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Full Name of Author — Nom complet de l’auteur

JEFFREY, RICHARD HARRIS

Date of Birth — Date de naissance

DEC. 27 / 1953

Country of Birth — Lieu de naissance

CANADA

Permanent Address — Résidence fixe

Title of Thesis — Titre de la thèse

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

University — Université

Carleton University

Degree for which thesis was presented — Grade pour lequel cette thèse fut présentée

Master of Arts

Year this degree conferred — Année d’obtention de ce grade

1982

Name of Supervisor — Nom du directeur de thèse

M. F. Fox

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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
Studies and Research in partial fulfillment
of the requirements for the degree of Master
of Arts
in Geography

Department of Geography
Carleton University
Ottawa, Ontario

May 1982
The undersigned recommend to the Faculty of Graduate Studies and Research acceptance of the thesis

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

submitted by Jeffrey Richard Harris, B.A. Honours

in partial fulfilment of the requirements for

the degree of Master of Arts.

[Signature]

THESES SUPERVISOR

[Signature]

CHAIRMAN, DEPARTMENT OF GEOGRAPHY

Carleton University

May 25, 1982.
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.
Acknowledgements

To thank everyone who contributed both mentally and physically to this thesis is impossible within this context. However, I wish to express my greatest appreciation to Professor Mike Fox for constructive criticism, sound advice and moral support, Bill Bruce, CCRS, for an education in digital analysis techniques and Dave Forsyth, Earth Physics Branch, Energy, Mines and Resources for guidance and constructive criticism. Lynen Warren, E.P.B., deserves much credit for cartographic and technical assistance. Many thanks to Steve Prashker for assistance in computer programming.

Financial support for the acquisition of imagery and photographic supplies was provided by the E.P.B., E.M.R.

Finally, many thanks to Paula Timmons who worked many hours typing this manuscript and to Nancy for moral support.
# Table of Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Abstract</strong></td>
<td>ii</td>
</tr>
<tr>
<td><strong>Acknowledgements</strong></td>
<td>iii</td>
</tr>
<tr>
<td><strong>Table of Contents</strong></td>
<td>iv-vii</td>
</tr>
<tr>
<td><strong>List of Figures</strong></td>
<td>viii-x</td>
</tr>
<tr>
<td><strong>List of Tables</strong></td>
<td>xi</td>
</tr>
<tr>
<td><strong>Chapter 1</strong>              Introduction</td>
<td>1</td>
</tr>
<tr>
<td>1.1 Introduction</td>
<td>1</td>
</tr>
<tr>
<td>1.2 Thesis Goals</td>
<td>2</td>
</tr>
<tr>
<td>1.3 Landsat Applications to Geology and Seismology</td>
<td>2</td>
</tr>
<tr>
<td>1.4 Conclusions</td>
<td>7</td>
</tr>
<tr>
<td><strong>Chapter 2</strong>              Study Region - Review of the Geological, Biophysical, Surficial and Seismological Characteristics</td>
<td>8</td>
</tr>
<tr>
<td>2.1 Study Area Location</td>
<td>8</td>
</tr>
<tr>
<td>2.2 Biophysical Environment</td>
<td>8</td>
</tr>
<tr>
<td>2.3 Geology</td>
<td>13</td>
</tr>
<tr>
<td>2.3.1 Major Structural Features</td>
<td>13</td>
</tr>
<tr>
<td>2.3.1.1 Lake Temiskaming Rift Valley</td>
<td>21</td>
</tr>
<tr>
<td>2.4 Surficial Geology</td>
<td>23</td>
</tr>
<tr>
<td>2.5 Seismicity</td>
<td>25</td>
</tr>
<tr>
<td><strong>Chapter 3</strong>              Techniques of Image Analysis and Interpretation Methodology</td>
<td>28</td>
</tr>
<tr>
<td>3.1 Landsat and Geology</td>
<td>28</td>
</tr>
<tr>
<td>3.1.2 Landsat Characteristics</td>
<td>29</td>
</tr>
<tr>
<td>3.2 Interpretation</td>
<td>31</td>
</tr>
<tr>
<td>3.2.1 Visual Interpretation</td>
<td>33</td>
</tr>
</tbody>
</table>
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 Textural Enhancement
     (Unsupervised Classification) .................................. 48
   3.2.2.3 Lineament Enhancement ....................................... 56
       3.2.2.3.1 Biomass-Ratio ........................................ 56
       3.2.2.3.2 Spatial Filtering ..................................... 61
       3.2.2.3.3 Line 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
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
<table>
<thead>
<tr>
<th>Figure</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>9</td>
</tr>
<tr>
<td>2.2</td>
<td>12</td>
</tr>
<tr>
<td>2.3</td>
<td>14</td>
</tr>
<tr>
<td>2.4</td>
<td>19</td>
</tr>
<tr>
<td>2.5</td>
<td>20</td>
</tr>
<tr>
<td>2.6</td>
<td>22</td>
</tr>
<tr>
<td>2.7</td>
<td>24</td>
</tr>
<tr>
<td>2.8</td>
<td>26</td>
</tr>
<tr>
<td>3.1a</td>
<td>35</td>
</tr>
<tr>
<td>3.1b</td>
<td>36</td>
</tr>
<tr>
<td>3.1c</td>
<td>37</td>
</tr>
<tr>
<td>3.1d</td>
<td>38</td>
</tr>
<tr>
<td>3.2</td>
<td>40</td>
</tr>
<tr>
<td>3.3</td>
<td>44</td>
</tr>
<tr>
<td>3.4</td>
<td>45</td>
</tr>
<tr>
<td>3.5a, b</td>
<td>46-47</td>
</tr>
<tr>
<td>3.6</td>
<td>49</td>
</tr>
<tr>
<td>3.7</td>
<td>50</td>
</tr>
<tr>
<td>3.8</td>
<td>51</td>
</tr>
<tr>
<td>Figure</td>
<td>Description</td>
</tr>
<tr>
<td>--------</td>
<td>-------------</td>
</tr>
<tr>
<td>3.9</td>
<td>Versatec Theme (water) Map - Rib Lake Subscene</td>
</tr>
<tr>
<td>3.10</td>
<td>Cluster Statistics - Unsupervised Classification - Rib Lake Subscene - Theme 4</td>
</tr>
<tr>
<td>3.11</td>
<td>Unsupervised Classification (6 Themes) - Rib Lake Subscene - Photograph of the CRT</td>
</tr>
<tr>
<td>3.12</td>
<td>Unsupervised Classification - Theme 4 - Rib Lake Subscene - Versatec Printout</td>
</tr>
<tr>
<td>3.13</td>
<td>Biomass Ratio (7/5) - Rib Lake Subscene - Photograph of the CRT</td>
</tr>
<tr>
<td>3.14</td>
<td>Biomass Ratio (7/5) - Rib Lake Subscene - Versatec Printout</td>
</tr>
<tr>
<td>3.15</td>
<td>Vertical (1 x 5) High Pass Filter - Maxam Lake Subscene - Photograph of the CRT</td>
</tr>
<tr>
<td>3.16</td>
<td>Linear Extraction - Rib Lake Subscene - Versatec Printout</td>
</tr>
<tr>
<td>3.17</td>
<td>Methodology Flow Chart - Digital Analysis</td>
</tr>
<tr>
<td>4.1</td>
<td>Landsat Lineament Map</td>
</tr>
<tr>
<td>4.1a</td>
<td>Prominent Lineament Trends on Geology - Aeromagnetic Maps</td>
</tr>
<tr>
<td>4.2</td>
<td>Rib Lake Subscene - Digital Lineament Map</td>
</tr>
<tr>
<td>4.3</td>
<td>Rib Lake Subscene - Digital Data Sources</td>
</tr>
<tr>
<td>4.4</td>
<td>Rib Lake Subscene - Lineaments Derived From Geology Maps</td>
</tr>
<tr>
<td>4.5</td>
<td>Maxam Lake Subscene - Digital Lineament Map</td>
</tr>
<tr>
<td>4.6</td>
<td>Northeast Arm Subscene - Digital Lineament Map</td>
</tr>
<tr>
<td>4.7</td>
<td>Rib Lake Subscene - Lineaments Derived From Air Photo Analysis</td>
</tr>
<tr>
<td>4.8</td>
<td>Rib Lake Subscene - Surficial Expression of Lineaments</td>
</tr>
<tr>
<td>4.9</td>
<td>Rib Lake Subscene - Lineaments Derived From General Landsat Lineament Map (1:1,000,000 - Visual Analysis)</td>
</tr>
<tr>
<td>4.10</td>
<td>Tee Lake Subscene - Digital Lineament Map</td>
</tr>
<tr>
<td>4.11</td>
<td>Lake St. Amand - Digital Lineament Map</td>
</tr>
<tr>
<td>5.1</td>
<td>Grenville Province 10° Azimuth Class Trend Diagrams</td>
</tr>
<tr>
<td>5.2</td>
<td>Grenville Province 20° Azimuth Class Trend Diagrams</td>
</tr>
<tr>
<td>5.3</td>
<td>Cobalt Embayment 10° Azimuth Class Trend Diagrams</td>
</tr>
<tr>
<td>5.4</td>
<td>Cobalt Embayment 20° Azimuth Class Trend Diagrams</td>
</tr>
<tr>
<td>Figure</td>
<td>Description</td>
</tr>
<tr>
<td>--------</td>
<td>-------------</td>
</tr>
<tr>
<td>5.5</td>
<td>Pontiac Gneiss Belt 10° Azimuth Class Trend Diagrams</td>
</tr>
<tr>
<td>5.6</td>
<td>Pontiac Gneiss Belt 20° Azimuth Class Trend Diagrams</td>
</tr>
<tr>
<td>5.7</td>
<td>Abitibi Volcanic Belt 10° Azimuth Class Trend Diagrams</td>
</tr>
<tr>
<td>5.8</td>
<td>Abitibi Volcanic Belt 20° Azimuth Class Trend Diagrams</td>
</tr>
<tr>
<td>5.9</td>
<td>Kapuskasing Belt 20° Azimuth Class Trend Diagrams</td>
</tr>
<tr>
<td>5.10</td>
<td>Opatica Belt 10° Azimuth Class Trend Diagrams</td>
</tr>
<tr>
<td>5.11</td>
<td>Opatica Belt 20° Azimuth Class Trend Diagrams</td>
</tr>
<tr>
<td>5.12</td>
<td>Summary of Major Lineament Trends</td>
</tr>
<tr>
<td>5.13</td>
<td>Lineament Density Contour Map (Total Frequency Per 20 x 20 km Grid Square)</td>
</tr>
<tr>
<td>5.14</td>
<td>Lineament Density Contour Map (Total Length Per 20 x 20 km Grid Square)</td>
</tr>
<tr>
<td>5.15</td>
<td>Lineament Intersection Density Map (20 x 20 Grid Square)</td>
</tr>
</tbody>
</table>
# List of Tables

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>Advantages of Landsat Data for Mineral Exploration</td>
<td>5</td>
</tr>
<tr>
<td>2.1</td>
<td>Summary of the Biophysical Environment</td>
<td>10</td>
</tr>
<tr>
<td>2.2</td>
<td>Geologic Time Scale</td>
<td>15</td>
</tr>
<tr>
<td>2.3</td>
<td>Precambrian Time-Stratigraphic Classification in Relation to Orogenies of the Canadian Shield</td>
<td>16</td>
</tr>
<tr>
<td>2.4</td>
<td>Geology Summary Via Tectonic Subdivisions</td>
<td>17</td>
</tr>
<tr>
<td>3.1</td>
<td>Landsat Imagery</td>
<td>32</td>
</tr>
<tr>
<td>3.2</td>
<td>Image Processing Methods</td>
<td>41</td>
</tr>
<tr>
<td>3.3</td>
<td>Factors Affecting Plant Forms</td>
<td>52</td>
</tr>
<tr>
<td>4.1</td>
<td>Digital Data Sources - Rib Lake Subscene</td>
<td>73</td>
</tr>
<tr>
<td>4.2</td>
<td>Numerical Summary - Surficial Expression of Lineaments</td>
<td>86</td>
</tr>
<tr>
<td>4.3</td>
<td>Summary of the Surficial Expression of Lineaments from Digital Analysis (Emphasis on the Rib Lake Subscene)</td>
<td>88</td>
</tr>
<tr>
<td>4.4</td>
<td>Areas of Low Lineament Density Within Digital Subscenes</td>
<td>94</td>
</tr>
<tr>
<td>4.5</td>
<td>Identification of Textural Themes (Rib Lake Subscene)</td>
<td>98</td>
</tr>
<tr>
<td>4.6</td>
<td>Factors Which Affect the Detectability of Lineaments on Landsat Imagery</td>
<td>101</td>
</tr>
<tr>
<td>5.1</td>
<td>Grenville Province - Summary of Trend Statistics (10° Azimuth Class)</td>
<td>111</td>
</tr>
<tr>
<td>5.2</td>
<td>Summary of Trend Statistics (20° Azimuth Class) - Total Frequency</td>
<td>124</td>
</tr>
<tr>
<td>5.3</td>
<td>Summary of Trend Statistics (20° Azimuth Class) - Total Length</td>
<td>125</td>
</tr>
<tr>
<td>5.4</td>
<td>Summary of Major Lineament Trends and Origins</td>
<td>129</td>
</tr>
<tr>
<td>5.5</td>
<td>Surficial Expression of Circular Features - Rib Lake</td>
<td>135</td>
</tr>
<tr>
<td>5.6</td>
<td>Interpretation of Total Length Contour Density Map</td>
<td>141</td>
</tr>
<tr>
<td>6.1</td>
<td>Analog Enhancements</td>
<td>146</td>
</tr>
</tbody>
</table>
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 Wetlaufer, 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, 1975; 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 F 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
Table 2.1 - Summary of The Biophysical Environment

<table>
<thead>
<tr>
<th>Class</th>
<th>Topography</th>
<th>Soils</th>
<th>Surficial</th>
<th>Tree Type</th>
<th>Geology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boreal Forest</td>
<td>nearly level to gently rolling topography, resulting from the presence of Glacial Lake Objective</td>
<td>grey tills - developed on calcareous clays and modified tills, lowland/flood-peaty phase gley soils</td>
<td>lacustrine materials, especially extensive deposits of water worked tills</td>
<td>black spruce - on gently rising uplands as well as lowlands; widespread sedge fans and sphagnum bogs</td>
<td>Precambrian volcanic and granitic rocks</td>
</tr>
<tr>
<td>Hudson Bay Lowlands</td>
<td>flat, poorly drained</td>
<td>calcareous clays on marine tills, organic soils</td>
<td>marine clay, beach sand deposits ridges and strand lines</td>
<td>subcortical appearance; open woodland - black spruce and tamarack; musk ox patterned fans, linear string bogs</td>
<td>Paleozoic sedimentary bedrock</td>
</tr>
<tr>
<td>Mississinewa-Cotinga</td>
<td>high elevation - rolling topography; located on drainage divide between the Great Lakes and Hudson Bay; numerous tills along river and lake shores</td>
<td>humic podzol</td>
<td>shallow till, some water modification of surface drift (Glacial Lake Objective)</td>
<td>mixed association of black spruce, balsam fir and white birch; east areas of scrub tilled forest (shrubs) - regeneration of burnt over or diseased areas</td>
<td>Precambrian granite, volcanic and sedimentary rock</td>
</tr>
<tr>
<td>Great Lakes/St. Lawrence Forest</td>
<td>rough Irregular topography</td>
<td>soils are coarse in texture</td>
<td>thin glacial till, sand terraces glacio-fluvial deposits, localized drumlin and esker landforms, spodic lucentine flats and broad swamps</td>
<td>eastern white pine and red pine are or were predominant forest trees/forest fires/logging activity have caused depletion - replaced by white birch and trembling aspen; secondary species - yellow birch, maple, black spruce - upland sites</td>
<td>granites, granite/granites, metasediments</td>
</tr>
</tbody>
</table>
# Table 2.1 - Continued

<table>
<thead>
<tr>
<th>Class</th>
<th>Topography</th>
<th>Soils</th>
<th>Surficial</th>
<th>Tree Type</th>
<th>Geology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sudbury/North Bay</td>
<td>Lowlands and flats interspersed with rugged outcrops of bedrock, recent erosion has removed soil.</td>
<td>Humo-ferric podzols</td>
<td>Water modified tills, lacustrine slits and sands, influenced by post-glacial Lakes Nipissing and Algomaque</td>
<td>Fire, cutting and pollution from mining have reduced many of the natural occurring species - replaced by hardy pioneer species (trembling aspen and white birch)</td>
<td>PreCambrian rocks</td>
</tr>
<tr>
<td>Haliburton Clay</td>
<td>Gently undulating plain - slopes northward from the tip of Lake Temiskaming.</td>
<td>Organic soils predominate (poor surface drainage), gray loess and humo-ferric podzols (well drained sites).</td>
<td>&quot;Little Clay Soil&quot;, lacustrine clays (varves) and sand (glacial Lake Barlow).</td>
<td>Transitional - close to Northern Clay Class, 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</td>
<td>Temiskaming Rift Valley, PreCambrian - volcanic rock, metasediments</td>
</tr>
<tr>
<td>Temagami</td>
<td>Rugged, broken</td>
<td>Sand, gravelly soils, humo-ferric podzols, stones - organic (peat) soils - depressions.</td>
<td>Shallow till overgrown, extensive areas of exposed bedrock.</td>
<td>Eastern white pine and scattered white birch, spruce trembling aspen, balsam fir, jack pine - sandy sites; black spruce, cedar, tamarack - poorly drained sites.</td>
<td>PreCambrian</td>
</tr>
</tbody>
</table>

*Source: Rowe, 1977*
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 Grenville') 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

Hudson Bay Lowlands (Phanerozoic Basin) is included in the Tectonic Map (Figure 2.3 F).
<table>
<thead>
<tr>
<th>Eon</th>
<th>Era</th>
<th>Period</th>
<th>Characteristic Life</th>
<th>Total estimated time in years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cenozoic</td>
<td></td>
<td>Recent</td>
<td>Man</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tertiary</td>
<td>Pleistocene</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pliocene</td>
<td>Mammals and modern plants</td>
<td>1,500,000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Miocene</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Oligocene</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Eocene</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Paleocene</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mesozoic</td>
<td></td>
<td>Cretaceous</td>
<td>Reptiles</td>
<td>65,000,000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Jurassic</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Triassic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Paleozoic</td>
<td></td>
<td>Permian</td>
<td>Amphibians</td>
<td>223,000,000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Carboniferous</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Devonian</td>
<td>Fishes</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Silurian</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ordovician</td>
<td>Higher invertebrates</td>
<td>576,000,000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Cambrian</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neoproterozoic</td>
<td></td>
<td>Hurynian</td>
<td>Primitive invertebrates and algae</td>
<td>880,000,000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Late Precambrian (Proterozoic)</td>
<td>1,640,000,000</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Heliikian</td>
<td></td>
<td>2,390,000,000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Aphelikian</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Early Precambrian (Archean)</td>
<td></td>
<td></td>
<td></td>
<td>3,000,000,000 or more</td>
</tr>
</tbody>
</table>

Table 2.2 Geologic Time Scale

<table>
<thead>
<tr>
<th>Eon</th>
<th>Era</th>
<th>Sub-Era</th>
<th>Orogeny (mean K–Ar mica age, m.y.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proterozoic</td>
<td>Hadrynian</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Neohelikian</td>
<td>Grenvillian (955)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Helikian</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Paleohelikian</td>
<td>Eisonian (1370)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Aphebian</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Hudsonian (1735)</td>
</tr>
<tr>
<td>Archean</td>
<td></td>
<td></td>
<td>Kenoran (2480)</td>
</tr>
<tr>
<td>Province</td>
<td>Subprovince</td>
<td>Major Rock Types</td>
<td>Structure</td>
</tr>
<tr>
<td>---------------</td>
<td>----------------------</td>
<td>----------------------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Superior</td>
<td></td>
<td>altered volcanic &amp; sedimentary rock of Archean Age &amp; large bodies of granite</td>
<td>easterly trending structures (eugeosynclines); Archean rocks involved in Kenoran Orogeny;</td>
</tr>
<tr>
<td>Province</td>
<td></td>
<td>(plutons) and related gneisses</td>
<td>- 2480 m.y. (folding, shearing, metamorphism, intrusion of granite rocks); rocks intruded by</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>several diabase dike swarms of various azimuths (Figure 2.4).</td>
</tr>
<tr>
<td>Abitibi Belt</td>
<td>Greenstone Belt</td>
<td>volcanic rocks</td>
<td>Archean rocks folded along easterly trending axes and are cut by several eastward trending</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>faults (Larder, Cadillac, Destor-Porcupine, - Kenoran orogeny)</td>
</tr>
<tr>
<td>Pontiac Gneiss</td>
<td>Metasedimentary Gneiss Belt - sedimentary - greywacke, arkose, quartz-feldspar</td>
<td>more highly metamorphosed and completely folded than rocks of the Abitibi Belt</td>
<td></td>
</tr>
<tr>
<td>Belt</td>
<td>gneiss</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Opatika</td>
<td>Metasedimentary Gneiss Belt - metasediments and metavolcanic rocks</td>
<td>intruded by numerous northward trending diabase &amp; gabbro (mafic igneous) dikes (Aphebian age</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- 1700 m.y.)</td>
</tr>
<tr>
<td>Kapuskasing</td>
<td></td>
<td>volcanic and sedimentary rocks intruded by granite rocks - also includes belt of</td>
<td>NE striking belt - includes a series of faults that strike in a similar direction, marked by</td>
</tr>
<tr>
<td></td>
<td></td>
<td>pyroxene bearing gneiss and alkaline elliptical masses</td>
<td>major gravity and magnetic anomalies</td>
</tr>
<tr>
<td>Southern</td>
<td>Cobalt Embayment</td>
<td>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</td>
<td>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</td>
</tr>
<tr>
<td>Province</td>
<td>(plate)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Grenville Province
quartzofeldspathic 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)

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

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)
Figure 2.5

Source: Wynne-Edwards (1972)
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

- Geological boundary
- Lineament
- Fault
- Kimberlite occurrences
- End moraine
- Pleistocene Lake Bigror-Ojibway sediments more than 100 deep (averagers)
- Paleozoic outlier
- Alkaline igneous intrusion
- Archean metavolcanics and metasediments

Scale: 1 inch to 25 miles

Source: Lovell and Caine (1970)
activity has taken place during Phanerzoic 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
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 Quebec 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:
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 diachronic 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

<table>
<thead>
<tr>
<th>Frame I.D.</th>
<th>Date</th>
<th>Band</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temiskaming</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E-1822-15284-6</td>
<td>23/Oct/74</td>
<td>6</td>
</tr>
<tr>
<td>E-1110-15145</td>
<td>7/Aug/75</td>
<td>6</td>
</tr>
<tr>
<td>E-1534-15364-6</td>
<td>8/Jan/74</td>
<td>6</td>
</tr>
<tr>
<td>E-1110-15145</td>
<td>7/Aug/75</td>
<td>4, 5, 7</td>
</tr>
<tr>
<td>Abitibi</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E-20189-15332</td>
<td>30/Jul/75</td>
<td>6</td>
</tr>
<tr>
<td>E-11309-15075</td>
<td>22/Feb/76</td>
<td>6</td>
</tr>
<tr>
<td>E-Y111-15200</td>
<td>8/Aug/75</td>
<td>4, 5, 7</td>
</tr>
<tr>
<td>Moose</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E-20190-15384</td>
<td>31/Jul/75</td>
<td>6</td>
</tr>
<tr>
<td>E-11292-15141</td>
<td>5/Feb/76</td>
<td>6</td>
</tr>
<tr>
<td>E-20190-15384</td>
<td>31/Jul/75</td>
<td>4, 5, 7</td>
</tr>
</tbody>
</table>
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 feature 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).
Temiskaming Area - East-West 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 extraneous 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 iemiskaming 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 ( = 40 x 30 kms)
Figure 3.2 Methodology Flow Chart - Visual Interpretation

DATA SOURCES

Landsat Images
1:1,000,000 Transparencies
(Band 6 + Colour Composite)

Landsat Images
1:500,000 Paper Enlargements
(Band 6)

PAS Edge Enhanced Products
-35 mm slides
+Prints (Mosaic)

COMPI LATION

A. Lineaments plotted on transparent overlays registered to 1:500,000 paper enlargements or 1:500,000 (approximate) PAS Edge enhanced mosaics

B. Compilation of all lineaments onto 1 transparent overlay registered to each 1:500,000 paper enlargement

CLASSIFICATION + INTERPRETATION

Classification process assisted by comparison to other data sources (Topographic, Geology, Surficial, Vegetation and Geophysical maps)

DATA TRANSFER

A. Registration of 1:500,000 overlays to 1:500,000 topographic maps

B. Transfer of lineaments to 1:1,000,000 plotting base (topographic map)

FINAL DRAFTING

\[\text{See Appendix C for description of classification system}\]
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
Raw Colour Composite (Bands 4, 5, 7)
Rib Lake Subscene - Different Gain Settings

(Photograph of the CRT)
**OVERVIEW** + COMPARISON FILE:

<table>
<thead>
<tr>
<th>LB</th>
<th>UB</th>
<th>DEL</th>
<th>PEAK</th>
<th>MEAN</th>
<th>S.E.</th>
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</thead>
<tbody>
<tr>
<td>1</td>
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<td>2</td>
<td>28</td>
<td>1513</td>
<td>81</td>
<td>5.2</td>
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<td>1</td>
<td>32</td>
<td>243</td>
<td>49</td>
<td>15.7</td>
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<tr>
<td>4</td>
<td>0</td>
<td>42</td>
<td>185</td>
<td>56</td>
<td>17.6</td>
</tr>
</tbody>
</table>

TRAINING AREA=260099. PIXELS
ALARMED AREA=262143. PIXELS(100.0%)

TYPE: CHANNEL $ OR E(X)IT.
Figure 3.5a
Contrast Stretch Enhancement

A) HISTOGRAM

B) NO STRETCH

C) LINEAR STRETCH

D) HISTOGRAM STRETCH

E) SPECIAL STRETCH

Source: CCRS-CIAS manual
Figure 3.5b

Contrast Stretch Enhancement

SPECIAL CONTRAST STRETCH

LOGARITHMIC

BREAKPOINT

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. 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 Subacene

(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**: 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
- light (solar insolation)
- temperature
- wind

B. Geomorphic
- slope aspect
- slope steepness
- relief

C. Edaphic
- soil texture and structure
  - 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)
**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.
Unsupervised Classification (6 Themes)

Rib Lake Subscene

(Photograph of the CRT)
Unsupervised Classification - Theme 4

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

(Photograph of the CRT)
3.2.2.3.2 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.

3.2.2.3.3 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
Vertical (1 x 5) High Pass Filter -
Maxam Lake Subscene

(Photograph of the CRT)
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

DIGITAL PROCESSING PROCEDURES

A
Colour Composite (summer) (Raw Image Bands 4, 5, 7)
  ↓
Contrast Stretch

B
Lineament Enhancement
  ↓
Ratio (Band 4 / Band 5)
  ↓
Spatial Filtering
(High Pass-Vertical Horizontal)
  ↓
Lineament Extraction

C
Textural Enhancement

DATA SOURCES

Raw Data
  ↓
Contrast Stretch
  ↓
Ratio
  ↓
Filter
  ↓
Extraction
  ↓
Textural

COMPILATION

lineaments plotted on individual overlays registered to Versatec plots (1:125,000)

compilation of all lineaments onto 1 overlay registered to water map (Versatec plot)

INTERPRETATION & CLASSIFICATION

classification process assisted by comparison to other data sources

FINAL CLASSIFIED OVERLAY

registered to water map (1:125,000)
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

1Geology 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. 4.1a - Prominent Lineament Trends on Geology & Aeromagnetic Maps

DIKE SWARMS
A - ABITIBI
B - MATACHewan
C - SUDbury

FAULT ZONES
D - TEMISKAMING
E - MATTAGAMI
F - LARDER
G - DEsTOR - POrcuPINe, PIPESTONE
H - KAPUSKASING

TEMISKAMING AREA

0 100 km
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.
Fig. 4.2

-RIB LAKE SUBSCENE-
DIGITAL LINEAMENT MAP

-Mapped Fault
- Mapped Dike
- Landsat Lineament
- Lithological Contact
- Low Density (see table 4.4)
RIB LAKE SUBSCENE DIGITAL DATA SOURCES

POOR COPY
COPIE DE QUALITEE INFERIEURE

Fig. 4.3

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

Theme 1

Textural Enhancement

Scale: 1: 201,812

Top Left: 9, 8

<table>
<thead>
<tr>
<th>Digital Data Source (Output)</th>
<th># of Circular Features Detected</th>
<th># of Lineaments Detected</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Relative</td>
<td>Absolute</td>
</tr>
<tr>
<td>Contrast Stretch</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water Map (Drainage)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Theme 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Theme 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Theme 3</td>
<td></td>
<td></td>
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<td>Theme 5</td>
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<tr>
<td>Theme 6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ratio 7/5</td>
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<tr>
<td>High Pass Filter (Vertical &amp; Horizontal)</td>
<td>27</td>
<td>2</td>
</tr>
<tr>
<td>Combination of Data Sources</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Total 6 | Total 107

**Definition of Terms:**
- **Combination of Data Sources**: includes 2 or more data sources
- **Relative**: Data source was used to detect "x" # of lineaments in combination with 2 or more data sources
- **Absolute**: "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 area\(^1\) (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 maps\(^2\) 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  \(^2\) NTS - 31M (1:250,000)
Ontario Dept. of Mines - Map 2198  NTS - 31M/SW (1: 25,000)
RIB LAKE SUBSCENE

Fig. 4.4
LINEAMENTS DERIVED FROM GEOLOGY MAPS

Source: Ontario Geological Survey - Map 2361 - Sudbury - Cobalt
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 analysis\(^1\) 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

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

Scale: 1:20,612
RIB LAKE SUBSCENE
LINEAMENTS: DERIVED FROM AIR PHOTO ANALYSIS (B/W)

Fig. 4.7
RIB LAKE SUBSCENE
SURFICIAL EXPRESSION OF LINEAMENTS

Legend:
- Combination (Topography/Drainage)
- Drainage
- Ridge, Hill
- Valley

1-6

Circular Features (see table 5.5)

Exceptionally Strong Textural Enhancement (see section 4.4)

No Expression
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

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

Mapped Fault

Mapped Dike

2nd Order Landsat Lineaments
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 dike's 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 contrasts, Figure 4.8 F and Table 4.2 (deduced from topographic and surficial geology maps and air photo analysis) 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. Several of these

1 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

<table>
<thead>
<tr>
<th>Surficial Expression</th>
<th># of Lineaments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combination (Topographic/Drainage)</td>
<td>32</td>
</tr>
<tr>
<td>Ridge/Hill</td>
<td>35</td>
</tr>
<tr>
<td>Valley</td>
<td>Topographic</td>
</tr>
<tr>
<td>Drainage</td>
<td>11</td>
</tr>
<tr>
<td>Drainage</td>
<td>29</td>
</tr>
<tr>
<td>No Expression</td>
<td>6</td>
</tr>
</tbody>
</table>
Lineaments were identified from the textural data (themes 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)

**LANDSAT DATA**

- All lineaments inherently tonal (spectral contrast)

**Surficial Expression**

- Textural Enhancement
  - Differential vegetation growth

**Controlling Factors**

- Slope/aspect (see Table 3.3)
- Soil moisture

**Modes of Detection**

*Non-Topographic Control*

- Differential vegetation growth along a dike
- Differences in soil moisture

**Topographic Control**

- Structural
- Non-Structural (Surficial)

* - 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, drumlinoid 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 4.1F) and the digitally produced lineament maps.

4.5.1.1 Surficial Cover

Visual comparison of the surficial geology map (Figure 2.7F) with the general lineament map (Figure 4.1F) 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. 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 subsences. 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 subsence showed that the textural enhancement procedure was useful for the isolation and

1 The Englehart subsence, 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

<table>
<thead>
<tr>
<th>Subscene</th>
<th>Location of Low Density Area</th>
<th>Terrain Type</th>
<th>Geological Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tee Lake</td>
<td>Fig. 4.10 (F) - L</td>
<td>low plain - organic deposits</td>
<td>lack of structural lineaments or terrain conditions (lack of topographic expression) responsible for low lineament density</td>
</tr>
<tr>
<td>Maxam Lake</td>
<td>Fig. 4.5 (F) - L</td>
<td>till/clay plain interspersed with bedrock knobs</td>
<td>surficial cover may obscure lineaments</td>
</tr>
<tr>
<td>Northeast Arm</td>
<td>Fig. 4.6 (F) - L</td>
<td>flat to gently rolling organic terrain</td>
<td>low density in these areas may be due to lack of structural lineaments since geology maps show very little structural features (faults, dikes, etc.)</td>
</tr>
<tr>
<td>Lake St. Amand</td>
<td>Fig. 4.11(F) - L</td>
<td>clay plains/flat marshy terrain interspersed with areas of bedrock - agricultural activity</td>
<td>agricultural activity (fields) may obscure structural lineaments as well as creating new cultural lineaments (e.g. field boundaries)</td>
</tr>
<tr>
<td>Rib Lake</td>
<td>Fig. 4.2 (F) - L</td>
<td>very small area of flat, marshy terrain</td>
<td></td>
</tr>
<tr>
<td>Englehart</td>
<td>Entire subscene</td>
<td>area located within &quot;Little Clay Belt&quot;</td>
<td>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)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>flat terrain interspersed with marshy areas</td>
<td>surficial cover and agricultural activity may obscure structural lineaments</td>
</tr>
<tr>
<td></td>
<td></td>
<td>agricultural activity - rectangular grid pattern of roads</td>
<td>geology maps indicate a lack of structural lineaments</td>
</tr>
</tbody>
</table>

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

- air photos - listed previously
- topographic maps - Haileybury 31M/SW, 1:250,000 - Ville Marie - 31M
- Forest Stand Maps (Ontario Natural Resources - see bibliography)
<table>
<thead>
<tr>
<th>Themes</th>
<th>Vegetation Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Pure Coniferous Stands (e.g., cedar, black spruce) Wetlands</td>
</tr>
<tr>
<td>2/3</td>
<td>Mixed (greater % coniferous)</td>
</tr>
<tr>
<td>4/5</td>
<td>Mixed (greater % deciduous)</td>
</tr>
<tr>
<td>6</td>
<td>Pure Deciduous Stands and Short Grass Meadows</td>
</tr>
<tr>
<td>7</td>
<td>Water</td>
</tr>
</tbody>
</table>

Slope/Aspect - Differential shadowing can cause variable classification
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

<table>
<thead>
<tr>
<th>Factors Affecting Detectability</th>
<th>Effect on Lineament Detection</th>
<th>Geological Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A) Environmental Conditions</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surficial Cover</td>
<td>- may obscure structural lineaments</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- surficial lineaments may predominate</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- drainage pattern will not reflect underlying bedrock</td>
<td></td>
</tr>
<tr>
<td>Flat Marshy Terrain</td>
<td>- lack of topographic expression makes lineaments more difficult to detect</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- organic terrain may obscure lineaments</td>
<td></td>
</tr>
<tr>
<td>Vegetated Areas</td>
<td>1. vegetation may obscure lineaments</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2. lineaments may be highlighted by vegetation (textural enhancement)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- textural enhancement can enhance both continuous and discontinuous linear textural patterns that may reflect underlying geologic structure</td>
<td></td>
</tr>
<tr>
<td>Areas of Thinly Covered or Exposed Bedrock</td>
<td>- topographic expression - prime mode of lineament expression (differential shadowing, textural enhancement)</td>
<td>less confusion between surficial and structural lineaments</td>
</tr>
<tr>
<td></td>
<td>- drainage pattern often reflects bedrock structure</td>
<td></td>
</tr>
</tbody>
</table>

* areas of thick surficial cover and flat terrain also present difficult conditions for structural mapping using other techniques (e.g. ground mapping procedures)
<table>
<thead>
<tr>
<th>Factors Affecting Detectability</th>
<th>Effect on Lineament Detection</th>
<th>Geological Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cut (Logging) and Burnt Over Areas</td>
<td>- may effect relationship between vegetation and geology</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- present confusing signatures</td>
<td>- filtered except in cases where road, rail is coincident with a structural lineament</td>
</tr>
<tr>
<td>Cultural Lineaments</td>
<td>- present confusing signatures</td>
<td></td>
</tr>
<tr>
<td>Agricultural Areas</td>
<td>- may obscure structural lineaments</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- presents confusing signatures (field boundaries)</td>
<td></td>
</tr>
<tr>
<td>B) System Parameters</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sun Azimuth</td>
<td>- suppression of lineaments parallel to sun azimuth</td>
<td></td>
</tr>
<tr>
<td>Scan Lines</td>
<td>- scan lines - false lineaments</td>
<td></td>
</tr>
</tbody>
</table>
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 (i.e. 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 overlayed 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 photo-interpreter 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 sub-scene 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 subsence, 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 \((-90^\circ \text{ (west)} \text{ to } 90^\circ \text{ (east)}, \text{ north } = 0^\circ\); 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 \(10^\circ\) and \(20^\circ\) 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 \(20^\circ\) 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 $10^\circ$ Azimuth Class Trend Diagrams
Table 5.1 - Grenville Province - Summary of Trend Statistics (10° Azimuth Class)

<table>
<thead>
<tr>
<th>Type</th>
<th>Dominant Trends</th>
<th>Frequency</th>
<th>Secondary Trends</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>-40 to -50°</td>
<td>30</td>
<td>-30 to -40°</td>
<td>20</td>
</tr>
<tr>
<td>Frequency</td>
<td>-60 to -70°</td>
<td>29</td>
<td>-70 to -80°</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>-50 to -60°</td>
<td>24</td>
<td>0 to -10°</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>10 to 20°</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>20 to 30°</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>30 to 40°</td>
<td>17</td>
</tr>
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<td></td>
<td>40 to 50°</td>
<td>17</td>
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<td></td>
<td></td>
<td></td>
<td>50 to 60°</td>
<td>10</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Type</th>
<th>Secondary Trends</th>
<th>Total Length (km)</th>
<th>Average Length (km)</th>
<th>Standard Deviation</th>
<th>Total Length (km)</th>
<th>Average Length (km)</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>-60 to -70°</td>
<td>374.5</td>
<td>12.9</td>
<td>15.0</td>
<td>219.6</td>
<td>21.9</td>
<td>28.7</td>
</tr>
<tr>
<td>Length</td>
<td>-50 to -60°</td>
<td>287.0</td>
<td>11.9</td>
<td>10.3</td>
<td>212.2</td>
<td>7</td>
<td>7.8</td>
</tr>
<tr>
<td></td>
<td>-70 to -80°</td>
<td>275.3</td>
<td>13.8</td>
<td>13.6</td>
<td>160.6</td>
<td>8.0</td>
<td>4.6</td>
</tr>
<tr>
<td></td>
<td>0 to -10°</td>
<td>157.5</td>
<td>8.7</td>
<td>7.6</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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 $10^\circ$ 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 $10^\circ$ and $20^\circ$ azimuth class rose diagrams for each tectonic unit, Tables 5.2 and 5.3 summarize the dominant and secondary trends present on the $20^\circ$ 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 ($-30^\circ$ to $-70^\circ$) ($-70^\circ$ to $-90^\circ$) 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 ($-10^\circ$ to $0^\circ$) consisting of first order lineaments and the other striking NE ($30^\circ$ to $70^\circ$) paralleling the Grenville Front consisting of mapped faults and second order lineaments.
Figure 5.2. Grenville Province $20^\circ$ 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 $10^0$ 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
Figure 5.8. Abyibi 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. Opatica Belt 20° Azimuth Class Trend Diagrams
<table>
<thead>
<tr>
<th>Tectonic Unit</th>
<th>Dominant Trends</th>
<th>Frequency</th>
<th>Secondary Trends</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grenville Province</td>
<td>-50 to -70°</td>
<td>53</td>
<td>30 to 50°</td>
<td>31</td>
</tr>
<tr>
<td></td>
<td>-30 to -50°</td>
<td>50</td>
<td>-70 to -90°</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>-10 to 10°</td>
<td>29</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>50 to 70°</td>
<td>29</td>
</tr>
<tr>
<td>Southern Province</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cobalt Embayment</td>
<td>-10 to 10°</td>
<td>61</td>
<td>10 to 30°</td>
<td>45</td>
</tr>
<tr>
<td></td>
<td>i.e. (-10 to 0°</td>
<td></td>
<td>-30 to -50°</td>
<td>43</td>
</tr>
<tr>
<td></td>
<td>0 to 10°</td>
<td></td>
<td>30 to 50°</td>
<td>42</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>-50 to -70°</td>
<td>37</td>
</tr>
<tr>
<td>Superior Province</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pontiac Gneiss</td>
<td>10 to 30°</td>
<td>36</td>
<td>30 to 50°</td>
<td>21</td>
</tr>
<tr>
<td>Belt</td>
<td></td>
<td></td>
<td>50 to 70°</td>
<td>20</td>
</tr>
<tr>
<td>Abitibi Volcanic</td>
<td>-10 to 10°</td>
<td>86</td>
<td>50 to 70°</td>
<td>55</td>
</tr>
<tr>
<td>Belt</td>
<td></td>
<td></td>
<td>-10 to -30°</td>
<td>49</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>30 to 50°</td>
<td>44</td>
</tr>
<tr>
<td>Opatica Belt</td>
<td>-10 to 10°</td>
<td>66</td>
<td>-10 to -30°</td>
<td>53</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>-30 to -50°</td>
<td>28</td>
</tr>
<tr>
<td>Kapuskasing Belt</td>
<td>30 to 50°</td>
<td>13</td>
<td>70 to 90°</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>10 to 30°</td>
<td>13</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>-10 to 10°</td>
<td>12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tectonic Unit</td>
<td>Dominant Trends</td>
<td>Total Length (km)</td>
<td>Average Length (km)</td>
<td>Standard Deviation</td>
</tr>
<tr>
<td>------------------------</td>
<td>-----------------</td>
<td>-------------------</td>
<td>---------------------</td>
<td>-------------------</td>
</tr>
<tr>
<td>Grenville Province</td>
<td>-50 to -70°</td>
<td>661.5</td>
<td>12.4</td>
<td>13.1</td>
</tr>
<tr>
<td></td>
<td>70 to -90°</td>
<td>495.9</td>
<td>16.5</td>
<td>20.3</td>
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<td></td>
<td>-30 to -50°</td>
<td>372.9</td>
<td>7.4</td>
<td>6.7</td>
</tr>
<tr>
<td>Southern Province</td>
<td>Cobalt Embayment</td>
<td>-30 to -50°</td>
<td>595.8</td>
<td>13.8</td>
</tr>
<tr>
<td></td>
<td>-50 to -70°</td>
<td>560.1</td>
<td>15.1</td>
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<td>-10 to 10°</td>
<td>491.9</td>
<td>8.0</td>
<td>7.5</td>
</tr>
<tr>
<td>Superior Province</td>
<td>Pontiac</td>
<td>10 to 30°</td>
<td>626.7</td>
<td>17.4</td>
</tr>
<tr>
<td></td>
<td>Geiss Belt</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Abitibi Volcanic Belt</td>
<td>-10 to 10°</td>
<td>841.1</td>
<td>9.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Opatica Belt</td>
<td>-10 to 10°</td>
<td>723.3</td>
<td>10.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Kapuskasing</td>
<td>30 to 50°</td>
<td>178.4</td>
<td>13.7</td>
</tr>
</tbody>
</table>
FIG. 512
SUMMARY OF MAJOR LINEAMENT TRENDS

TEMISKAMING AREA

- Dominant Trends
- Secondary Trends
1-10 Trend identification Numbers (see table 5.4)
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 $-10^0$ to $30^0$; however, the total length rose diagram narrows this range to $30^0$ to $50^0$ (NE) (see Figure 5.9). Although the $30^0$ to $50^0$ azimuth interval has the same number of lineaments (13) as the $10^0$ to $30^0$ and $-10^0$ to $10^0$ intervals, its total length figure (178.4 km) is about twice as large. Included in this trend direction is a long lineament ($\approx 70$ 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 Opatica Belt

A strong NNW to northward striking trend ($-10^0$ to $10^0$) 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>
<thead>
<tr>
<th>Tectonic Unit</th>
<th>Trends</th>
<th>Origin</th>
<th>I.D. #’s</th>
<th>Interpretation Problems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grenville Province</td>
<td>NW -30 to -70°</td>
<td>Temiskaming Rift Valley</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>WNW -70 to -90°</td>
<td>Nipissing Branch of the Ottawa Graben</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>NE 30 to 70°</td>
<td>Grenville Front</td>
<td>3</td>
<td>Glacial/structural origin?</td>
</tr>
<tr>
<td>Southern Province</td>
<td>NW -30 to -50°</td>
<td>Temiskaming Rift Valley</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Cobalt Embayment</td>
<td>WNW -50 to -70°</td>
<td>Diabase Dikes (Sudbury)</td>
<td>4</td>
<td>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.</td>
</tr>
<tr>
<td></td>
<td>NNW-NNE -10 to 10°</td>
<td>Associated with similar trend in the Abitibi Volcanic Belt (see #7)</td>
<td>5</td>
<td>Glacial/structural origin</td>
</tr>
<tr>
<td>Superior Province</td>
<td>NE 10 to 30°</td>
<td>Possible fault zone/joints (see written description Section 5.2.3)</td>
<td>6</td>
<td>Glacial/structural origin. Chagnon (1968) - concluded that bedrock geology exerted the strongest control on lineament orientation and that glaciation had an accentuating effect only.</td>
</tr>
<tr>
<td>Pontiac Gneiss Belt</td>
<td>NNW 0 to -20°</td>
<td>Fault Zone</td>
<td>7</td>
<td>Glacial/structural origin</td>
</tr>
<tr>
<td></td>
<td>NE 50 to 70°</td>
<td>Fault Zone/Dike Swarm (Ahti.)</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Abitibi Volcanic Belt</td>
<td>NE 30 to 50°</td>
<td>Fault Belt</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Kapuskasing Belt</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Location</td>
<td>Trend</td>
<td>Angular Range</td>
<td>Origin</td>
<td></td>
</tr>
<tr>
<td>----------</td>
<td>-------</td>
<td>---------------</td>
<td>--------</td>
<td></td>
</tr>
<tr>
<td>Opatika</td>
<td>NNW–NNE</td>
<td>-10 to 10°</td>
<td>Glacial/structural origin</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>10</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>surficial lineaments and third order</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>possible dike swarm (Matachewan)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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. Wetmillier, personal communication). The possibility of a shallow focal depth less than 10 kms does not seem likely as no surface breaks were observed (R. Wetmillier, 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° to 10°) 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° to 10°) of the Opatika 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

<table>
<thead>
<tr>
<th>Circular Feature</th>
<th>Surficial Expression</th>
</tr>
</thead>
<tbody>
<tr>
<td>Identification Number, See Fig. 4.2F</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>rounded crest lines</td>
</tr>
<tr>
<td>2</td>
<td>tonal anomalies (differential vegetation growth) associated with positive relief</td>
</tr>
<tr>
<td>3</td>
<td>light tone (Band 6) indicates high infrared reflectance (eg. Deciduous veg vs. Coniferous veg)</td>
</tr>
<tr>
<td>4</td>
<td>bright red (colour composite)</td>
</tr>
<tr>
<td>5</td>
<td>drainage pattern</td>
</tr>
<tr>
<td>6</td>
<td>no appreciable surficial expression (slight circular pattern evident in contour lines)</td>
</tr>
</tbody>
</table>
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 20 x 20 km GRID SQUARE)

TEMISKAMING AREA

6 Classes - Minimum 4 Lineaments
- Maximum 29 Lineaments

Contour Interval = 5 Lineaments

Areas of uncertain interpretation due to surficial cover
LINEAMENT DENSITY CONTOUR MAP
(TOTAL LENGTH PER 20x20 km GRID SQUARE)

FIG. 5.14

TEMISKAMING AREA

6 Classes - Minimum = 14 km
- Maximum = 146 km

Contour Interval = 22 km

L1-3 = Low Density
H1-5 = High Density

Areas of uncertain interpretation
due to surficial cover

see Table 56
FIG 5.15
LINEAMENT INTERSECTION DENSITY MAP (20x20 km GRID SQUARE)

6 Classes - Minimum = 0 Intersections
- Maximum = II Intersections
Contour Interval = 183 Intersections
--- Areas of uncertain interpretation due to surficial cover

TEMISKAMING AREA
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

<table>
<thead>
<tr>
<th>Area (Fig. 4.14)</th>
<th>Surficial Cover</th>
<th>Lineament Type</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1</td>
<td>Clay</td>
<td>mapped faults</td>
<td>two interpretations</td>
</tr>
<tr>
<td></td>
<td>- corresponds with the</td>
<td></td>
<td>1. paucity of structural lineaments</td>
</tr>
<tr>
<td></td>
<td>&quot;Little Clay Belt&quot;</td>
<td></td>
<td>2. masking effect of clay</td>
</tr>
<tr>
<td>L2</td>
<td>thinly covered or</td>
<td>mapped faults</td>
<td>area is contoured as low density because</td>
</tr>
<tr>
<td></td>
<td>exposed bedrock</td>
<td></td>
<td>most is water (area centered over Lake</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Timagami)</td>
</tr>
<tr>
<td>L3</td>
<td>&quot;</td>
<td></td>
<td>one lineament</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>edge effect and/or incomplete data unit must</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>be taken into account</td>
</tr>
<tr>
<td>H1</td>
<td>&quot;</td>
<td>second and third</td>
<td>since most lineaments are second and third</td>
</tr>
<tr>
<td></td>
<td></td>
<td>order</td>
<td>order, the structural significance of the</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>area cannot be ascertained</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>lithological contacts may have less structural</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>significance</td>
</tr>
<tr>
<td>H2</td>
<td>&quot;</td>
<td>second order -</td>
<td>first order lineaments represent western half</td>
</tr>
<tr>
<td></td>
<td></td>
<td>some first order</td>
<td>of a dominant curvilinear structure (intrusion)</td>
</tr>
<tr>
<td>H3</td>
<td>ground moraine</td>
<td>mapped faults</td>
<td>since these areas are occupied by a high</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>number of mapped faults they might be considered</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>to be more structurally significant than H1 and H2</td>
</tr>
<tr>
<td>H4</td>
<td>thinly covered or</td>
<td>mapped faults</td>
<td>H4 may correspond to structural activity along</td>
</tr>
<tr>
<td></td>
<td>exposed bedrock</td>
<td></td>
<td>the Nipissing branch of the Ottawa Valley graben</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- H5 SYMAP &quot;edge effect&quot; must be taken into account</td>
</tr>
<tr>
<td>H5</td>
<td>&quot;</td>
<td>mapped faults and</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>second order</td>
<td></td>
</tr>
</tbody>
</table>
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 five 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 \(1 = x \) 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 x 5, 5 x 1) resulted in the production of many artifacts which added confusion to the interpretation procedure. A larger filter size (25 x 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 raticing 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

\[
\frac{n(\Sigma xy) - (\Sigma x)(\Sigma y)}{\sqrt{n(\Sigma x^2) - (\Sigma x)^2}(n(\Sigma y)^2 - (\Sigma y)^2)}
\]
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

<table>
<thead>
<tr>
<th>Reference</th>
<th>Definition</th>
<th>Comment</th>
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<tr>
<td>Hobbs (1904)</td>
<td>A lineament is &quot;nothing more than a generally rectilinear earth feature&quot; (p. 485)</td>
<td>Term introduced to characterize spatial relationships of &quot;1) crests of ridges or boundaries of elevated areas, 2) drainage lines, 3) coast lines, 4) boundary lines of formations, or physiographic rock types, or lines of outcrops&quot; (p. 485). Any of these may be joined end to end. Term is scale related: &quot;lineaments ... are rectilinear ... only in proportion as the scale of the map is small&quot; (p. 486). Lineaments tend to be obscure.</td>
</tr>
<tr>
<td>Hobbs (1912)</td>
<td>Lineaments are &quot;significant lines of landscape which reveal the hidden architecture of the rock basement&quot; (p. 227); &quot;the character lines of the earth's physiognomy&quot; (p. 227)</td>
<td>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 &quot;seismotectonic lines.&quot; They are composite features.</td>
</tr>
<tr>
<td>Sonder (1938)</td>
<td>&quot;The lineament of a region then denotes a definite direction which is contained in the tectonics, the jointing, and the relief&quot; (p. 223)</td>
<td>Used in a general, regional sense, individual features (compare Hobbs, 1904, 1912) are termed &quot;linears.&quot;</td>
</tr>
<tr>
<td>Wilson (1941)</td>
<td>Lineaments are &quot;straight and gently curving lines&quot; formed by &quot;the great scarps and troughs which cross all the Precambrian rocks&quot; (p. 496)</td>
<td>Emphasized structure: Their association in definite patterns strongly suggests that they are members of connected systems of faulting&quot; (p. 496). Described as regional features better seen in air photos than on ground.</td>
</tr>
<tr>
<td>Kaiser (1950)</td>
<td>&quot;A lineament is a straight linear surface feature that is at least many hundreds of feet and commonly many miles long&quot; (p. 1475)</td>
<td>&quot;Lineaments are well shown on aerial photographs and ... may consist of 1) linear topographic features, either trenches or ridges; 2) linear vegetational patterns; 3) linear patterns of soil color or texture; Gaps and stream segments typically form parts of lineaments&quot; (p. 1475).</td>
</tr>
<tr>
<td>Gross (1951)</td>
<td>&quot;The straight line or gently curved physiographic features on the earth's surface are known as linears&quot; (p. 79)</td>
<td>&quot;Linears&quot; generally fault related; synonyms are &quot;topographic linear&quot; and &quot;linear topographic feature.&quot; Used &quot;lineal&quot; as adjectival substitute for &quot;linear.&quot; Used &quot;lineation&quot; to refer implicitly to general trend of linear (compare Sonder, 1938).</td>
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<td>Kelly (1955)</td>
<td>&quot;In general terms a lineament is a rectilinear feature of considerable extent on the surface of the earth. A tectonic lineament...is either a general alignment of structural features or a boundary between contrasting structural features&quot; (p. 58)</td>
<td>Lineaments are usually &quot;interrupted or discontinuous features&quot; not readily mapped in the field and are &quot;agreements of boundary or line observed generally on regional maps&quot; (p. 59). Term is usually reserved for &quot;transverse or oblique alignments of one sort or another&quot; (p. 58), but included &quot;in the broadest sense&quot; (p. 58) are features such as the eastern Rocky Mountains.</td>
</tr>
<tr>
<td>Kupsch and Wild (1958)</td>
<td>No specific definition</td>
<td>Related lineaments to extended faults. Tonal lineaments...are believed to reflect differences in soil moisture resulting perhaps from micrelief&quot; (p. 129). Noted that &quot;linear...is an etymologically undesirable term; suggestion use of &quot;linear trends, linear features, or lineaments&quot; (p. 129) instead.</td>
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<tr>
<td>Lattman (1958)</td>
<td>A lineament is &quot;a natural linear feature consisting of topographic (including straight stream segments), vegetation, or soil tional alignments, visible primarily on aerial photographs or mosaics, and expressed continuously or discontinuously for many miles&quot; (p. 569)</td>
<td>Lineaments are expressions of subsurface faults. Defined &quot;fracture trace&quot; as a lineament &quot;expressed continuously for less than one mile&quot; (p. 569), the expression of local jointing or small faults; included &quot;only natural linear features not otherwise related to outcrop pattern of tilted beds, lineation and foliation, and stratigraphic contacts ... included are joints mapped on aerial photographs where bare rock is exposed&quot; (p. 569).</td>
</tr>
<tr>
<td>Parkinson in Lueder (1959)</td>
<td>&quot;Any linear feature of the landscape 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&quot; (p. 343)</td>
<td>An implicit definition. &quot;Bedrock linears...represent the surface traces of such geologic planar features as fault contacts, joints, and bedding planes&quot; (p. 343). They also represent &quot;true or several structural features&quot; (p. 343), including schistosity, gneissosity, or narrow dikes.</td>
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<td>Reference</td>
<td>Definition</td>
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<td>Anderson  (1915)</td>
<td>Lineation is &quot;a sort of striation visible on practically any well-exposed diastrophically bedded plane of the granulites...This lineation is sometimes seen to be parallel over wide districts, even with changes of strike&quot; (p. 22)</td>
<td>Definition is collective and restrictive</td>
</tr>
<tr>
<td>Cloos  (1946)</td>
<td>&quot;Lineation is a descriptive and nongenic term for any kind of linear structure within or on a rock...includes strain on slickensides, fold axes, flow lines, stretching, elongate pebbles or seds, wrinkles, streaks, intersections of planes, linear parallelism of minerals or components...any other kind of linear structure of megascopic, microscopic, or regional dimensions&quot; (p. 1)</td>
<td>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</td>
</tr>
<tr>
<td>Fairbairn  (1949)</td>
<td>&quot;Paralleling of linear elements shows as lineation&quot; (p. 3)</td>
<td>Definition is collective and related entirely to petrofabrics. Features have &quot;marked rectilinear character&quot; (p. 1748). Recognized two types: macrofabrics and microfabrics. Macrofabrics are generally longer than 3.2 km (2 mi). Definition is given: &quot;Macrofabrics...have been generated at the level of the basement...the majority of macrofabrics have their origin below the halfway point in the sedimentary column.&quot; Features include: &quot;cements, sutures, intersections of cleavages, sedimentary structures, etc.&quot; (p. 307). Especially useful are areas of folies where closure can be observed in large outcrops or closely spaced groups of outcrops.&quot; (p. 307)</td>
</tr>
<tr>
<td>Blancher (1957)</td>
<td>&quot;...by the term fracture is meant the generally abundant, natural lineations discernible on aerial photographs&quot; (p. 1748)</td>
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<td>Compton (1962)</td>
<td>&quot;A lineation is a preferred (subparallel) orientation of one or more kinds of linear features&quot; (p. 306)</td>
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<td>Turner and Weiss (1963)</td>
<td>&quot;All true lineations are penetrative discontinuities&quot; (p. 31), that is, &quot;...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&quot; (p. 21)</td>
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<td>Denton (1967)</td>
<td>&quot;Lineation includes all linear structures in rocks without regard to origin. The term excludes purely superficial features, such as glacial striations.&quot; (p. 103)</td>
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<tr>
<td>Billings (1972)</td>
<td>&quot;Lineation is the result of the parallelism of some directional property in the rock, such as the long axes of hornblende crystals. Play minerals or spherical grains may be stretched in lines to produce a lineation&quot; (p. 328)</td>
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</tbody>
</table>

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

**AGT Glossary of Geology** (Gary and others, 1972)

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

Classification System

- Fault
- Dike
- Lithological Contact
- Landsat lineament
- Degree of Expression (subjective categorization)

geology maps
any straight to curvilinear feature not identified as a fault, dike or lithological contact
- 1st Order - strongly expressed
- 2nd Order
- 3rd Order - weakly expressed
Computer Programs Used to Generate Lineament Statistics

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166 &CHAP-1
168 &CHAP-1
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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 Opatica Belt

Actual Azimuth Classes

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On the Printout

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180° = -90° (west) in text
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- 40 - 60: 3.875753
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APPENDIX E - FORMULA

Formula Used for Calculation of Pearson Product Moment Correlation Coefficient

\[
\frac{n(\sum xy) - (\sum x)(\sum y)}{\sqrt{n(\sum x^2) - (\sum x^2)(n(\sum y^2) - (\sum y)^2)}}
\]
BIBLIOGRAPHY


Bruce, B. (1981) - oral communication, Canada Centre for Remote Sensing, Ott.


Wetmiller (1980) - oral communication, Earth Physics Branch, E.M.R.


A. Topographic - National Topographic Series, E.M.R.

1:250,000
31L  -  North Bay
31M  -  Ville Marie
32D  -  Noranda-Rouyn
32E  -  Upper Harricanaw
32L  -  Lower Harricanaw
41-L  -  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
  - Guay - Bruchesi Area - No. 1397
  - Compilation Geologique du District De Kipawa, P. Tremblay
    and C.L. Kish - No. 579.

- Geological Survey of Canada 1:2,000,000 "Geology of Eastern Canada and Adjacent Areas" Map 1401A (SW)
C. Surficial Geology


- Northern Ont. Engineering Geology Terrain Study Maps (Nos. 5019 to 5041), 1:100,000, Ministry of Natural Resources.

D. Forest Stand Maps (1:50,000)

- Ontario Ministry of Natural Resources
  - by county - Coleman Best
    Kittson Chambers
    Lorrain Strathy
    Brigstocke Cassels
    Gillies-Limit
    Banting

E. Aeromagnetic Maps

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

F. AIR PHOTOS

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 0 Prints 2 to 10, 30 to 37

obtained from N.A.P.L. (National Air Photo Library), Ottawa
NORTHEAST ARM SUBSCENE DIGITAL LINEAMENT MAP
-NORTHEAST ARM SUBSCENE-
DIGITAL LINEAMENT MAP

Fig. 4.6
- Mapped Fault
- Mapped Dike
- Landsat Lineament
- Lithological Contact
- Grenville Front
- Low Density (see table 4.4)
RIB LAKE SUBSCENE
SURFICIAL EXPRESSION OF LINEAMENTS

Fig. 4.8
-TEE LAKE SUBSCENE-
DIGITAL LINEAMENT MAP
- Mapped Fault
- Landsat Lineament
- Epicentre Area (Tee Lake Earthquake-1935)
- Lithological Contact
- Low Density (see table 4.4)
- 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)
C Circular Feature (see section 5.2.3.1)
LAKE ST. AMAND SUBSCENE
DIGITAL LINEAMENT MAP
Landsat Lineament
Low Density (see table 4.4)
RIB LAKE SUBSCENE
LINEAMENTS DERIVED FROM AIR PHOTO ANALYSIS

RIBL.U3NA WATER MAP
TOP LEFT (O. 0)
SCALE 1:120000
THEMES: 7
RIB LAKE SUBSCENE
LINEAMENTS DERIVED FROM GEO.
RIB LAKE SUBSCENE
LINEAMENTS DERIVED FROM GEOLOGY MAPS
Fault
- Dike

Identification Mark (see section 4.3.2.1)

1. Ontario Geological Survey - Map 2361 - Sudbury - Cobalt
2. Ontario Dept. of Mines - Map 2198 - Ontario Geological Map East Central Sheet
RIB LAKE SUBSCENE
LINEAMENTS DERIVED FROM GENERAL
LINEAMENT MAP (1:1,000,000 - VISUAL

RIB LAKE SUBSCENE WATERSHED

TOP LEFT: (6, 0)
SCALE: 1:1,000,000
RIB LAKE SUBSCENE

LINEAMENTS DERIVED FROM GENERAL LANDSAT LINEAMENT MAP (1:1,000,000 - VISUAL ANALYSIS)
Fig. 4.5

MAXAM LAKE SUBSCENE
DIGITAL LINEAMENT MAP
- 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

Low Density (see table 4.4)
RIB LAKE SUBSCENE
DIGITAL DATA SOURCES

Fig. 4.3
FIG. 5
BOREAL FOREST AND
BOREAL FOREST PREDOMINANT
FIG. 2.2
FOREST REGIONS

5

BOREAL FOREST
FOREST AND BARREN

BOREAL FOREST
PREDOMINANTLY FOREST
AREA

Source -
FIG. 5.14
SANDSTONE DENSITY CONTOUR MAP
(LENGTH PER 20x20 km GRID SQUARE)
6 Classes - Minimum = 14 km
- Maximum = 146 km

Contour Interval = 22 km

L1–3 = Low Density
H1–5 = High Density

Areas of uncertain interpretation
due to surficial cover

See table 5.6
6 Classes - Minimum = 0 Intersections
- Maximum = 11 Intersections

Contour Interval = 1.83 Intersections

--- Areas of uncertain interpretation due to surficial cover
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
Ψ Glacial Striation (sense of direction known or inferred)
↓ Drumlinoid Ridge
Sources
Northern Ontario Engineering Geology Map Series
1:100,000 - O.G.S. Map 5000 et seq.

Ontario Department of Lands and Forests
Maps S365 and S465 (1:50,000) A.N. Boissooneau

Prest et al 1967 - Glacial Map of Canada (1:5,000,000)
G.S.C. Map 1253-A

J.J. Veillette (G.S.C. pers comm., 1981)
FIG. 5.13
LINEAMENT DENSITY CONTOUR MAP
(FREQUENCY PER 20 x 20 km GRID SQUARE)
6 Classes - Minimum = 4 Lineaments
- Maximum = 25 Lineaments
Contour Interval = 3.5 Lineaments
--- Areas of uncertain interpretation due to surficial cover
FIG. 512

HISTORY OF MAJOR LINEAMENT TRENDS

Legend:
- Arrow 9: Northwest-Southeast
- Arrow 10: Northeast-Southwest
END
100984
FIN