) is also in a NW direction although in the southern portion of the map a strong NE trend consisting of faults, Landsat lineaments, and lithological contact zones is present. These lineaments may be related to activity along the Grenville Front, which lies approximately 20 kms to the south of the map area. More specifically, they fall within the Grenville Front Tectonic Zone (GFTZ) (Wynne-Edwards, 1972). The rather abrupt change in lineament direction between the GFTZ and the rest of the map is also reflected in the lithology. In the southern part of this subscene mafic to felsic metavolcanics (basalt, andesite, rhyolite, chert) dominate whereas conglomerates, greywacke and siltstone of the Huronian Group and early Precambrian igneous and metamorphic granite rocks predominate in the central and northern area.

The Tee Lake subscene is significant in a seismo-tectonic sense due to the occurrence of a large earthquake in this area in 1935. Figure 4.10 shows the epicentre region. This earthquake is thought to have a focal depth in the mid to upper crust (R.B. Wetmiller, personal communication). The possibility of a shallow focal depth less than 10 kms. does not seem likely as no surface breaks were observed (R. Wetmiller, IBID). A number of prominent lineaments have been mapped within the epicentre area, five of which strike in a NW direction. These lineaments may be associated with the Temiskaming Rift Valley since

they are within the region demarcating the rift valley (Lovell and Caine, 1970) and have a similar strike to major rift valley faults (Montreal, Cross, Latchford, Quince Dam Faults). If these lineaments were verified as faults they could be examined for evidence of the Tee Lake earthquake.

The strong NE trend in the Pontiac Gneiss Belt consisting of sub-parallel lineaments may represent faults, joints or glaciation according to Chagnon (1968). He states that... "these linears (lineaments) in the area are not accompanied by shearing, silification or brecciation. However to the north (Wilson, 1918, Podolsky, 1950) there is more definite evidence that some linears, a few of which extend into the Pontiac Gneiss Belt are related to faults. Also as the lineaments are parallel to the dominant directions of joints in the area, many are probably related to joints". (Chagnon, 1968: 81).

In the Abitibi Volcanic Belt the dominant northward lineament trend (-10^0 to 10^0) includes a series of eskers located in the northern portion of this subprovince. At first glance it would not seem logical to include these eskers in a map of supposed structural lineaments since they would tend to bias the trend statistics. However, because geological structure appears to have controlled glacial flow and the possibility that these eskers have been deposited along zones of structural weakness (J. Viette, personal communication), they have been included.

The dominant lineament within the NE trend of the Kapuskasing Belt (see Section 5.2.2.5) exhibits strong tonal/colour expression on the Landsat imagery due to differential vegetation growth on either side of the lineament. Topographically, the lineament roughly corresponds to the 500 ft. contour line (1:250,000 "Moose River" Topographic map sheet), thus the difference in vegetation could be topographically related

with the better drained, higher area south of the lineament supporting coniferous vegetation as opposed to the lower wetland environment to the north. Field checking in this area would be required to verify the structural origin of this lineament as well as other similar trending ones.

Many of the lineaments comprising the northward trend (-10^0 to 10^0) of the Opatica Belt are surficial lineaments since they are expressed as linear bogs, string fens, eskers and drumlinoid ridges on surficial geology maps of the area. The majority of these lineaments are expressed vegetationally/topographically on the Landsat imagery and probably represent areas of better drainage along rivers, eskers (sand) or outwash deposits where coniferous vegetation is able to thrive. Some of these lineaments are expressed on the Landsat summer colour composite as a darker magenta colour, while others appear in a yellowish-brown hue indicating marsh vegetation. Although much of this speculative evidence would support the surficial origin of many of these lineaments the possibility that the bedrock exerts control over glacial deposition and erosion must be considered. Extensive field checking is recommended to help solve this problem.

The ODM (Ontario Department of Mines) geology map (map 2198) shows numerous northward trending interpreted dikes (magnetic lineaments) in this area (see Figure 2.4). Many of the similar trending third and second order lineaments on the general lineament map (Figure 4.1 F), especially in the areas south of Pierre and Little Abitibi Lakes and west of Kesogami Lake where the density of dikes (magnetic lineaments) is the highest, may represent the surficial expression of these structural features. Many of the linear bogs and string fens in these areas may have formed where the dikes have been differentially eroded

by glaciation.

5.2.3.1 Circular Features

Circular features on both the general lineament map (Figure 4.1 F) and the digital subscene maps (Figures 4.2 F, 4.5 F, 4.6 F, 4.10 F and 4.1 F) are expressed either by tonal anomalies (differential vegetation growth associated with positive or negative relief) or by circular drainage patterns. Table 5.5 summarizes the surficial expression of circular features within the Rib Lake subscene.

The geological origin of these circular features can be partially suggested by reference to geology maps, however field checking is required for verification. In the Rib Lake subscene (Figure 4.8 F) the small circular feature labelled by a "2" could be the topographic expression of a small elliptical outcrop of basalt in an area of predominantly unsubdivided migmatic rocks. In the Tee Lake subscene (Figure 4.10 F) the circular feature labelled by a "1" may correspond to a small gneissic dome.

The remaining circular features may represent structural or topographic domes or basins, intrusions (plutons, batholiths), impact craters or non-geologic surficial features.

5.2.4 Lineament Density

As mentioned in Chapter 1, there is evidence to suggest that earthquakes occur with greater frequency in zones of high lineament density and high lineament intersection density. Therefore lineament density and intersection density maps may be useful in the study of the relationship between earthquakes and geologic structure.

Table 5.5 - Surficial Expression of Circular Features - Rib Lake

Circular Feature (Identification Number, See Fig. 4.2F)	Surficial Expression
1	- rounded crest lines
2	- tonal anomalies (differential vegetation growth) associated with positive relief
3	<div> <div>- light tone (Band 6)</div> <div>- bright red (colour composite)</div> <div> <div>indicates high infrared reflectance</div> <div>(eg. Deciduous veg vs. Coniferous veg)</div> </div> </div>
4	
5	- drainage pattern
6	- no appreciable surficial expression (slight circular pattern evident in contour lines)

5.2.4.1 Density Definition

Lineament density can be defined in two ways: (1) the frequency of lineament occurrence per unit area or (2) the total length of lineaments per unit area. Each definition involves a separate approach to the measurement of lineament density. Mussakowski (1974) calculated lineament density by summing lineament lengths per unit area. Conversely, Geo-Analysis (1981) used the total lineament frequency per unit area in a study of NW Ontario. In this thesis a comparison between the two methods is made in which relative differences and similarities are assessed.

Intersection density is defined as the frequency of lineament intersection per unit area. Intersection refers to situations in which the lineaments, including circular features, actually cross one another or when they are in contact but not crossing.

5.2.4.2 Lineament Density Maps

Three contour maps were produced, two dealing with lineament density (Total Frequency - Figure 5.13F, total length - Figure 5.14F) and the third with intersection density (Figure 5.15F). All three are registered to the general lineament map (Figure 4.1F). A 20 x 20 km grid overlay formed the unit area of measurement and the maps were generated by a SYMAP computer mapping program in the Geography Department of Carleton University.

The location of the contour maps was chosen to assist in minimizing the interpretation problem that exists between areas of lacustrine cover and thinly covered or exposed bedrock (discussed in Chapter 4). Dashed lines on the map represent areas of ambiguous interpretation. The two surficial units cannot really be accurately compared for lineament

FIG. 5.13
LINEAMENT DENSITY CONTOUR MAP
(TOTAL FREQUENCY PER 20x20 km GRID SQUARE)

FIG. 5.14 LINEAMENT DENSITY CONTOUR MAP
(TOTAL LENGTH PER 20x20 km GRID SQUARE)

FIG 5.15
LINEAMENT INTERSECTION DENSITY MAP (20x20 km GRID SQUARE)

density on a quantitative or qualitative basis. Therefore, the maps were chosen to cover the area south of the Abitibi Clay Belt, where thinly covered or exposed bedrock predominates.

5.2.4.3 Interpretation

Table 5.6 presents an interpretative summary of areas of high and low lineament density located on Figure 5.14 (total length). Areas of low density along the sides of the map cannot be accurately relied upon since they may represent an "edge effect" of the SYMAP interpretation algorithm in that the unit measurement areas (20 x 20 km) are only partially occupied.

The areas of high and low intersection density (Figure 5.15) generally reflect the areas of higher and lower lineament density. In order to provide a clearer structural interpretation of these areas, the intersection density map should be compared with the general lineament map (Figure 4.1 F). A high density area where intersections consist primarily of faults may be structurally more significant than one where third order lineaments, lithological contacts, dikes and circular features intersect. Although third order lineaments merely reflect a poor to fair degree of expression on the Landsat imagery, the structural significance of these areas with many intersecting third order lineaments cannot be ascertained without extensive field checking.

5.2.4.4 Comparison of Density Measuring Approaches

A Pearson Product Moment correlation coefficient (Appendix E) was calculated to compare the data set calculated from total lineament

Table 5.6 - Interpretation of Total Length Contour Density Map

L = Low Density; H = High Density - Areas Located on Figure 5.14

Area (Fig. 4.14)	Surficial Cover	Lineament Type	Interpretation
L1	Clay -corresponds with the "Little Clay Belt"		- two interpretations 1. paucity of structural lineaments 2. masking effect of clay
L2	-thinly covered or exposed bedrock	- mapped faults	- area is contoured as low density because most is water (area centered over Lake Timagami)
L3	"		- one lineament - edge effect and/or incomplete data unit must be taken into account
H1	"	- second and third order	- since most lineaments are second and third order, the structural significance of the area cannot be ascertained
H2	"	- second order - some first order	- lithological contacts may have less structural significance
H3	-ground moraine	- mapped faults	- first order lineaments represent western half of a dominant curvilinear structure (intrusion)
H4	-thinly covered or exposed bedrock	- mapped faults	- since these areas are occupied by a high number of mapped faults they might be considered to be more structurally significant than H1 and H2
H5	"	- mapped faults and second order	- H4 may correspond to structural activity along the Nipissing branch of the Ottawa Valley graben - H5 SYMAP "edge effect" must be taken into account

length per unit area with the data set calculated from total lineament frequency. A correlation coefficient of 0.80 was obtained which indicates the two data sets are quite similar although small differences do exist.

Both maps (Figure 5.13 and 5.14) show essentially the same areas of high and low lineament density which indicates that the areas of higher lineament frequency are also areas of higher absolute length. The differences between the two data sets are reflected in a slightly different spatial arrangement of the contour lines.

For example, in the bottom half of the density contour map calculated from total lineament frequency (Figure 5.13) class five¹ is spatially less extensive than class five on the density contour map calculated from total lineament length (Figure 5.14). Slight differences are probably due to the fact that a few long lineaments measured per unit area may constitute a fairly dense area when their lengths are totalled whereas the actual number of lineaments may yield an area of lower relative density.

Although more evidence is required to justify the superiority of one method over the other, this study would seem to indicate that either method can be used to satisfactorily depict lineament density. Depending on the scale of measurement, the calculation of total frequency is certainly less time consuming and much easier on the eyes.

¹ classes (5 in total) are based on divisions of frequency and length
 i.e. class 1 = x number of lineaments
 or class 1 = x length of lineaments

5.3 Conclusion

It is hoped that an improved understanding of seismo-tectonic relationships within the study area can be gained by depicting the spatial pattern of lineaments and regional structural features. Dominant structural trends have been identified and possible origins of lineaments have been suggested. Lineament density maps have been produced in order to isolate areas of high lineament density and intersection density. Some of these high density areas may represent zones of higher regional seismic risk. In addition, many new, previously unidentified lineaments including curvilinear and circular features have been mapped.

Chapter 6

Summary and Conclusions

6.1 Summary

A series of lineament maps derived from Landsat data has been produced to: 1) evaluate the use of Landsat data and associated processing techniques for the detection of lineaments in a glaciated and vegetated terrain and 2) help provide a clearer picture of regional seismo-tectonic patterns in a 185 by 450 kms area centered on Lake Temiskaming, Ontario.

A 1,000,000 scale general lineament map of the entire study area, produced by visually interpreting the Landsat imagery and by employing analog edge enhancement techniques, has been analysed for lineament trends, origins and densities. Lineament data for the study region have been summarized in graphical, statistical and map form.

Five computer processed digital maps have also been produced using the CCRS program entitled "Landsat Geological Analysis Aid Package" available on the Computer Image Analysis System (C.I.A.S.). This package, which includes a contrast optimized image, linear enhancement product and a textural enhancement product has been used to facilitate the detection of lineaments. The performance of this package has been assessed through a detailed analysis of one of these digital maps (Rib Lake Sub-scene).

An organized methodology indicating how visual and digital analysis of Landsat imagery can be used effectively for the study of structural (and surficial) lineaments has been presented. In addition the environmental and system factors which affect the detectability of lineaments

on Landsat imagery have been identified.

6.2 Evaluation of Interpretation Aids (Analog and Digital)

6.2.1 Photographic Analysis System (PAS)

Although the PAS did not aid in the detection of any new lineaments per se, it did help to confirm the existence of lineaments that were almost imperceptible to the eye. The production of artifacts (spurious lineaments) and the enhancement of cultural lineaments (cut-over and logging roads) seemed to be fairly common with the edge enhancement feature of the PAS. However, such features could be easily identified for elimination by reference to the raw image or collateral data sources.

The transfer of data from the edge enhanced imagery to the raw image was quite tedious since the exact location of individual lineaments on the edge enhancements relative to the raw image was difficult to ascertain.

Image quality is an important parameter to consider when using the PAS. Since it is an electro-optical system, loss of image quality during processing is inherent. If an image that is to be analysed is initially of poor quality then optimal results cannot be expected.

Although only the edge enhancement feature of the PAS was used, a number of different procedures are possible, some of which may prove useful for lineament detection if further investigated. Table 6.1 presents a summary of these procedures.

Table 6.1

Analog Enhancements

- density slicing of Band 6
 - ratioing (7/5)
 - edge enhancement of a 7/5 ratioed image
 - double edge enhancement
 - colour composite (4, 5 and edge enhancement of Band 6)
 - colour composite compiled from various ratioed images (i.e. 7/5, 4/5, 6/5)
-

6.2.2 Digital Processing Techniques

The "Landsat Geological Analysis Aid Package" was a valuable interpretation aid insofar as the number of lineaments detected was much greater than by visual analysis alone. Furthermore, these techniques helped to isolate and enhance subtle linear and circular features by: 1) displaying the imagery at a larger scale on the CRT and, more importantly 2) separating linear features and patterns from background "noise".

This package, which serves as a useful complement to the synoptic overview offered by the visual analysis of smaller scale Landsat image formats, is best utilized for site specific studies in which a fairly detailed picture of the structural fabric of an area is required. Structural data interpreted from the various digital output products can serve as an additional geologic data source in conjunction with geological and geophysical maps. Analysis of the Rib Lake subscene showed that a greater number of lineaments were found on the digital output products than on existing geology maps of the area. Thus digital analysis would also be particularly useful in areas where the geology is not well

known. However, certain terrain limitations discussed in Chapter 4 must be recognized if the package is to be used effectively. A number of improvements to the package can be suggested based on the results of this work.

1. The small size of the high pass directional filters (1×5 , 5×1) resulted in the production of many artifacts which added confusion to the interpretation procedure. A larger filter size (25×25) has been introduced since the current work was undertaken and this is producing useful results (B. Bruce, oral comm.) It is expected that use of a larger filter would result in the generation of fewer artifacts. Furthermore a larger filter may also enable the detection of a greater number of lineaments since features that are oblique to the filter direction (i.e. diagonal rather than strictly horizontal or vertical) may be selectively enhanced.

2. Since the themes (textural complexes) produced were basically the same for all the subscenes, with the exception of Englehart, it may be possible to develop a model to predict the nature of these themes according to specific biophysical environments. Input variables such as vegetation types, topography (slope, aspect), surficial geology and soils could be used to determine the general spectral characteristics of terrain units. Such a model would not only save time by reducing the need for field checking but would also aid the interpreter in establishing basic relationships between textural complexes and selected biophysical environments.

3. Burdick and Speirer (1980) have utilized a preliminary processing measure (filtering program) which inspects any image, whether it be a

ratio, contrast stretched or raw version, one pixel at a time and determines if the pixel is either darker or lighter than the two adjacent pixels. If the pixel is darker it is saved as a black dot; if not, the pixel is blanked out or turned white. A resulting digital map is produced that contains all of the information from the original image pertaining to lineaments. This procedure could serve as a useful preliminary processing measure to the linear extraction process.

4. Although the Versatec printouts of each theme were useful data sources, a high degree of noise did tend to confuse interpretation. One method of consolidating the themes is to use a nearest neighbour filter (presently available on CIAS). Another way of making these themes spatially continuous would be to employ a filter of the type described and successfully used by Burdick and Speirer (1980) that could be moved across a prescribed portion of the data at discrete 5° increments from 5° to 180° (this filter could also be used on the digital output described under item 3).

5. Principal component analysis may yield valuable lineament information; however, the program was not available on the CIAS during the time when data was being processed, thus experimentation with this technique was not possible. A useful technique that has already been implemented is to subject the data to a general purpose transform (GPT) in which three transformations (components) are created. The first component which contains primarily brightness information and accounts for over 90% of the image variance can be contrast enhanced and then filtered (25 x 25 filter). This technique has recently shown promise as an additional lineament enhancement product which can be applied to

Landsat data (Bill Bruce, personal communication).

Hayden (1977) has found that the interpreter is often confronted with too much detail both in a textural and spectral sense. As a result minor features cannot always be detected. Therefore, the second and third components of lower information content may also yield valuable lineament information. Hayden found that in a study done using Landsat imagery of selected regions of Saudi Arabia, the lower order transformations clearly revealed additional linear and circular features which had not been mapped beforehand.

6. A system in which collateral data sources (topographic, geological and geophysical) are digitized and integrated with the output obtained from the digital processing procedures would greatly aid the geologic interpretation process. Such a system is currently under development at CCRS and will be included in the next version of the image analysis package (Bill Bruce, personal communication).

7. Topography is the most important single source of geological information in any image. Slight changes in the morphology of a landscape may yield clues to subsurface structure. Since most lineaments within the subscenes analysed were expressed in the topography, it might be advantageous to filter the contrast stretched Band 6 image in addition to the 7/5 ratio. The 7/5 ratio image is generated to maximize vegetational differences and minimize topographic differences. However, by filtering the contrast stretched image in which topographic information is not suppressed useful lineament information may be obtained.

The reflected light from a solid surface in general is comprised of

two types of information (components): 1) reflection due to variations related to the intrinsic properties of the material (colour, albedo) and 2) variations due to slope (topography). Since ratioing minimizes the topographic component geological information is lost. A method such as the one developed by Eliason et al. (1981) whereby the topographic component of the reflected light could be isolated, enhanced and filtered might prove to be a useful addition to the "Landsat Geological Analysis Aid Package".

6.3 Conclusions

Specific conclusions regarding the usefulness of Landsat imagery for the detection of lineaments in a glaciated and vegetated landscape can be drawn from the results of both the visual and digital analysis.

Landsat imagery is most valuable for the detection of lineaments in areas of thinly covered or exposed bedrock where topographic, drainage and vegetational patterns reflect the underlying structural geology.

The detection of lineaments on Landsat imagery is much more difficult in areas covered by a thick glacial overburden which can conceal underlying structural features. Although lineaments still can be detected, determination of their origin is often complicated by the presence of linear glacial and fluvioglacial features.

Flat and/or marshy terrain may inhibit the detection of lineaments on Landsat imagery. This is demonstrated especially in the analysis of the Rib Lake subscene where the majority of lineaments displayed some form of topographic expression. Topographic expression may be the key to lineament detection on Landsat imagery in that lineaments found by

digital procedures were either detected directly as a result of topographic expression or the prime mode of lineament expression (vegetation/tonal, drainage) was a direct result of the topography.

Based on the results obtained primarily from the Englehart subscene one may expect that the digital techniques would have most limited value in the northern portion of the study area which is characterized by fairly flat marshy terrain. However, it must be stated that the extrapolation of results obtained in one type of biophysical environment to a very different type of environment must be treated with extreme caution. The relationship between specific digital techniques and different aspects of the biophysical setting may change as the environment changes. Analysis of the Englehart subscene revealed that the textural enhancement did enhance non-topographic lineaments (although many of these features were cultural in nature - field boundaries). In the northern portion of the study area where the expression of many lineaments appears to be due primarily to differences in vegetation and moisture (linear fens, bogs) as opposed to topographic variation, the textural enhancement and ratio images may assume relatively greater importance as lineament detection aids. However, whether or not vegetational features reflect the underlying geology is up to the interpreter to determine through the analysis of collateral data sources and field investigation.

Cultural lineaments (roads, field boundaries, mining and forestry activity) present confusing signatures and are enhanced by the PAS and the digital processing techniques, especially the textural enhancement. Careful analysis of topographic maps is required to identify and filter out these types of lineaments.

6.4 Future Research

More research into the application of the "Landsat Geological Analysis Aid Package" in fairly flat areas covered by glacial overburden and vegetation, typical of the middle and northern portion of the study area, is required. Ultimately, a terrain model could be established in which specific enhancement techniques could be matched to specific biophysical environments.

In the last few years much research has been directed toward radar (SLAR and SAR) applications in geology (SURSAT, SEASAT, RADARSAT) and encouraging results have been obtained. It appears that Landsat data and radar data are complementary in nature with Landsat offering spectral characteristics of the terrain while radar highlights morphological characteristics. Future research should focus on an analysis (visual and digital), comparison and integration of both multichannel Landsat D data (30 m resolution) and multiband SAR data.

Emphasis should be placed on the co-registration of remotely sensed data sources (Landsat - MSS, Radar) with geophysical, geochemical and geological data to facilitate lineament interpretation.

APPENDIX E - FORMULA

Formula Used for Calculation of
Pearson Product Moment Correlation Coefficient

$$\frac{n(\sum xy) - (\sum x)(\sum y)}{\sqrt{n(\sum x^2) - (\sum x)^2}(n(\sum y^2) - (\sum y)^2)}$$

map of classes overlain on the image display.

unconformities - a break in sediment deposition and/or geologic structure.

unsupervised classification - a form of digital image analysis whereby pixels having similar spectral signatures are grouped together and identified as being the same although what they actually represent on the ground is unknown.

versatec - computer paper printout (17 grey levels) of an image displayed on the CRT.

Appendix A

Current emphasis on the problem of radioactive waste disposal is focused on the burial of radioactive material in deep underground vaults located in a body of rock that can be relied upon to provide full protection for as long as any part of the waste remains potentially harmful (Classen, 1976). This period may be as long as 250,000 years for some of the longer lived radionuclides (Classen, 1976).

It is vital that several requirements of any geological disposal site be met. The waste must be located in a rock of fairly homogeneous composition that will over the long term remain free of fissures or fractures; otherwise groundwater could seep through such natural channels, interact with the radioactive waste and carry some of it off into the surrounding environment (Classen, 1976). The rock must also be capable of absorbing the emitted heat from the used nuclear fuel. Furthermore, the rock and its immediate surroundings must contain no potentially valuable mineral deposits, and the general burial site must obviously be located in a zone that is seismically stable.

In order that the selected site meet these requirements much geological and physical information, including overall rock structure, lithological and stratigraphic variation, rock quality, the character of specific fracture systems and the long term seismic stability of potential disposal areas must be ascertained. Two types of rock formations are presently being considered as potential recipients for radioactive wastes: salt deposits and large bodies of igneous rock termed plutons. Since plutons are especially abundant in the Canadian shield, which comprises most of Ontario, much research has been directed towards the study of these hardrock masses.

Appendix B

Definitions for Lineament and Lineation

Source: O'Leary et al., 1976

Reference	Definition	Comment
Hobbs (1904)	A lineament is "nothing more than a <i>generally rectilinear earth feature</i> " (p. 485)	Term introduced to characterize spatial relationships of "1) crests of ridges or boundaries of elevated areas, 2) drainage lines, 3) coast lines, 4) boundary lines of formations, or petrographic rock types, or lines of outcrops" (p. 485). Any of these may be joined end to end. Term is scale related: "lineaments . . . (are) rectilinear . . . only in proportion as the scale of the map is small" (p. 486). Lineaments tend to be obscure
Hobbs (1912)	Lineaments are " <i>significant lines of landscape which reveal the hidden architecture of the rock basement</i> (p. 227); " <i>the character lines of the earth's physiognomy</i> " (p. 227)	Features include ravines, valleys, and visible lines of fracture or fault breccia zones but are in every case some surface expression of a buried feature. Many are equivalent to "seismotectonic lines." They are composite features
Sonder (1938)	"The lineament of a region then denotes a definite direction which is contained in the tectonics, the jointing, and the relief" (p. 223)	Used in a general, regional sense, individual features (compare Hobbs, 1904, 1912) are termed "linears"
Wilson (1941)	Lineaments are " <i>straight and gently curving lines</i> " formed by "the great scarps and troughs which cross all the Precambrian rocks" (p. 496)	Emphasized structure: "Their association in definite patterns strongly suggests that they are members of connected systems of faulting" (p. 496). Described as regional features better seen in air photos than on ground
Kaiser (1950)	"A lineament is a <i>straight linear surface feature</i> that is at least many hundreds of feet and commonly many miles long" (p. 1475)	"Lineaments are well shown on aerial photographs and . . . may consist of 1) linear topographic features, either trenches or ridges; 2) linear vegetation patterns; 3) linear patterns of soil color or texture. Gaps and stream segments typically form parts of lineaments" (p. 1475)
Gross (1951)	"The <i>straight line or gently curved physiographic features</i> on the earth's surface are known as linears" (p. 79)	"Linears" generally fault related; synonyms are "topographic linear" and "lineal topographic feature." Used "lineal" as adjectival substitute for "linear." Used "lineation" to refer implicitly to general trend of linears (compare Sonder, 1938)
Kelly (1955)	"In general terms a lineament is a <i>rectilinear feature of considerable extent on the surface of the earth</i> . A tectonic lineament . . . [is] either a general alignment of structural features or a boundary between contrasting structural features" (p. 58)	Lineaments are usually "interrupted or discontinuous features" not readily mapped in the field and are "agreements of boundary or line observed generally on regional maps" (p. 58). Term is usually reserved for "transverse or oblique alignments of one sort or another" (p. 58), but included "in the broadest sense" (p. 58) are features such as the eastern Rocky Mountains
Kupsch and Wild (1958)	No specific definition	Related lineaments to extended faults. Tonal lineaments "are believed to reflect differences in soil moisture resulting perhaps from microrelief" (p. 129). Noted that "linear" is an etymologically undesirable term; suggested use of "linear trends, linear features, or lineaments" (p. 129) instead
Lattin (1958)	A lineament is " <i>a natural linear feature consisting of topographic (including straight stream segments), vegetation, or soil tonal alignments, visible primarily on aerial photographs or mosaics, and expressed continuously or discontinuously for many miles</i> " (p. 569)	Lineaments are expressions of subsurface faults. Defined "fracture trace" as a lineament "expressed continuously for less than one mile" (p. 569), the expression of local jointing or small faults; included "only natural linear features not obviously related to outcrop pattern of tilted beds, lineation and foliation, and stratigraphic contacts . . . included . . . are joints mapped on aerial photograph where bare rock is exposed" (p. 569)
Parkinson in Lupder (1959)	"Any <i>linear feature of the landscape</i> which possesses an abnormal degree of regularity . . . whether straight or gently curving, [is] generally believed to be the surface expression of some structural feature in the bedrock. Experience and careful judgement are required . . . to distinguish a diagnostic linear from random river stretches, hills, and similar results of random erosion" (p. 343)	An implicit definition. "Bedrock linears . . . represent the surface traces of such geologic planar features as fault contacts, joints, and bedding planes" (p. 343). They also represent "one of several structural features" (p. 343), including schistosity, gneissosity, or narrow dikes

Reference	Definition	Comment
Anderson (1915)	Lineation is " <i>a sort of striation visible on practically any well-exposed divisional bedding plane of the granulites. . . . This lineation is sometimes seen to be parallel over wide districts, even with changes of strike</i> " (p. 22)	Definition is collective and restrictive
Cloos (1946)	"Lineation is a descriptive and nongenic term for <i>any kind of linear structure within or on a rock</i> . It includes striae on slickensides, fold axes, flow lines, stretching, elongate pebbles or ooids, wrinkles, streaks, intersections of planes, linear parallelism of minerals or components, or any other kind of linear structure of megascopic, microscopic, or regional dimensions" (p. 1)	"On a large scale [sic] lineations can be seen on maps in the trends of folds or systems of folds like the Alps, the Appalachians, or the Andes" (p. 1). Definition is comprehensive, exhaustive, but equivocal
Fairbairn (1949)	" <i>Parallelism of linear elements shows as lineation</i> " (p. 5)	Definition is collective and related entirely to petrofabrics
Blanchet (1957)	"... by the term <i>fracture</i> is meant the generally abundant, natural lineations discernible on aerial photographs" (p. 1748)	Features have "marked rectilinear character" (p. 1748). Recognized two types: macrofractures and microfractures. Macrofractures are generally longer than 3.2 km (2 mi). Definition is generic: "macrofractures . . . have been generated at the level of the basement, . . . the majority of microfractures have their origin above the half-way point in the sedimentary column"
Compton (1962)	"A lineation is a <i>preferred (subparallel) orientation of one or more kinds of linear features</i> " (p. 306)	Features include "crenulations in schist, intersections of cleavages, sedimentary structures, etc." (p. 307). "Especially useful are areas of folds whose closure can be observed in large outcrops or closely spaced groups of outcrops" (p. 307)
Turner and Weiss (1963)	"All true lineations are <i>penetrative discontinuities</i> " (p. 31), that is, ". . . discontinuities in structure . . . repeated at distances so small, compared with the scale of the whole crystal [or rock], that they can be considered to pervade it uniformly and be present at every point" (p. 21)	"... the arrangement of grain boundaries in planar parallel orientation imparts to the whole aggregate a penetrative planar structure . . . and . . . a penetrative discontinuity . . . is statistically present in every sample of the fabric" (p. 22). "Penetrative surfaces" ("S-surfaces") include foliation, bedding, and, at certain scales, joints. Features that define lineation, singly or in combination, include "1. Parallel elongate aggregates of individual minerals forming parallel streaks, trains, or bodies of cylindrical prismatic or spindle-shaped form . . . Grains . . . may . . . be equant, tabular, or prismatic. To this general category also belong elongate rock fragments and ellipsoidal ooliths and microfossils whose inequidimensional outlines are due to deformation. 2. Linear preferred orientation of boundaries of prismatic or tabular crystals. 3. Axes of microcrenulations of a set of S-surfaces. . . . 4. Intersection of two or more corazonal S-surfaces . . ." (p. 101)
Dennis (1967)	"Lineation includes <i>all linear structures in rocks without regard to origin</i> . The term excludes purely superficial features, such as glacial striations" (p. 103)	Compare Cloos (1946)
Billings (1972)	"Lineation is the result of the <i>parallelism of some directional property in the rock</i> , such as the long axes of hornblende crystals. Platy minerals or spherical grains may be strung out in lines to produce a lineation" (p. 328)	"Primary lineation" is caused in igneous rocks by flow of magma or lava, and in sedimentary rocks by depositional agents. "Secondary lineation" includes features superimposed on rocks by one or more phases of deformation following crystallization or deposition. Features include fold axes, "stretched" pebbles, crenulated foliation, mineral orientation, intersection of bedding and cleavage, slickenside, bonding, rodding, and millon structure. Lineation ranges in development from the fabric of nearly homogeneous rocks to the anisotropy of certain intensely deformed rocks
AGI Glossary of Geology (Gary and others, 1972)	Sedimentary: Lineation is " <i>any linear structure, of megascopic or microscopic nature, on or within a sedimentary rock</i> " (p. 408) caused by primary deposition. Structural: Lineation is " <i>a general nongenic term for any linear structure in a rock of whatever scale</i> " (p. 409)	Definitions are equivocal. Meaning of "nongenic" is unclear

Note: Key elements of definitions are in italics (ours).

Reference	Definition	Comment
Hills (1963)	"Megalineament is a term for large, somewhat vague, controversial lineaments of continental dimensions" (p. 460)	Megalineaments form definite patterns "over areas as large as subcontinents or ocean basins" (p. 460) (compare Hobbs, 1904, 1912)
Dennis (1967)	Lineaments are " <i>rectilinear or gently curved alignments of topographic features</i> on a regional scale, generally judged to reflect crustal structure" (p. 102)	Lineament "most commonly refers to regional features; 'linear' has a more local connotation and is used for lines of unsure origin on aerial photographs" (p. 103)
Billings (1972)	"In the broad sense of the word, a lineament is a <i>line resulting from natural processes</i> that may be observed or inferred" (p. 208). "A lineament is expressed on the surface of the earth as a relatively straight line" (p. 419). "The lineament may be a long depression or a long ridge" (p. 208)	Lineaments presumably represent "the trace of a fracture or fracture systems on the surface. Most lineaments are caused by steeply dipping faults or joint systems" (p. 419), but "the exact cause is unknown. The term may be used even if the cause is well established" (p. 419). They may be easily confused with ridges and valleys resulting from the erosion of steeply dipping interbedded strata of varying hardness" (p. 208). Noted that the term "linear" is sometimes misused for "lineament"
Gay (1972)	No specific definition	Applied concept to aeromagnetic maps. Lineament is a "disruption in the contour pattern" (p. 5) manifested by two or more "elements": (1) termination of highs, (2) termination of lows, (3) change in contour gradient, (4) linear (straight) contour patterns. Elements may not be contiguous
Brock (1972)	"A lineament is defined briefly as a <i>geological or topographical alignment</i> too precise to be fortuitous" (p. 187)	Types include "seismic," "coastal," and "island arc lineaments." Scale is emphasized: "If it does not show up on a map it is not a lineament" (p. 188). They occur on all scales from air photos to outlines of continents (for example, the Andes, which are "rectilinear for 2,000 miles"; p. 187). Cited a tectonic relationship, but noted that no specific structure need be ascribed
AGI Glossary of Geology (Gary and others, 1972)	Photogeologic (compare Allum, 1966, p. 31): "A lineament is <i>any line on an aerial photograph, that is structurally controlled</i> . . . the term is widely applied to lines representing beds, lithologic horizons, mineral bandings, veins, faults, joints, unconformities, and rock boundaries" (p. 408) Tectonic: Lineaments are " <i>straight or gently curved lengthy features of the earth's surface, frequently expressed topographically as depressions or lines of depressions</i> " (p. 408)	May also be manifested by stream beds and alignments of vegetation, and so forth Have varied origins — for instance, "faults, aligned volcanoes, and zones of intense jointing . . . but the meaning of others is obscure . . . and their origins may be . . . purely accidental" (p. 408)
Gay (1973)	"Basement fracture lineament" (p. 101): a lineament observed directly on "basement" or its shallow cover "Joint lineament" (p. 101): lineament caused by jointing not coincident with basement fractures "Fracture trace lineament" (p. 101): compare Blanchet, "macrofracture," Lattman, "photogeologic lineament"	Generally a direct manifestation of basement fractures (or faults) Generally less than 1 to 2 km long; equivalent to Blanchet's (1957) "microfractures" and Lattman's (1958) "fracture traces." Terminology and usage presumes an accurate knowledge of structural geology

Note: Key elements of definitions are in *italics* (ours).

APPENDIX C

Classification System

- Fault	}	geology maps
- Dike		
- Lithological Contact		
- Landsat lineament	}	any straight to curvilinear
feature not identified as a
fault, dike or lithological
contact
- Degree of Expression
(subjective categorization)		
	}	- 1st Order - strongly expressed
		- 2nd Order
		- 3rd Order - weakly expressed

Appendix D-1

Computer Programs Used to Generate
Lineament Statistics

```

10 REM-PROGRAM LINIMENT
20 REM-PROGRAM TO COMPUTE LINIMENT LENGTHS AND AZIMUTHS
30 DIM X(1000),Y(1000),J(16)
40 INPUT "ENTER TECTONIC UNIT NUMBER = ",N
50 C$="TECT"+N
60 IF FILELEN(C$)=0 THEN GOTO 40
70 OPEN #1,C$
80 P=0
90 F=180/3.14159265
100 INPUT "ENTER 1 FOR UPDATE; ELSE PRESS RETURN = ",A
110 IF LEN(A)=0 THEN GOTO 105
120 FOR P=1 TO 10000 \ IF TYF(1)=0 THEN GOTO 102 \ READ #1,G \ NEXT G
122 P=P+1 \ P=P/3
130 P=P+1
140 "ENTER LINIMENT CODE FOR LINIMENT #",P
150 GOSUB 2000 \ GOSUB 1000
160 IF P=1 THEN C$="1" \ IF P=2 THEN C$="2" \ IF P=3 THEN C$="3" \ IF P=4 THEN C$="4" \ IF P=5 THEN C$="5" \ IF P=6 THEN C$="6" \ IF P=7 THEN C$="7" \ IF P=8 THEN C$="8"
170 IF P=8 THEN C$="1"
180 "NEW LINIMENT = CODE",C$," SELECTED"
190 "DIGITIZE POINTS - PRESS RETURN TO END LINIMENT, 12 TO END"
200 J=0 \ L=0
210 GOSUB 2000
220 GOSUB 1000
230 IF P=2 THEN GOTO 230
240 IF P=4 THEN GOTO 240
250 J=J+1
260 X(J)=X1 \ Y(J)=Y1
270 GOTO 180
280 "ENTER TWO POINTS TO DETERMINE AZIMUTH"
290 GOSUB 2000
300 "DIGITIZE POINT 1" \ GOSUB 1000 \ A=X1 \ B=Y1
310 GOSUB 2000
320 "DIGITIZE POINT 2" \ GOSUB 1000 \ E=X1 \ D=Y1
330 K1=A-E \ K2=B-D
340 IF K1=0 THEN GOTO 290
350 D=90 \ GOTO 300
360 D=ATN(K2/K1) \ D=D*F
370 IF D<0 THEN D=D+180
380 FOR K=P TO J-1
390 F1=X(K+1) \ F2=X(K) \ F3=Y(K+1) \ F4=Y(K)
400 L=L+SQRT((F1-F2)*(F1-F2)+(F3-F4)*(F3-F4))
410 NEXT K
420 "LINIMENT = LENGTH",L," MM. AZIMUTH=",D," DEGREES"
430 "-----"
440 WRITE #1,C$,L,D
450 GOTO 105
460 CLOSE #1 \ END
1000 INPUT " ",D$
1010 M1=VAL(D$(1,1))
1020 X1=VAL(D$(2,8))
1030 Y1=VAL(D$(10,16))
1040 RETURN
2000 "CHRS(7)", \ RETURN

10 REM- LINIMENT STATISTICS PROGRAM
20 REM- APRIL 15, 1981
30 REM
40 GOSUB 300
50 "==== LINIMENT STATISTICS ====="
60 INPUT "ENTER UNIT NUMBER = ",N
70 INPUT "ENTER INTERVAL VALUE = ",F
80 INPUT "ENTER CODE = ",C$
90 A$="TECT"+N
100 DIM F(16,100),M(16),S(16),L(16)
110 OPEN #1,A$
120 IO=180/F
130 IF TYF(1)=0 THEN GOTO 140
140 J=0
150 READ #1,C$,L,A
160 IF C$=0 THEN GOTO 180
170 IF C$=C$ THEN GOTO 130
180 FOR J=1 TO 15
190 J=J+F \ E=D-F
200 IF A=E AND A=D THEN GOTO 210 ELSE GOTO 220
210 S(J)=S(J)+1 \ L(J)=L(J)+L \ F(J,S(J))=L \ EXIT 130
220 NEXT J
230 GOTO 130
240 "TECTONIC UNIT #",N," CODE #",C$
250 "INTERVAL = " \ FREQUENCY \ TOT LENGTH \ MEAN \ STD DEV"
260 J=0
270 FOR K=1 TO 15
280 J1=J+F \ J1=J1-F
290 IF S(K)=0 THEN GOTO 280
300 M(K)=L(K)/S(K)
310 NEXT K
320 M5=S(1)
330 IF M5=0 THEN S(K)=1
340 T1=B1/S(K) \ T1=SQRT(T1)
350 "12,J1" \ "11,TAN(18-M5,TAN(30+L(K)+TAN(45+M(K)+TAN(60+T1)
360 NEXT K
370 END
380 "CHRS(12)", \ FOR Y=1 TO 15 \ NEXT Y \ RETURN

```

Appendix D-2

Printout of Lineament Data

Tec 1 Grenville Province
Tec 2 Cobalt Embayment
Tec 3 Pontiac Gneiss Belt
Tec 4 Abitibi Volcanic Belt
Tec 5 Kapuskasing Belt
Tec 6 Opatika Belt

Actual Azimuth Classes 0 - 9.99
 10 - 19.99 etc.

 0 - 19.99
 20 - 39.99 etc.

On the Printout $0^{\circ} = 90^{\circ}$ (east) in text
 $180^{\circ} = -90^{\circ}$ (west) in text

TECTONIC UNIT #1 INTERVAL	CODE # FREQUENCY	TOT LENGTH	MEAN	STD DEV
0 - 10	3	11.27341	3.1578753	1.7628896
10 - 20	10	67.481766	6.7461766	5.6162896
20 - 30	17	106.97053	6.2823841	3.9420251
30 - 40	12	67.572459	5.6316383	2.273591
40 - 50	14	74.192104	5.2996507	3.3081641
50 - 60	17	124.70644	7.6297906	4.0591093
60 - 70	17	82.95189	7.5410809	6.5302316
70 - 80	5	89.451122	9.9390131	10.050183
80 - 90	11	60.961185	5.5419255	1.9124396
90 - 100	18	157.50089	8.7500494	7.6019143
100 - 110	9	55.100872	6.1223191	4.0855192
110 - 120	16	115.77361	7.2358906	4.8253091
120 - 130	20	160.68702	8.0342515	4.6174264
130 - 140	30	212.21459	7.0738197	7.8426053
140 - 150	24	287.01514	11.958964	10.39542
150 - 160	20	374.54592	11.915376	15.067077
160 - 170	20	276.32527	13.816268	13.698417
170 - 180	10	219.61891	21.561891	26.779144

TECTONIC UNIT #1 INTERVAL	CODE # FREQUENCY	TOT LENGTH	MEAN	STD DEV
0 - 20	13	18.755193	4.0561072	4.6541141
20 - 40	20	174.54206	8.0187138	3.5646407
40 - 60	31	205.90154	6.577464	5.14400
60 - 80	20	172.40301	6.620151	6.3862034
80 - 100	20	216.46107	7.0311748	7.2541664
100 - 120	25	170.87447	6.8546794	4.6710511
120 - 140	50	272.90163	7.4580216	6.706416
140 - 160	53	661.5011	12.482285	12.166921
160 - 180	30	495.94426	16.531475	20.394172

TECTONIC UNIT #2 INTERVAL	CODE # FREQUENCY	TOT LENGTH	MEAN	STD DEV
0 - 10	7	52.379336	7.4827626	4.4368196
10 - 20	10	75.282734	7.5282734	6.1255319
20 - 30	12	122.64484	6.179456	5.9573642
30 - 40	12	67.913606	6.7625922	3.7741571
40 - 50	19	135.97615	6.1640076	3.6459988
50 - 60	22	160.51687	6.9789487	4.1592556
60 - 70	22	201.91997	9.1781807	4.1737319
70 - 80	23	144.48908	6.2821336	3.1572448
80 - 90	31	278.81625	6.993679	5.740021
90 - 100	30	213.17268	7.105716	4.1520409
100 - 110	18	188.46203	10.476117	9.6687519
110 - 120	10	60.826701	6.0628701	4.6427031
120 - 130	22	273.4277	10.426532	13.52853
130 - 140	21	322.45557	15.355027	21.602621
140 - 150	14	127.56541	9.111815	6.1152522
150 - 160	23	432.60483	16.808906	17.616145
160 - 170	11	190.39203	17.306457	26.634834
170 - 180	6	56.815216	5.9692027	3.9631488

TECTONIC UNIT #2 INTERVAL	CODE # FREQUENCY	TOT LENGTH	MEAN	STD DEV
0 - 20	17	127.66207	7.5095335	6.8515756
20 - 40	26	210.60645	7.5217304	5.1113004
40 - 60	42	276.4931	6.587164	3.9163927
60 - 80	45	346.40901	7.6979788	3.9632116
80 - 100	61	451.95295	6.6652971	7.588484
100 - 120	28	249.28074	6.9635407	5.6443066
120 - 140	43	552.88326	13.857751	17.491704
140 - 160	37	560.17024	15.136736	15.138507
160 - 180	17	250.20814	14.718132	24.210804

TECTONIC UNIT #3 INTERVAL	CODE # FREQUENCY	TOT LENGTH	MEAN	STD DEV
0 - 10	8	98.68689	12.335661	8.0706304
10 - 20	8	47.257763	5.2509626	3.049695
20 - 30	12	75.367191	6.2805993	2.587937
30 - 40	8	67.374707	12.171838	2.8820164
40 - 50	10	70.047747	6.367977	2.5774807
50 - 60	10	82.028297	8.2678397	5.9118034
60 - 70	12	242.32217	20.193514	19.862627
70 - 80	14	384.39701	16.016542	13.223318
80 - 90	5	60.857011	12.171402	8.4136497
90 - 100	6	44.236692	7.372762	2.754467
100 - 110	7	74.87777	4.609777	7.011077
110 - 120	2	20.46158	6.487167	6.651997
120 - 130	6	36.12264	6.420477	1.2257653
130 - 140	6	27.38194	4.230336	4.8661413
140 - 150	7	36.49866	7.2997891	4.1384706
150 - 160	1	10.670253	10.070253	0
160 - 170	6	29.462511	4.8934187	2.398844
170 - 180	4	16.173906	4.043476	1.2511176

TECTONIC UNIT 43	CODE # 0				
INTERVAL	FREQUENCY	TOT LENGTH	MEAN	STD DEV	
0 - 20	17	145.54465	8.3849764	6.934087	
20 - 40	20	172.7419	8.637005	6.0951632	
40 - 60	21	152.07605	7.241756	4.5783864	
60 - 80	36	626.71919	17.408866	10.87711E	
80 - 100	11	105.0937	9.5539777	6.482282	
100 - 120	10	60.414447	6.0414447	4.4444444	
120 - 140	12	63.904826	5.3254022	5.0508405	
140 - 160	8	46.569199	7.7615352	3.9168787	
160 - 180	10	45.534417	4.5534417	2.062076	

TECTONIC UNIT 44	CODE # 0				
INTERVAL	FREQUENCY	TOT LENGTH	MEAN	STD DEV	
0 - 10	11	83.392462	7.5811347	3.1908599	
10 - 20	16	154.90296	7.806435	2.9136821	
20 - 30	29	202.55608	7.0141457	4.3213794	
30 - 40	27	190.40203	7.051927	4.232209	
40 - 50	22	136.76438	6.3074718	4.0748633	
50 - 60	20	143.39386	6.5179027	4.6172378	
60 - 70	13	95.477505	7.3444235	4.8069552	
70 - 80	24	205.44427	8.5601779	4.7994606	
80 - 90	34	306.78081	9.022975	6.3840509	
90 - 100	22	534.41716	10.277252	9.1212413	
100 - 110	34	463.21343	13.623924	11.662066	
110 - 120	15	182.14116	9.4760773	5.684333	
120 - 130	17	240.50364	14.147282	13.231666	
130 - 140	16	129.31444	8.0821013	5.4502383	
140 - 150	14	119.9597	8.4971214	2.6165497	
150 - 160	6	33.555316	5.592553	4.3044796	
160 - 170	7	46.723298	6.6747564	1.9513126	
170 - 180	5	56.150615	11.236123	6.7275604	

TECTONIC UNIT 44	CODE # 0				
INTERVAL	FREQUENCY	TOT LENGTH	MEAN	STD DEV	
0 - 20	27	208.29544	7.7146459	3.0316907	
20 - 40	55	392.95812	7.1446931	4.278807	
40 - 60	44	282.15825	6.4126875	4.3557742	
60 - 80	37	300.92178	8.1330211	4.837042	
80 - 100	86	841.19799	9.7813719	6.1727688	
100 - 120	49	605.35458	12.354175	10.389251	
120 - 140	33	369.81824	11.206614	10.668978	
140 - 160	20	152.51502	7.625751	3.481772	
160 - 180	12	102.87391	8.5728258	5.1110977	

TECTONIC UNIT 45	CODE # 0				
INTERVAL	FREQUENCY	TOT LENGTH	MEAN	STD DEV	
0 - 10	3	29.063297	9.687796	3.8725394	
10 - 20	5	54.159562	10.831412	4.532072	
20 - 30	1	8.578276	8.578276	0	
30 - 40	2	11.75923	5.879615	2.4133241	
40 - 50	6	64.605686	7.1744046	4.6276217	
50 - 60	6	41.367815	6.8946308	2.089816	
60 - 70	7	49.953092	7.136156	5.952066	
70 - 80	7	39.630024	5.646756	2.3076982	
80 - 90	20	70.042048	7.0084096	3.1765307	
90 - 100	4	28.440399	7.1100998	2.5785627	
100 - 110	1	5.3338642	5.3338642	0	
110 - 120	1	4.2566042	4.2566042	0	
120 - 130	1	10.121911	5.0659511	3.3063851E-02	
130 - 140	1	6.2008644	6.2008644	0	
140 - 150	0	0	0	0	
150 - 160	0	0	0	0	
160 - 170	0	0	0	0	
170 - 180	0	0	0	0	

TECTONIC UNIT 45	CODE # 0				
INTERVAL	FREQUENCY	TOT LENGTH	MEAN	STD DEV	
0 - 20	8	83.202999	10.40287	4.3321824	
20 - 40	6	48.925976	8.1654947	4.1054506	
40 - 60	13	176.46521	13.728407	17.179361	
60 - 80	13	71.370907	7.0247807	4.5941600	
80 - 100	12	70.472677	5.8726895	2.811477	
100 - 120	5	33.774253	6.7548106	2.4132077	
120 - 140	3	14.486345	4.828801	1.33547948	
140 - 160	1	6.2008644	6.2008644	0	
160 - 180	0	0	0	0	

TECTONIC UNIT INTERVAL	% FREQUENCY	CODE # 0	TOT LENGTH	MEAN	STD DEV
0 - 10	5		47.115515	9.423103	7.2528068
10 - 20	3		15.784765	5.2615883	1.1071077
20 - 30	0		0	0	0
30 - 40	8		55.085044	6.8856311	2.1688169
40 - 50	8		53.974356	9.3304942	6.4251676
50 - 60	6		68.622379	8.5777974	4.0334717
60 - 70	9		55.685079	4.187221	1.7808616
70 - 80	7		67.151967	9.5931381	5.1233629
80 - 90	16		209.64929	11.002594	7.1504558
90 - 100	47		514.74678	10.943546	10.069546
100 - 110	36		317.14291	8.3458681	7.9502044
110 - 120	15		135.36619	9.0244127	8.4204363
120 - 130	12		78.817044	6.5680874	3.1106808
130 - 140	16		173.41249	10.838281	5.6631404
140 - 150	10		54.473861	5.4473861	2.178294
150 - 160	0		0	0	0
160 - 170	0		0	0	0
170 - 180	0		0	0	0

TECTONIC UNIT INTERVAL	% FREQUENCY	CODE # 0	TOT LENGTH	MEAN	STD DEV
0 - 20	8		62.90028	7.862535	6.1151936
20 - 40	8		55.085044	6.8856311	2.1688169
40 - 60	17		152.59674	8.9762788	5.4454278
60 - 80	16		122.83704	7.677315	4.0152907
80 - 100	66		723.39608	10.960547	9.3238386
100 - 120	53		452.5091	6.5379071	8.071836
120 - 140	28		252.22954	9.0081974	5.1902777
140 - 160	10		54.473861	5.4473861	2.178299
160 - 180	0		0	0	0

APPENDIX E - FORMULA

Formula Used for Calculation of
Pearson Product Moment Correlation Coefficient

$$\frac{n(\sum xy) - (\sum x)(\sum y)}{\sqrt{n(\sum x^2) - (\sum x)^2} (n(\sum y^2) - (\sum y)^2)}$$

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MAPS

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1:250,000 31L - North Bay
 31M - Ville Marie
 32D - Noranda-Rouyn
 32E - Upper Harricanaw
 32L - Lower Harricanaw
 41-1 - Sudbury
 41-P - Gogama
 42-A - Timmins
 42-H - Cochrane
 42-I - Moose River

1:500,000 31N.W. - Upper Ottawa River
 32S.W. - Noranda - Waswanipi
 41N.E. - Chapleau - Sudbury
 42S.E. - Hearst - Cochrane
 42N.E. - Moosonee

1:125,000 31 M/N.W. - New Liskeard
 31 M/S.W. - Haileybury

B. Geology

- Ontario Geological Survey 1:253,440 series

Maps 2361 - Sudbury - Cobalt
 2205 - Timmins - Kirkland Lake
 2161 - Coral Rapids - Cochrane Sheet
 2171 - Moosonee Sheet
 2166 - Hearst - Kapuskasing

- Ontario Dept. of Mines 1:1,013,760 compilation

East Central Sheet - Map 2198

- Quebec Natural Resources - 1:63,360

- Quinze Lake - Barriere Lake Area - No. 1643
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- by county - Coleman Best
Kittson Chambers
Lorrain Strathy
Brigstocke Cassels
Gillies-Limit
Banting

- Ontario Dept. of Mines - 1:1,013,760 - East Central Compilation Sheet

A. October 19/70 - 1:36,000, Roll #22092 - Prints 5 to 59
Roll #22091 - Prints 110 to 155

B. May 16/80 - 1:50,000, Roll #25419 - Prints 48 to 63
Roll #25418 - Prints 2 to 10, 30 to 37

obtained from N.A.P.L. (National Air Photo Library), Ottawa

-NORTHEAST ARM SUBSCENE
DIGITAL LINEAMENT MAP

NEA UMM WATER MAP
TOP LEFT (9 9)
SCALE 1 : 125000
THEMES: 7

1 of

-NORTHEAST ARM SUBSCENE- Fig. 4.6
DIGITAL LINEAMENT MAP

29

- 3 of
- Mapped Fault
 - - - - - Mapped Dike
 - - - - - Landsat Lineament
 - Lithological Contact
 - . . . - Grenville Front
 - L Low Density (see table 4.4)

- Mapped Fault
- - - Mapped Dike
- - - Landsat Lineament
- ... Lithological Contact
- Grenville Front
- Low Density (see table 4.4)

4 of 4

RIB LAKE SUBSCENE SURFICIAL EXPRESSION OF LINEAMENT

RIB LAKE WATER MAP
TOP LEFT (0, 0)
SCALE 1 : 125000
THEMES: 7

RIB LAKE SUBSCENE
SURFICIAL EXPRESSION OF LINEAMENTS

Fig. 4.8

——— Combination (Topography/Drainage)
 - - - Ridge, Hill
 - - - Valley

- - - Drainage
 No Exposed
 T Except Enhanced
 1-6 Circular (see to

3 of 1

3

— Combination (Topography/Drainage)
 — Ridge, Hill
 - - - Valley

- · - · - Drainage
 No Expression

T Exceptionally Strong Textural Enhancement (see section 4.4)
 1-6 Circular Features (see table 5.5)

-TEE LAKE SUBSCENE-
DIGITAL LINEAMENT MAP

TEELUMH WATER MAP
TOP LEFT (0, 0)
SCALE 1 : 125000
THEMES: 7

1 of

-TEE LAKE SUBSCENE-
DIGITAL LINEAMENT MAP

Fig. 4.10

3 of 1

- Mapped Fault
- - - Landsat Lineament
- Epicentre Area (Tee Lake Earthquake -1935)
- Lithological Contact
- L Low Density (see table 4.4)
- 1 Circular Feature (see section 5.2.3.1)

- Mapped Fault
- Landsat Lineament
- Epicentre Area (Tee Lake Earthquake -1935)
- Lithological Contact
- L Low Density (see table 4.4)
- 1 Circular Feature (see section 5.2.3.1)

- LAKE ST. AMAND SUBSCENE -
DIGITAL LINEAMENT MAP

STANL. UMM WATER MAP
TOP LEFT (0, 0)
SCALE 1 : 125000
THEMES: 7

1 of

- LAKE ST. AMAND SUBSCENE -
DIGITAL LINEAMENT MAP

Fig. 4.11

29

Landsat Lineament

L

Low Density (see table 4.4)

----- Landsat Lineament
L Low Density (see table 4.4)

RIB L. UNH WATER MAP
TOP LEFT (0. 0)
SCALE 1 : 125000
THEMES: 7

RIB LAKE SUBSCENE LINEAMENTS DERIVED FROM AIR PHOTO ANALY

LINE

LY

RIB LAKE SUBSCENE
LINEAMENTS DERIVED FROM AIR PHOTO ANALYSIS (B/W)

Fig. 4.7

— Lineaments

Lineaments

RIB LAKE SUBSCENE
LINEAMENTS DERIVED FROM GEO

RIB LAKE WATER MAP
TOP LEFT (0 0)
SCALE 1 : 125000
THAMES 7

104

RIB LAKE SUBSCENE
LINEAMENTS DERIVED FROM GEOLOGY MAPS

Fig. 4.4

29

- 3 of
- Fault
 - - - - Dike
 - ★ Identification Mark (see section 4.3.2.1)

Source : 1. Ontario Geological Survey - Map 2361 - Sudbury - Cobalt
2. Ontario Dept. of Mines - Map 2198 - Ontario Geological Map East Central S

1. On
2. On

- Fault
- - - Dike
- ★ Identification Mark (see section 4.3.2.1)

4 of 4

1. Ontario Geological Survey - Map 2361 - Sudbury - Cobalt
2. Ontario Dept. of Mines - Map 2198 - Ontario Geological Map East Central Sheet

RIB L. UNK WATER MAP
TOP LEFT (0, 0)
SCALE 1 : 125000
THEMES: 7

RIB LAKE SUBSCENE
LINEAMENTS DERIVED FROM GENER
LINEAMENT MAP (1:1,000,000 - VISUAL

10f

RIB LAKE SUBSCENE

Fig. 4.9

LINEAMENTS DERIVED FROM GENERAL LANDSAT
LINEAMENT MAP (1:1,000,000 - VISUAL ANALYSIS)

- Mapped Fault
 - - - - Mapped Dike
 - - - - 2nd Order
 - 3rd Order
- } Landsat Lineaments

3 of

- Mapped Fault
- - - - Mapped Dike
- - - - 2nd Order } Landsat Lineaments
- 3rd Order }

4 of 4

- MAXAM LAKE SUBSCENE -
DIGITAL LINEAMENT MAP

MAXL UMM WATER MAP
TOP LEFT (0, 0)
SCALE 1 : 125000
THEMES: 7

104

- MAXAM LAKE SUBSCENE -
DIGITAL LINEAMENT MAP

Fig. 4.5

37

- Mapped Fault
- - - - - Mapped Dike
- Landsat Lineament
- Lithological Contact
- - Grenville Front
- L Low Density (see table 4.4)

- Mapped Fault
- - - - - Mapped Dike
- - - - - Landsat Lineament
- Lithological Contact
- ····· - Grenville Front
- L Low Density (see table 4.4)

4 of 4

RIB LAKE WATER MAP
TOP LEFT (0. 0)
SCALE 1 : 125000
THEMES: 7

-RIB LAKE SUBSCENE - DIGITAL LINEAMENT MAP

1 of

-RIB LAKE SUBSCENE -
DIGITAL LINEAMENT MAP

Fig. 4.2

- Mapped Fault
- - - - - Mapped Dike
- - - - - Landsat Lineament
- Lithological Contact
- L Low Density (see table 4.4)

3 of

- Mapped Fault
- - - Mapped Dike
- - - Landsat Lineament
- Lithological Contact
- L Low Density (see table 4.4)

4 of 4

RIB LAKE SUBSCENE
DIGITAL DATA SOURCES

RIB LAKE WATER MAP
TOP LEFT (0, 0)
SCALE 1 : 125000
THEMES: 7

1 of

RIB LAKE SUBSCENE
DIGITAL DATA SOURCES

Fig. 4.3

3 of 1

—————	Combination of Data Sources	—————	Theme
—————	Water Map	—————	"
-----	Contrast Stretch	-----	"
.....	Ratio		"
.....	High Pass Filter		"
			"

—————	Combination of Data Sources	—————	Theme 1
———	Water Map	———	" 2
-----	Contrast Stretch	-----	" 3
.....	Ratio		" 4
.....	High Pass Filter		" 5
			" 6

Textural Enhancement

4 of 4

FIG. 1
FOREST

29

REGIONS

WEST
GREEN

WEST
FOREST

37

BOREAL P
PREDOMINANT

49°

48°

47°

GREAT LAKES - ST

40f

5 of 1

BOREAL FOREST PREDOMINANTLY FOREST

4

7

8

9

FOREST

WERRENCÉ FOREST

——— Forest Region Boundary
 - - - Forest Section Boundary

- 4e Sudbury - North Bay
- 4b Algonquin - Pontiac
- 9 Timagami
- 8 Haileybury Clay
- 7 Missinaibi - Cabonga
- 5 Hudson Bay Lowland
- 4 Northern Clay

TEMISKAMING
 SCALE

14 of

81°

U.T.M. PROJECTION

80°

79°

TEMISKAMING AREA

SCALE 1:1,000,000

Source -

Forest Regions of Canada
Canadian Forestry Service
1972. Forestry Information
Forestry Branch, 1956.

104

FIG.2.1

STUDY AREA

29

STUDY AREA LOCATION

ICATION

3 of

407

49°

48°

LA M ENC

AMMENT DENSITY CONTOUR MAP
(LENGTH PER 20x20 km GRID SQUARE)

4

40f

50°

49°

48°

AREA

100

9 of 9

FIG.4.1

LANDSAT L NI

29

This is a detailed map of the Saginaw River and its tributaries. The map is oriented with North at the top. The Saginaw River flows from the top center towards the bottom right. Major tributaries include the Kalamazoo River (top left), Raisin River (top center), Tittabawassee River (bottom left), and Huron River (bottom right). The map shows numerous islands and lakes, including Lake Huron, Lake Michigan, Lake St. Clair, and Lake Erie. Settlements and towns are marked with dots and labeled, such as Saginaw, Bay City, and Port Huron. The map includes a coordinate grid with latitude and longitude markings. The latitude ranges from 42° to 46° North, and the longitude ranges from 82° to 80° West. The map is titled 'SAGINAW RIVER' in large, bold letters across the center.

3 of 3

49°

48°

40

---	1st. Order Lineament	} Degree of Expression
- - -	2nd. Order Lineament	
	3rd. Order Lineament	

—	} Mapped Fault
- - -	
---	Mapped Dike
	Lithological Contact
	Surficial Lineament (Esker).

U.T.M.

TEMISKAM

SCALE

142

81° U.T.M. PROJECTION 80° 79°

TEMISKAMING AREA

SCALE 1:1,000,000

8 of 1

GNEISS

CTION

IG AREA

1,000

100

9 of 9

LINEAMENT INTERSECTION DENSEC

104

FIG. 5.15

27

SECTION DENSITY MAP (20 x 20 km GRID SQUARE)

5
MAP (20x20 km GRID SQUARE)

49°

48°

40f

TEMISKAMING

6 Classes - Minimum = 0 Intersections
 - Maximum = 11 Intersections

Contour Interval = 1.83 Intersections

----- Areas of uncertain interpretation
 due to surficial cover

144

81° 80° 79°

U.T.M. PROJECTION

TEMISKAMING AREA

SCALE 1:1,000,000

8 of

This map illustrates the Saginaw River watershed, a major water system in Michigan. The Saginaw River is shown as a prominent feature, originating in the north and flowing southward. Key tributaries include the Kalamazoo River, Raisin River, and Shiawassee River. The map also shows the river's proximity to Lake Huron and Lake Michigan. Various geographical features, such as the Kalamazoo River, Raisin River, and Shiawassee River, are labeled. The map includes a coordinate grid with latitude and longitude markings, and a scale bar indicating distances in miles.

3 of

GNEISS
BELT

KAPUSKASING BELT

49°

SUPERIOR P

ABITIBI VOLCANIC

48°

WAWA VOLCANIC
AND PLUTONIC

COB

407

SUPERIOR PROVINCE

ABITIBI VOLCANIC BELT

PONTIAC GNEISS

COBALT ENTRAINMENT

6 of

- Province Boundary
- Subprovince Boundary

TEMISKAMING

SCALE

174

81° 80° 79°
U.T.M. PROJECTION
TEMISKAMING AREA

SCALE 1:1,000,000

Source -
Compiled from Map 1401A (S.W.),
of Eastern Canada and Adjacent A
(G.S.C. Publication)

8 of 1

SURFIC S

FIG. 2.7
SURFICIAL GEOLOGY

27

LOGY

3 of

R Bare or thinly covered bedrock

L Lacustrine sediments (lake or river sediments)

M Ground Moraine

C Clay

R(C) Rock Knob and Clay

OT Organic Terrain

↓ Glacial Striation (sense of direction known or inferred)

◆ Drumlin Ridge

TEMISKA

SCALE

174

TEMISKAMING AREA

SCALE 1:1,000,000

Sources

Northern Ontario Engineer
1:100,000 - O.G.S. Map

Ontario Department of L
Maps S365 and S465

Prest et al 1967 - Glacia
G.S.C. Map 1253 A

J. J. Veillette (G.S.C. p

8 of 1

LINEAMENT DEM (TOTAL FREQUENCY PER

104

4 4
OF / DE

FIG. 5.13

LINEAMENT DENSITY CONTOUR MAP
(FREQUENCY PER 20x20 km GRID SQUARE)

3

Hof

16 of

81°

U.T.M. PROJECTION

80°

79°

TEMISKAMING AREA

SCALE 1:1,000,000

8 of 1

EAI

ELEMENT TRENDS

40f

81°

U.T.M. PROJECTION

80°

79°

TEMISKAMING AREA

SCALE 1:1,000,000

8 of 1

ION
G AREA
000
100

9 of 9

END

1	0	0	9	H	8	4
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FIN