The University of British Columbia

FACULTY OF GRADUATE STUDIES

PROGRAMME OF THE

FINAL ORAL EXAMINATION

FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

of

NEIL CHURCH

B.Sc., McMaster University, 1959
M.Sc., McMaster University, 1963

FRIDAY, MAY 26, 1967 AT 10.30 A.M.

IN ROOM 102, GEOLOGY BUILDING.

COMMITTEE IN CHARGE

Chairman:  I. McTaggart Cowan
A. L. Farley        J. V. Ross
W. H. Mathews       G. E. Rouse
K. C. McTaggart     W. F. Slawson

Research Supervisor:  W. H. Mathews

External Examiner:  Howel Williams
Professor Emeritus,
Department of Geology,
University of California,
Berkeley.
GEOLOGY OF THE WHITE LAKE AREA

ABSTRACT

The object of this study is to establish the stratigraphy, structure and petrology of early Tertiary rocks in the White Lake area near Penticton, British Columbia. This is achieved by field mapping and laboratory work.

Early Tertiary rocks of the White Lake area, thought to be mainly Eocene age, consist of five main stratigraphic divisions:

1. discontinuous beds of basal breccia and conglomerate;
2. a thick and widely distributed succession of volcanic rocks of diverse composition - mainly phonolite, trachyte, and andesite lavas;
3. discontinuous volcanic beds - mainly rhyodacite lava;
4. locally thick volcanic sandstone and conglomerate beds interdigitated with lahar and pyroclastic deposits;
5. local deposits of slide breccia and some volcanic rock overlain by fanglomerate beds.

Each division rests with some angular or erosional unconformity on older rock. Aggregate thickness of the Tertiary strata, where best developed, is about 12,000 ft.

These rocks are regionally downfaulted accounting, in part, for their preservation from erosion. Greatest downward movement is near the Okanagan Valley where, in places, it is estimated that basal beds exceed depths of -5000 feet (m.s.l.). In general, beds are tilted easterly as if rotated downward forming a trap-door-
like structure. Locally, folds are developed but these are without regional pattern and may be the result of simple flexures in the basement rocks.

Petrographic and chemical data indicates a three-fold division of igneous rocks:

'A' series - mainly plagioclase porphyries: lavas of rhyodacite and andesite composition;
'B' series - mainly two feldspar porphyries with co-existing plagioclase and sanidine; lavas of trachite and trachyandesite composition;
'C' series - mainly anorthoclase porphyries: lavas of phonolite composition; and some tephrite.

Phase diagrams and subtraction plots indicate that rocks of 'A' and 'C' series were probably formed by crystal fractionation. In the case of 'A' series, precipitation of mainly plagioclase and pyroxene from andesite produces rhyolite; and for 'C' series, precipitation of mainly pyroxene and some biotite from tephrite produces phonolite.

Rocks of 'B' series are intermediate in composition to 'A' and 'C' and were probably formed by mixing of magmas.
GRADUATE AND RELATED STUDIES

X-ray Mineralogy
Spectrochemical Analysis
Igneous Petrology
Advances Geochemistry
Paleobotany
Advanced Igneous and Metamorphic Petrology
Structural Analysis
Geomorphology

AWARDS

1957-58 The California Standard Company Scholarship
1958-59 The E.S. Moore Prize in Geology
1960-61 The National Research Council Studentship
1964 The Shell Company Grant-in-aid
1965-67 The University of British Columbia Fellowship

PUBLICATIONS


GEOLOGY OF THE WHITE LAKE AREA

by

BARRY NEIL CHURCH
B.Sc., McMaster University, 1959
M.Sc., McMaster University, 1963

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF
THE REQUIREMENTS FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

in the Department of
GEOLOGY

We accept this thesis as conforming
to the required standard

THE UNIVERSITY OF BRITISH COLUMBIA

May, 1967
In presenting this thesis in partial fulfilment of the requirements for an advanced degree at the University of British Columbia, I agree that the Library shall make it freely available for reference and study. I further agree that permission for extensive copying of this thesis for scholarly purposes may be granted by the Head of my Department or by his representatives. It is understood that copying or publication of this thesis for financial gain shall not be allowed without my written permission.

Department of

Geology

The University of British Columbia
Vancouver 8, Canada

Date May 26th, 1967
Abstract

The object of this study is to establish the stratigraphy, structure, and petrology of early Tertiary rocks in the White Lake area near Penticton, British Columbia. This is achieved by field mapping and laboratory work.

Early Tertiary rocks of the White Lake area, thought to be mainly Eocene age, consist of five main stratigraphic division:

1. discontinuous beds of basal breccia and conglomerate,
2. a thick and widely distributed succession of volcanic rocks of diverse composition - mainly phonolite, trachyte, and andesite lavas,
3. discontinuous volcanic beds - mainly rhyodacite lava,
4. locally thick volcanic sandstone and conglomerate beds interdigitated with lahar and pyroclastic deposits,
5. local deposits of slide breccia and some volcanic rock overlain by fanglomerate beds.

Each division rests with some angular or erosional unconformity on older rock. Aggregate thickness of the Tertiary strata, where best developed, is about 12,000 feet.

These rocks are regionally downfaulted accounting, in part, for their preservation from erosion. Greatest downward movement is near the Okanagan Valley where, in places, it is estimated that basal beds exceed depths of -5,000 feet (m.s.l.). In general, beds are tilted easterly as if rotated downward forming a trap-door-like structure. Locally, folds are developed but these are without regional pattern and may be the result of simple flexures in the basement rocks.

Petrographic and chemical data indicates a three-fold division of igneous rocks:

'A' series - mainly plagioclase porphyries; lavas of rhyodacite and andesite composition;
'B' series - mainly two feldspar porphyries with co-existing plagioclase and sanidine; lavas of trachyte and trachyandesite composition;

'C' series - mainly anorthoclase porphyries; lavas of phonolite composition and some tephrite.

Phase diagrams and subtraction plots indicate that rocks of 'A' and 'C' series were probably formed by crystal fractionation. In the case of 'A' series, precipitation of mainly plagioclase and pyroxene from andesite produces rhyolite; and for 'C' series, precipitation of mainly pyroxene and some biotite from tephrite produces phonolite.

Rocks of 'B' series are intermediate in composition to 'A' and 'C' and were probably formed by mixing of magmas.
TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>CHAPTER I: INTRODUCTION</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCOPE AND CONTENT</td>
<td>1</td>
</tr>
<tr>
<td>LOCATION AND ACCESS</td>
<td>1</td>
</tr>
<tr>
<td>NATURE OF MAP-AREA</td>
<td>1</td>
</tr>
<tr>
<td>PREVIOUS WORK</td>
<td>4</td>
</tr>
<tr>
<td>FIELD WORK</td>
<td>6</td>
</tr>
<tr>
<td>GEOLOGICAL SETTING</td>
<td>6</td>
</tr>
</tbody>
</table>

CHAPTER II: GENERAL GEOLOGY AND STRUCTURE .................................. 14

PRE-TERTIARY ROCKS ......................................................................... 14

TERTIARY ROCKS ............................................................................. 14

1. BASAL TERTIARY SURFACE ............................................................... 15

2. DETAILED DESCRIPTION OF FORMATIONS ......................................... 17

   A. SPRINGBROOK FORMATION .......................................................... 17

      a. Distribution and Thickness ............................................. 17

      b. Lithology ....................................................................... 20

      c. Structure ..................................................................... 20

      d. Age ............................................................................ 25

      e. Correlation ................................................................. 25

   B. MARRON FORMATION .................................................................. 26

      Yellow Lake Porphyry Member .................................................. 28

      a. Distribution and Thickness ............................................. 28

      b. Lithology ..................................................................... 29

      Clot-Porphyry Member .......................................................... 29

      a. Distribution and Thickness ............................................. 32

      b. Lithology ..................................................................... 32
<table>
<thead>
<tr>
<th>Topic</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>'Basal Breccias'</td>
<td>67</td>
</tr>
<tr>
<td>a. Distribution and Thickness</td>
<td>67</td>
</tr>
<tr>
<td>b. Lithology</td>
<td>67</td>
</tr>
<tr>
<td>'Augite-Porphyry'</td>
<td>70</td>
</tr>
<tr>
<td>'Granite Breccia'</td>
<td>75</td>
</tr>
<tr>
<td>a. Distribution and Thickness</td>
<td>75</td>
</tr>
<tr>
<td>b. Lithology</td>
<td>78</td>
</tr>
<tr>
<td>Upper Member</td>
<td>85</td>
</tr>
<tr>
<td>a. Distribution and Thickness</td>
<td>85</td>
</tr>
<tr>
<td>b. Lithology</td>
<td>85</td>
</tr>
<tr>
<td>Structure</td>
<td>88</td>
</tr>
<tr>
<td>Age and Correlation</td>
<td>93</td>
</tr>
<tr>
<td>3. RÉSUMÉ OF GENERAL STRUCTURE</td>
<td>93</td>
</tr>
<tr>
<td>GLACIAL GEOLOGY</td>
<td>100</td>
</tr>
<tr>
<td>Ice Thickness and Movement</td>
<td>101</td>
</tr>
<tr>
<td>Meltwater Drainage and Glacial Deposits</td>
<td>101</td>
</tr>
<tr>
<td>CHAPTER III: IGNEOUS PETROLOGY</td>
<td>104</td>
</tr>
<tr>
<td>MAIN PETROGRAPHIC FEATURES</td>
<td>104</td>
</tr>
<tr>
<td>CHEMICAL VARIATION</td>
<td>106</td>
</tr>
<tr>
<td>PETROGRAPHIC PROVINCES</td>
<td>114</td>
</tr>
<tr>
<td>PETROGENESIS</td>
<td>119</td>
</tr>
<tr>
<td>CHAPTER IV: SUMMARY AND CONCLUSIONS</td>
<td>128</td>
</tr>
<tr>
<td>GEOLOGICAL HISTORY</td>
<td>128</td>
</tr>
<tr>
<td>PETROLOGY</td>
<td>131</td>
</tr>
<tr>
<td>SUGGESTIONS FOR FUTURE WORK</td>
<td>134</td>
</tr>
<tr>
<td>BIBLIOGRAPHY</td>
<td>135</td>
</tr>
<tr>
<td>APPENDIX 'A': CHEMICAL ANALYSES</td>
<td>Page</td>
</tr>
<tr>
<td>---------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>APPENDIX 'B': CALCULATION OF NORMS</td>
<td>147</td>
</tr>
<tr>
<td>APPENDIX 'C': PETROGRAPHIC DESCRIPTIONS</td>
<td>150</td>
</tr>
</tbody>
</table>

ROCKS OF 'A' SERIES

1 - Basaltic Andesite
2 - Andesite
3 - Rhyodacite
4 - Rhyolite

ROCKS OF 'B' SERIES (Trachytes, Trachyandesites)

1 - Clot-Porphyries
2 - Rosette-Porphyries
3 - White Lake Feldspar-Porphyries

ROCKS OF 'C' SERIES

1 - Rhomb-Porphyry (Phonolite)
2 - Augite-Porphyry (Tephrite)
# LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.0</td>
<td>Tertiary Formations</td>
</tr>
<tr>
<td>2.1</td>
<td>Summary of Lithology of Springbrook Formation and Lower Marron Formation</td>
</tr>
<tr>
<td>2.2</td>
<td>Composition of Yellow Lake Porphyries</td>
</tr>
<tr>
<td>2.3</td>
<td>Composition of Clot-Porphyries</td>
</tr>
<tr>
<td>2.4</td>
<td>Composition of Rosette-Porphyries</td>
</tr>
<tr>
<td>2.5</td>
<td>Composition of Park Rill andesite</td>
</tr>
<tr>
<td>2.6</td>
<td>Correlation of Marron Formation and Midway Group</td>
</tr>
<tr>
<td>2.7</td>
<td>Composition of Marama Rocks</td>
</tr>
<tr>
<td>2.8</td>
<td>Composition of Augite-Porphyry</td>
</tr>
<tr>
<td>2.9</td>
<td>Description of Common Boulders in Upper Member (Skaha Formation)</td>
</tr>
<tr>
<td>3.0</td>
<td>Key to Analyses, Figure 3.1</td>
</tr>
<tr>
<td>3.1</td>
<td>Key to Analyses, Figures 3.2, 3.3, and 3.4</td>
</tr>
<tr>
<td>3.2</td>
<td>Composition of Main Phases of Coryell Batholith and Similar Rocks of 'B' and 'C' Series</td>
</tr>
<tr>
<td>3.3</td>
<td>Normative Calculations, 'y' as Pyroxene, Biotite, and Potash Residuals</td>
</tr>
<tr>
<td>4.0</td>
<td>Outline of Cenozoic Geological Events</td>
</tr>
<tr>
<td>A.1</td>
<td>Chemical Composition of Rocks, White Lake Map-area</td>
</tr>
<tr>
<td>A.2</td>
<td>Partial Analyses of Rocks, White Lake Map-area</td>
</tr>
<tr>
<td>A.3</td>
<td>Chemical Analyses from Other Studies</td>
</tr>
<tr>
<td>A.4</td>
<td>Average Analyses from Other Studies</td>
</tr>
<tr>
<td>B.1</td>
<td>Normative Compositions</td>
</tr>
<tr>
<td>C.1</td>
<td>Feldspar X-ray Diffraction Data</td>
</tr>
<tr>
<td>C.2</td>
<td>Analyses of Rhomb-shaped Anorthoclase</td>
</tr>
</tbody>
</table>
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>Location of Map-Area</td>
<td>2</td>
</tr>
<tr>
<td>1.2</td>
<td>Plot of Reconnaissance Traverses in Map-Area</td>
<td>7</td>
</tr>
<tr>
<td>1.3</td>
<td>Location of Early Tertiary Bedded Rocks</td>
<td>10</td>
</tr>
<tr>
<td>1.4</td>
<td>Refractive Index Frequency for Lavas in the White Lake, Kelowna, and Midway Areas</td>
<td>11</td>
</tr>
<tr>
<td>1.5</td>
<td>Grabens of Southwestern British Columbia and Northern Washington State</td>
<td>12</td>
</tr>
<tr>
<td>1.6</td>
<td>Listric Normal Faults in South-Central B.C.</td>
<td>13</td>
</tr>
<tr>
<td>2.1</td>
<td>Inferred Configuration of Basal Tertiary Surface</td>
<td>18</td>
</tr>
<tr>
<td>2.2</td>
<td>Grain Analyses of Springbrook Sediment</td>
<td>23</td>
</tr>
<tr>
<td>2.3</td>
<td>Size Frequency Cumulative Curves of Springbrook Sediment</td>
<td>24</td>
</tr>
<tr>
<td>2.4</td>
<td>Glass Bead Refractive Indices of Marron and Marama Lavas</td>
<td>47</td>
</tr>
<tr>
<td>2.5</td>
<td>Trout Lake Graben</td>
<td>50</td>
</tr>
<tr>
<td>2.6</td>
<td>Generalized Columnar Sections of White Lake Beds</td>
<td>55</td>
</tr>
<tr>
<td>2.7</td>
<td>Structure Section of White Lake Beds on North Limb of Syncline</td>
<td>60</td>
</tr>
<tr>
<td>2.8</td>
<td>Composition of White Lake Sandstones</td>
<td>61</td>
</tr>
<tr>
<td>2.9</td>
<td>Refractive Index Variation of White Lake Volcanic Rocks</td>
<td>62</td>
</tr>
<tr>
<td>2.10</td>
<td>Resultant Vector Diagrams for Dip of White Lake Beds Measured from D.D.H. Core</td>
<td>63</td>
</tr>
<tr>
<td>2.11</td>
<td>Diagrammatic Structure Section of Concentric Folds and Related Faults</td>
<td>64</td>
</tr>
<tr>
<td>2.12</td>
<td>Cross-Bedding Directions in White Lake Sediments</td>
<td>65</td>
</tr>
<tr>
<td>2.13</td>
<td>Comparison of Refractive Indices of Pulakite Dikes and Trachyte - Trachyandesite Lavas</td>
<td>71</td>
</tr>
<tr>
<td>2.14</td>
<td>Size Distribution of Skaha Chert Breccia</td>
<td>72</td>
</tr>
<tr>
<td>2.15</td>
<td>Internal Structure of Part of Granite Breccia Unit</td>
<td>80</td>
</tr>
</tbody>
</table>
2.16 Composition of Skaha Sandstones .......................... 91
2.17 Some Late Structures in Rocks East of White Lake .... 94
2.18 Equal Area Diagrams ....................................... 95
2.19 Possible Stress Scheme for Late Movement, Area near White Lake .......................... 96
2.20 Structural Subdivisions of Map-Area and Adjacent Region .......................... 97
2.21 Cross-Section of White Lake Basin .......................... 99
2.22 Plot of Ice Movement in Area East of White Lake ... 101
2.23 Topographic Section Showing Glacial Features in Vicinity of the Hole .......................... 103
3.1 Early Tertiary Igneous Rock Series .......................... 107
3.2 Variation Diagram, 'A' Series .......................... 109
3.3 Variation Diagram, 'B' Series .......................... 110
3.4 Variation Diagram, 'C' Series .......................... 111
3.5 Some Minor Element Variations .......................... 115
3.6 Cenozoic Petrographic Regions of Southern British Columbia and Washington State .......................... 117
3.7 Phase Diagrams .......................... 121
3.8 Subtraction Diagram, 'A' Series .......................... 122
3.9 Subtraction Diagram, 'C' Series .......................... 123
3.10 Coexisting Plagioclase and Potassic Feldspar in Two Feldspar Rocks .......................... 125
3.11 Mixing Diagram .......................... 127
4.1 Generalized Columnar Section .......................... 130
C.1 Illustration of Habit and Optical Orientation of Rhomb-shaped Anorthoclase .......................... 174
<table>
<thead>
<tr>
<th>Plate</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Springbrook Formation, in west part of map-area south of Highway 3</td>
<td>19</td>
</tr>
<tr>
<td>2.2</td>
<td>Springbrook beds, two miles west of Green Ranch</td>
<td>22</td>
</tr>
<tr>
<td>2.3</td>
<td>Contact between Marron and Springbrook beds, near Yellow Lake</td>
<td>27</td>
</tr>
<tr>
<td>2.4</td>
<td>Blocky top of rhomb-porphyry lava flow</td>
<td>31</td>
</tr>
<tr>
<td>2.5</td>
<td>Slabby pillars, clot-porphyry lava</td>
<td>33</td>
</tr>
<tr>
<td>2.6</td>
<td>Conformable clot-porphyry and Yellow Lake porphyry lavas, north of Yellow Lake</td>
<td>40</td>
</tr>
<tr>
<td>2.7</td>
<td>Conformable Park Rill andesite and rosette-prophyry lavas, south of Park Rill near T.L. Ranch</td>
<td>40</td>
</tr>
<tr>
<td>2.8, 2.9, and 2.10</td>
<td>Gravity fault displacement of Marron rocks north of Yellow Lake</td>
<td>42</td>
</tr>
<tr>
<td>2.11</td>
<td>Marama Formation, west of Highway 3 near Marama Creek</td>
<td>45</td>
</tr>
<tr>
<td>2.12A, B</td>
<td>Small infill cycle, White Lake sediments, south limb of White Lake syncline</td>
<td>56</td>
</tr>
<tr>
<td>2.13</td>
<td>Interbedded lahar and pyroclastic deposits, White Lake volcanic rocks near White Lake</td>
<td>57</td>
</tr>
<tr>
<td>2.14</td>
<td>Bluffs of White Lake volcanic rocks, near White Lake.</td>
<td>57</td>
</tr>
<tr>
<td>2.15</td>
<td>'Basal breccias' (mainly dark chert) overlying White Lake beds (mainly light coloured pyroclastic rocks)</td>
<td>68</td>
</tr>
<tr>
<td>2.16</td>
<td>Conglomerate zone immediately below 'basal breccias' Indian Head</td>
<td>68</td>
</tr>
<tr>
<td>2.17</td>
<td>'Basal breccias' (highly fragmented bedded chert breccia) overlying White Lake volcanic rocks, canyon of Kearns Creek west of The Hole</td>
<td>69</td>
</tr>
<tr>
<td>2.18</td>
<td>Highly fragmented chert breccia, 'basal breccias'</td>
<td>69</td>
</tr>
<tr>
<td>2.19</td>
<td>Intrusive chert breccia in conglomerate beds, lower member Skaha Formation</td>
<td>73</td>
</tr>
<tr>
<td>2.20</td>
<td>Augite-porphyry lava (tephrite) overlying crossbedded sandstone, near The Hole</td>
<td>74</td>
</tr>
<tr>
<td>Plate</td>
<td>Description</td>
<td>Page</td>
</tr>
<tr>
<td>-------</td>
<td>--------------------------------------------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>2.21</td>
<td>Augite-porphyry dike and intrusive chert breccia in conglomerate, lower member Skaha Formation</td>
<td>76</td>
</tr>
<tr>
<td>2.22</td>
<td>Porphyritic granite</td>
<td>79</td>
</tr>
<tr>
<td>2.23</td>
<td>Aphanitic granite</td>
<td>79</td>
</tr>
<tr>
<td>2.24</td>
<td>Uncrushed granite typical of large slabs, 'granite breccia zone'</td>
<td>81</td>
</tr>
<tr>
<td>2.25</td>
<td>Granite 'autobreccia' with crushed dike</td>
<td>82</td>
</tr>
<tr>
<td>2.26</td>
<td>Internal structure of 'autobrecciated' dike</td>
<td>82</td>
</tr>
<tr>
<td>2.27</td>
<td>'Frictional breccia', layered deposits of mobilized granite and dike rock breccia, east of The Hole</td>
<td>83</td>
</tr>
<tr>
<td>2.28</td>
<td>Granite-block conglomerate cemented by arkose</td>
<td>84</td>
</tr>
<tr>
<td>2.29</td>
<td>Arkosic sandstone bed in granite-boulder conglomerate</td>
<td>84</td>
</tr>
<tr>
<td>2.30</td>
<td>Igneous intrusion in breccias, lower member Skaha Formation</td>
<td>86</td>
</tr>
<tr>
<td>2.31</td>
<td>Skaha beds east of The Hole</td>
<td>87</td>
</tr>
<tr>
<td>2.32</td>
<td>Boulder of arkosic sandstone in upper member, Skaha Formation</td>
<td>90</td>
</tr>
<tr>
<td>2.33</td>
<td>Chert block in upper member, Skaha Formation</td>
<td>90</td>
</tr>
<tr>
<td>2.34</td>
<td>Channel deposit in upper member, Skaha Formation</td>
<td>92</td>
</tr>
<tr>
<td>2.35</td>
<td>Hoodoo structure in conglomerate, upper member Skaha Formation</td>
<td>92</td>
</tr>
<tr>
<td>C.1</td>
<td>Hand specimen of typical basaltic andesite</td>
<td>152</td>
</tr>
<tr>
<td>C.2</td>
<td>Photomicrograph of basaltic andesite</td>
<td>152</td>
</tr>
<tr>
<td>C.3</td>
<td>Photomicrograph of merocrystalline andesite</td>
<td>156</td>
</tr>
<tr>
<td>C.4</td>
<td>Photomicrograph of vitric andesite</td>
<td>156</td>
</tr>
<tr>
<td>C.5</td>
<td>Typical platy habit of rhyodacite lava</td>
<td>158</td>
</tr>
<tr>
<td>C.6</td>
<td>Photomicrograph of rhyodacite</td>
<td>158</td>
</tr>
<tr>
<td>C.7</td>
<td>Fluidal banding in rhyolite</td>
<td>160</td>
</tr>
<tr>
<td>C.8</td>
<td>Photomicrograph of rhyolite</td>
<td>160</td>
</tr>
<tr>
<td>C.9</td>
<td>Photomicrograph of clot-porphyry trachyte</td>
<td>164</td>
</tr>
<tr>
<td>Plate</td>
<td>Description</td>
<td>Page</td>
</tr>
<tr>
<td>---------</td>
<td>-----------------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>C.10</td>
<td>Photomicrography of clot-porphyry trachyandesite</td>
<td>164</td>
</tr>
<tr>
<td>C.11</td>
<td>Typical massive rosette-porphyry lava</td>
<td>167</td>
</tr>
<tr>
<td>C.12</td>
<td>Photomicrograph of rosette-porphyry trachyandesite</td>
<td>168</td>
</tr>
<tr>
<td>C.13</td>
<td>Photomicrograph of rosette-porphyry trachyte</td>
<td>168</td>
</tr>
<tr>
<td>C.14</td>
<td>Photomicrograph of White Lake feldspar porphyry trachyte</td>
<td>171</td>
</tr>
<tr>
<td>C.15</td>
<td>Typical rhomb-shaped anorthoclase phenocryst from Yellow Lake lava</td>
<td>176</td>
</tr>
<tr>
<td>C.16</td>
<td>Photomicrograph of Yellow Lake lava</td>
<td>177</td>
</tr>
<tr>
<td>C.17</td>
<td>Photomicrograph of well cleaved apatite in rhomb-porphyry lava</td>
<td>177</td>
</tr>
<tr>
<td>C.18</td>
<td>Photomicrograph of (010) section of anorthoclase</td>
<td>178</td>
</tr>
<tr>
<td>C.19</td>
<td>Photomicrograph of (001) section of anorthoclase</td>
<td>178</td>
</tr>
<tr>
<td>C.20</td>
<td>Hand specimen of White Lake augite-porphyry (tephrite) charged with granite xenoliths</td>
<td>183</td>
</tr>
<tr>
<td>C.21</td>
<td>Photomicrograph of Skaha augite-porphyry lava</td>
<td>183</td>
</tr>
</tbody>
</table>
The writer wishes to convey his sincere thanks to Professor W.H. Mathews who sponsored the study and supervised preparation of the manuscript.

Gratitude is extended to Professor W.H. White, Professor R.M. Thompson, and Dr. R.V. Best for use of U.B.C. Geology Field School and for advice on geology of the map-area.

Special thanks are owing Dr. K.C. McTaggart, Dr. J.V. Ross, and Dr. A.L. Farley for helpful criticism of the work, and Professor Howel Williams who, through the courtesy of Anaconda American Metal Brass Co., was able to visit the field-area with the writer. Also, Dr. G.E. Rouse kindly assisted in identification of some plant fossils.

The writer is obliged to officers of the Geological Survey of Canada, especially Dr. H.W. Little and Dr. J.W.H. Monger for constructive suggestions, and Dr. J.G. Souther for chemical analyses.

Assistance provided by other staff members of the University of British Columbia, fellow graduate students, and technicians, is gratefully acknowledged.

Financial assistance was provided by the Shell Oil Co. and the University of British Columbia.
CHAPTER I
INTRODUCTION

SCOPE AND CONTENT

The object of this study is to establish the stratigraphic succession, structural history, and petrology of early Tertiary volcanic rocks in a typical, well exposed, and accessible area of southern British Columbia.

Field descriptions are amplified with detailed laboratory data including rock and mineral determinations and chemical studies.

LOCATION AND ACCESS

White Lake map-area is in south-central British Columbia, approximately 150 miles due east of Vancouver and 8 miles south of Penticton in the southern Okanagan region. It covers about 65 square miles lying roughly between lat. 49° 17' and 49° 23' N. and long. 119° 34' and 119° 48' W.

Provincial Highway 3 passes through the area on the northwest and 97 on the east. An excellent gravel road turns west from Highway 97 near junction with Highway 3 and passes south to the Dominion Radio Astrophysical Observatory, branching west here to Twin Lakes and south past White Lake. Dirt farm and logging roads provide good access to parts remote from secondary roads and highways (see Figure 1.1).

The village of Okanagan Falls is located in the east part of the map-area and provides local essential services. This is also a station on the Okanagan branch line of the Canadian Pacific Railway.

The Geology Field School of the University of British Columbia lies about 6 miles south of the map-area and is accessible on good gravel roads.

NATURE OF MAP-AREA

The White Lake map-area is characterized mainly by a low mountainous terrain bounded on the east by the Okanagan and tributary
Figure 1.1 Location of Map-Area
valleys (local base level about 1,100 feet m.s.l.), and on the west by valleys tributary to the Similkameen drainage system (local base level about 1,800 feet m.s.l.). Shales eroded from a basin-like geological structure underlie a dish-shaped topographic depression in the east-central part of the map-area. Slopes rise gently from White Lake, a small ephemeral body of water near the center of the depression (about 1,750 feet m.s.l.), to an almost complete ring of hills. Concordant summits northwest and southwest of White Lake underlie a remnant of a once continuous upland surface, about 4,500 feet m.s.l., known as the Thompson Plateau (Holland, 1965). To the east the depression is separated from Okanagan Valley by numerous small knobs and ridges and by Mt. Hawthorn which rises to 2,750 feet. The basin rim is breached by several valleys containing small intermittent streams.

Low parts and south-facing slopes in the map-area are open ranch lands with plentiful bunch-grass, sage brush, and cactus. Summits and north-facing slopes have forests of pine and fir of sufficient density to support several logging operations.

Climatic conditions are severe, the area being in a dry belt. The total annual precipitation, combined rain and snow, is only about 11 inches (heaviest precipitation is during winter months). Temperatures are recorded in excess of 100 degrees Fahrenheit for short periods during mid-summer.

Some ponds and larger bodies of open water in the area are saline or stagnant and are not considered drinkable.

Animal life is abundant and markedly varied. Bear, deer, and grouse are hunted by local sportsmen. Poisonous spotted prairie rattlesnakes inhabit talus slopes and rocky ledges and are considered hazardous by ranchers and surveyors. Brown mud turtles live in Mahoney and Green lakes in the southeast part of map-area and are a tourist attraction. Also, a popular magazine reports (Western Homes and Living, June 1966, p. 42):

"White Lake basin is of great interest to ornithologists, who come here to explore one of the few remaining nesting sites in British Columbia of the Long-billed Curlew. In early summer, lucky bird watchers may hear the flute-like tones 'curl-e-e-e-e-u-u-u' drifting across the open plain. 'It never ceases to sadden' one naturalist wrote, 'for this call with its mournful quality is the symbol of our vanishing grass lands.'"
The presence of Tertiary rocks in the White Lake area was reported by Dawson (1879) during a reconnaissance survey of southern British Columbia. No geological information on this area was published until local gold mining activity created a market for cheap blacksmithing coal.

The first geological report, prepared by Camsell (1913), was entitled White Lake Coal Area. This account is brief but accurate in broad aspect, providing the basis, in part, for later mapping by Bostock and for the present study. The following is an extract from Camsell's report (p.215):

"In general the structure of the White Lake coal area is that of a synclinal basin, the strike of which is east and west. In detail, however, there are often wide variations from this direction, especially on the eastern side of the area where apparently there has been considerable disturbance since the deposition of the coal-bearing beds. The dips range 0° to 50° and average about 20°. Some faulting has taken place, especially in the disturbed region on the east.

The rocks of the coal-bearing formation (White Lake Formation) appear to have been laid down in a gradually subsiding basin on the western edge of a region in which volcanism was active at intervals throughout the whole period of their deposition. The eruptions at this focus were of the explosive type and great volumes of tuff were blown out and deposited in the basin. In parts of the basin these tuffs were water worn to form true sandstones; but in other parts they have not been so worn and they retain the same angularity of the grain when first ejected.

Overlying the coal-bearing rocks on the east is a series of volcanic breccias and tuffs and some flows of an andesite or more acid nature. In places the overlying volcanic rocks succeed the coal-bearing rocks conformably; but in other places there is a marked angular unconformity between them. It is probable, however, that this unconformity does not indicate any great time interval between the two series. The upper volcanic rocks occupy an exceedingly irregular and broken country to the east of the coal basin, which no doubt is the source from which tuffs were derived. This broken country is apparently the locus of an ancient Tertiary volcano which was active at intervals during and after the deposition of the coal-bearing rocks. It has all the characteristics of an ancient, denuded volcanic crater about a mile in diameter, the bottom and sides of which have slumped in leaving a series of steep-sided hills and deep sinkholes now often filled with water."
Camsell's description of the coal-bearing beds will be given in chapter two of this report.

A report by Dowling (1915), entitled 'Coal Fields of British Columbia', contains a description by McEvoy of coal-bearing beds cropping out along Kearns Creek, about a half mile north of White Lake.

The first comprehensive geological survey of the area was completed by Bostock (1941). He clearly delineated the Tertiary deposits on 15 minute quadrangle maps 627A and 628A (Geological Survey, Canada) on a mile to an inch scale. The Tertiary rocks were divided into a lower sedimentary unit, the Springbrook Formation, overlain by a succession of lavas, the Marron Formation, overlain in turn by volcanic rocks and fluvial and lacustrine sediments, White Lake Formation, and an upper unnamed volcanic and sedimentary sub-unit.

Cairnes (1937) presented an account of the mineral deposits of the Kettle River area, west half; map 538A (Geological Survey, Canada) by Cairnes shows Bostock's geology of the White Lake area unmodified.

Map 15-1961 (Geological Survey, Canada) by Little, amplifies the structural data of the area.

Other information relative to the geology of the White Lake area stems from thesis-studies: concerning Marron volcanic rocks - Paterson (1960) B.Sc., Church (1963) M.Sc., Bird (1965) B.Sc., concerning White Lake sediments Ward (1964) B.Sc.

The distribution of Tertiary bedded rocks of central and southern British Columbia and northwestern Washington state is shown in Figure 1.3. Geological information on this region is provided by many authors. Dawson (1896) gave a detailed description of Tertiary rocks in the Kamloops area. This work was reviewed and brought up to date by Cockfield (1948). The most recent description of the Tertiary succession at Princeton was given by Hills (1961). Daly (1912) first described the Kettle River sediments and Midway volcanic rocks near the village of Midway. Recently, Little and Monger (1966) revised and added to this work. Tertiary rocks, similar to those near Midway, occur in the Beaverdell area and were described by Reinecke (1915). Drysdale (1915) reported on Kettle River type sediments and Midway type volcanic rocks at Franklin camp. Also, in Washington state, similar rocks occurring near the town of Republic
were mapped and described by Parker and Calkins (1964), and Staaz (1964). Other works applicable to the Tertiary rocks of the region are referred to in following sections.

FIELD WORK

Field work was done intermittently between October 1963 and September 1965; a total of 7\(\frac{1}{2}\) months were required to complete the mapping program. Previous to this, the author visited the area in July 1959 while employed by the Geological Survey of Canada and again in May 1963 to log drill core on the Dominion Observatory Site. Also, volcanologist Howel Williams and officials of the Anaconda American Brass Co. accompanied the author on a trip through the area in August 1966.

Facilities of the Geology Field School of University of British Columbia were used during the summer of 1965. This reduced costs and added greatly to efficiency of the field work.

Reconnaissance mapping was completed on the scale of approximately 3,000 feet to one inch, boundaries of geological units being interpolated between points of intersection on traverses with the aid of lineaments visible on air photographs (see map 100). Figure 1.2 shows the position of reconnaissance traverses in the map-area.

Also, a detail outcrop map, covering about eight square miles on the scale of one inch to 500 feet, was prepared for part of the geologically complex area east of White Lake (see map 200).

Geographic positions were transferred from photographs to topographic maps using altimeter readings and radial-line plots.

GEOLOGICAL SETTING

The distribution of early Tertiary bedded deposits of southwestern British Columbia and northern Washington state is shown in Figure 1.3. These deposits occur as scattered erosional remnants of what was probably a once continuous belt composed mainly of volcanic rocks extending from at least central Washington through the Interior to central British Columbia.

Specific ages are few, however, Mathews (1964) assigned a Middle Eocene age for deposits within 110 miles of the White Lake area;
Figure 1.2 Plot of Reconnaissance Traverses in Map-area
to the north, near Kamloops, 45 to 47 million years; to the west, near Princeton, 48 million years; to the east, near Midway, 48 to 49 million years. Fourteen age-determinations on rocks from the Princeton and Kamloops areas, by Hills and Baadsgaard (personal communication 1966) range from 47 to 51 million years. The age of a vertebrate fossil found in the Princeton area, determined by Russell (1935), agrees well with the above potassium-argon determinations.

Tilting and, in places, folding of these rocks are commonly sufficient to distinguish them from younger Tertiary units which are almost everywhere flat lying. Mathews (1964) gives ages 10, 12, and 13 million years for some of these younger rocks northwest of Kamloops.

Basal Tertiary rocks are typically coarse breccias and conglomerates. In many places these are overlain by volcanic beds with local interdigitated fluvial and lacustrine sediments.

In the Princeton and Kamloops areas, early Tertiary volcanic rocks are commonly dark coloured, probably of andesitic or basaltic composition, whereas, in the southern Okanagan area and near Midway these rocks are generally light coloured having varied composition of acid or intermediate character (see Figure 1.4).

Detailed data are scarce but regional studies show that these strata are rarely more than a few thousand feet thick.

Carr (1962) emphasizes the tensional character of structures in southwestern British Columbia and northern Washington state. Figure 1.5, taken from Carr's report, shows a fan-like system of grabens radiating from an area covered by Columbia River basalts in central Washington. White Lake area lies between the northerly-trending Republic graben, to the southeast, and the northwesterly-trending Methow and Chiwaukum grabens, to the west and southwest. Extensive areas of Tertiary rock are downfaulted in Republic and Chiwaukum grabens; however, Methow and other grabens to the north contain little Tertiary rock and are possibly Mesozoic structures. Carr also outlines the position of northwesterly-trending Tertiary grabens, not previously shown on government survey maps, in areas near Princeton and Kamloops.

According to Bailey et al. (1966) tensional conditions and uplift prevailed after Laramide thrusting and molasse-type deposition cased, during Paleocene times, in the Rocky Mountain area of
southeastern British Columbia and adjacent parts of Alberta. Uplift was accompanied by large scale 'listric normal' fault movement which was instrumental in formation of many longitudinally oriented valleys of interior British Columbia. These valleys became important drainage routes to the Pacific Ocean and favourable sites for early Tertiary deposition. Figure 1.6 shows the location and cross-section of two 'listric normal' fault bounded basins near White Lake map-area.
Figure I.3 Location of Early Tertiary Bedded Rocks

Scale
40  0  40  80  120  160 Miles
Figure I.4 Refractive Index Frequency for Lavas in White Lake, Kelowna, and Midway Areas

(Class interval for histogram is R.I. 0.010)

after Church, 1963
Figure 1.5 Grabens of Southwestern British Columbia and Northern Washington State

LEGEND

1. Republic graben
2. Methow graben
3. Chiwaukum graben

after Carr, 1962
Figure 1.6
Listric Normal Faults in South-Central, B.C.

Structure Section (after Bally et al., 1966)

- Okanagan R.
- Kettle R.
- Arrow L.
- early Tertiary deposits
- Coryell Intrusions
- listric normal fault
- Mesozoic plutonic rocks

Scale: 0 — 10 miles

---

White Lake map-area

Okanogan R.

Kettle River

Penticton

Arrow Lake

Location Map

50°

120°

0

10 miles

49°
CHAPTER II
GENERAL GEOLOGY AND STRUCTURE

The main object of this chapter is to set forth the stratigraphy and structure of the Tertiary rocks of the White Lake area in more detail than previously offered. Discussion covers distribution, thickness, lithology, local and regional structural relations and correlation of rock units. Brief reference is made to pre-Tertiary rocks and glacial geology.

PRE-TERTIARY ROCKS

Pre-Tertiary rocks are exposed in several small areas mainly at the margins of the map-area. According to Bostock (1941), these are Triassic or older metasedimentary and metavolcanic rocks. South of the map-area they are extensively intruded by Cretaceous and some Jurassic granites, granodiorites, and syenites (Cannon, 1966). Also, in places, they are cut by pulaskite dikes, probably Tertiary age.

The Shoemaker Formation, mainly dark grey chert, and Old Tom Formation, mainly greenstone, are interlayered units well exposed in an area about a mile west of Yellow Lake and south along Highway 3, and in the area south of Dorfler Ranch. Old Tom rocks are also exposed on the west wall of Okanagan valley about one mile north of Green Lake. A small window of Shoemaker Formation, showing through Tertiary rocks, is located about three-quarters of a mile northwest of Mahoney Lake.

The Vaseaux Formation is exposed in southeast corner of the map-area near Mahoney Lake and immediately west of Highway 97, one and one-half miles south of Okanagan Falls. These rocks are probably older than the Old Tom and Shoemaker rocks and consist mainly of siliceous and phyllitic gneiss and some schist.

TERTIARY ROCKS

The present study leads to several important modifications of Bostock's (1941) seven-fold division of Tertiary rocks (map 627A, Geol. Survey, Canada). Bostock's scheme is as follows:

7 - Unnamed conglomerate
6 - Unnamed agglomerate, conglomerate
5 -Unnamed andesitic breccia, tuff, and agglomerate
4 -White Lake Formation: conglomerate, sandstone, and shale; coal; tuff, agglomerate, breccia
3 -Marron Formation: mainly basalt and andesite; more feldspathic lavas in northern part of map-area; related breccia, agglomerate, and tuff; conglomerate.
2 -Unnamed coarse granite porphyry, coarse feldspar porphyry
1 -Springbrook Formation: mainly conglomerate; shale, sandstone, tuff, talus deposits.

Table 2.0 shows a revised scheme based on five-fold division of the rocks (see map 100). Bostock's Springbrook Formation '1' and White Lake Formation '4' are retained with only minor changes in description. Unit '2' is not observed in the map-area and, therefore, is dropped from the Table of Formations. The name Marama Formation is newly applied to rocks, mainly rhyodacite and rhyolite, equivalent to the upper part of Bostock's Marron Formation '3' but found to be unconformable on the older succession. The Marron Formation, as now defined, consists of five conformable volcanic members bounded below by the Springbrook Formation and above by the Marama Formation. The name Skaha Formation is newly applied to conglomerate and volcanic rocks, units '6' and '7' of Bostock's scheme, and interbedded slide breccia not recognized by Bostock.

1. BASAL TERTIARY SURFACE

The basal Tertiary surface in the map-area appears to be markedly warped and faulted. The form of this surface, according to the writer's interpretation, is shown in Figure 2.1. Structure contours are based on topographic data and estimated thicknesses of the volcanic and sedimentary pile. Also, information obtained from a vertical diamond drill hole, 2,000 feet deep, located about three-quarters of a mile north of White Lake, provides some contour control.

The surface is generally tilted in an easterly direction. Its regularity is broken by an east-trending syncline in the east-central part, and a southeast-trending anticline in the north part of the map-area. Also, near the east and southeast margins of the map-area, the surface is truncated abruptly by gravity faults of the Okanagan system which generally show westerly or northerly downthrow. Where faults pass
<table>
<thead>
<tr>
<th>Formation</th>
<th>Member/Range</th>
<th>Thickness Range in Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SKAHA FORMATION</strong></td>
<td>Upper member (0 to 600)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>essentially a fanglomerate unit with large boulders and blocks of Tertiary and pre-Tertiary rock</td>
<td>0 to 600</td>
</tr>
<tr>
<td></td>
<td>Lower member (0 to 300)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>mainly slide breccia with some intercalated conglomerate and tephrite (augite-porphyry)</td>
<td>0 to 300</td>
</tr>
<tr>
<td><strong>WHITE LAKE FORMATION</strong></td>
<td>Upper member (0 to 300)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>mainly light coloured pyroclastic rocks, volcanic breccia (Indian Head breccia) and some sediments and tephrite (augite-porphyry lava)</td>
<td>0 to 300</td>
</tr>
<tr>
<td></td>
<td>Middle and lower members (0 to 3500)</td>
<td>0 to 3500</td>
</tr>
<tr>
<td></td>
<td>consisting of interdigitated deposits, sediments (White Lake sediments) composed of volcanic sandstone, conglomerate, and some coal; and volcanic rocks (White Lake volcanic rocks) composed of feldspar-porphyry lavas, lahars, and pyroclastic rocks</td>
<td></td>
</tr>
<tr>
<td><strong>MARAMA FORMATION</strong></td>
<td>Not subdivided (0 to 1000)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>predominantly rhyolite and rhyodacite lava with some pyroclastic rocks and local basal conglomerate</td>
<td>0 to 1000</td>
</tr>
<tr>
<td><strong>MARRON FORMATION</strong></td>
<td>Park Rill Andesite Member (200 to 1500)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>mainly merocrystalline and glassy lava</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rossette-Porphyry Member (400 to 1000)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>mainly trachyte and trachyandesite lava</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Basaltic Andesite Member (0 to 400)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>mainly pyroxene-rich vesicular lava</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Clot-Porphyry Member (1000)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>mainly trachyte and trachyandesite lava</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Yellow Lake Porphyry Member (500 to 1800)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>mainly anorthoclase-, augite-porphyry lavas (phonolites) and pyroclastic rocks</td>
<td>0 to 700</td>
</tr>
<tr>
<td><strong>SPRINGBROOK FORMATION</strong></td>
<td>Not subdivided (0 to 700)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>mainly boulder conglomerate overlying valley talus with fragments of underlying pre-Tertiary rocks</td>
<td>0 to 700</td>
</tr>
</tbody>
</table>
subparallel to structure contours, the general slope of the surface is locally increased or decreased depending on the direction of downthrow.

The base of Tertiary strata northeast of White Lake and east of Skaha Lake is estimated to be near -5,500 feet (m.s.l.) and the maximum thickness to be about 8,000 feet. In comparison, Shaw (1952) shows that rocks of similar age in a basin-like structure near Princeton have a base about -400 feet (m.s.l.) and a thickness about 3,000 feet.

2. DETAILED DESCRIPTION OF FORMATIONS

A. SPRINGBROOK FORMATION

The Springbrook Formation was named and described by Bostock (1941) in marginal notes appended to Maps 627A, 628A, and 341A, G.S.C. The following description is on Map 627A:

"The Springbrook formation rests on a pre-Tertiary rock surface of steep relief. It is composed of soils, alluvium, talus, stream and lake deposits and tuffaceous materials that accumulated in the valleys before and during the early extrusions of the Marron volcanic rocks. Where the Springbrook formation is thick, the basal beds are of conglomerate containing large angular boulders. These beds grade upward into conglomerates composed of smaller, more rounded and better sorted materials. Uppermost strata include beds of polished pebbles, tuffaceous sandstones and silts."

a. Distribution and Thickness

The Springbrook Formation is exposed only on the western extremity of the map-area and immediately north of Mahoney Lake in the southeast corner of the map-area (see Map 100 and Plate 2.1).

The thickness of Springbrook sediments varies markedly over short distances. Beds about 700 feet thick are exposed on bluffs 2 miles west of Green Ranch, whereas, three-quarters of a mile west of Yellow Lake, the beds are only 200 feet thick, and immediately south of southwest corner of the map-area, younger Tertiary rocks rest directly on pre-Tertiary formations. Bostock's maps show about 60 percent of the exposed basal Tertiary unconformity in the region to be directly overlain by the Springbrook Formation and 40 percent by younger Tertiary rocks.
Figure 2.1 Inferred Configuration of Basal Tertiary Surface
Plate 2.1  Springbrook Formation, in west part of map-area south of Highway 3
b. Lithology

A summary of data from the stratigraphic section of lowest Tertiary beds 2 miles west of Green Ranch is given in Table 2.1 (see Plate 2.2).

The base of the Springbrook Formation, at this location, is established at elevation 2,150 feet where a small knob of breccia and conglomerate rests on massive black chert of the pre-Tertiary Shoemaker Formation. A rough estimate of the composition of the basal sediment gives:

- 70% feldspar-rich andesite (probably Old Tom Formation).
- 20% grey and black chert and argillite (Shoemaker F.).
- 10% chlorite schist and other unidentified fragments.

The top of Springbrook Formation here is close to elevation 2,850 feet. The uppermost, about 250 feet thick, is a well-bedded, cliff-forming unit consisting of alternate layers of large-pebble and small-pebble conglomerate with a few scattered boulders. Beds range from several inches to tens of feet thick. They are nearly horizontal low in the section but dip as much as 22 degrees east near the top, suggesting giant cross-bed or slump structure.

Data from analysis of a sample of conglomeratic sandstone from upper part of Springbrook beds (disaggregated by acid treatment for carbonate cement) are given in Figures 2.2 and 2.3. Size-sorting coefficient $\sigma_i$ (Folk, 1961) is found to be 1.8 $\sigma$. This is classified as poorly sorted but falls within the range 0.40 to 2.5 $\sigma$ quoted for river sediments. The composition is bimodal consisting of about two-thirds buff coloured weathered feldspar and clay minerals and one-third grey chert and quartz. Accessory heavy minerals include epidote, apatite, ilmenite, and magnetite.

c. Structure

In the western part of the map-area Springbrook beds (dipping 10 to 15 degrees east) are overlain, with some angular unconformity, by Marron volcanic rocks (dipping 0 to 5 degrees east). It is probable, however, that this unconformity represents only a short time interval because the contact between the two formations is generally smooth (see Plate 2.3).
<table>
<thead>
<tr>
<th>Elevation in Feet (m.s.l.)</th>
<th>Description</th>
<th>Formations</th>
</tr>
</thead>
<tbody>
<tr>
<td>3720 -- base of bluff and top of section</td>
<td>-- analcite porphyry</td>
<td>Lower Part of Marron F.</td>
</tr>
<tr>
<td>3200 -- contact</td>
<td>-- anorthoclase-augite porphyry; some columnar jointing</td>
<td></td>
</tr>
<tr>
<td>2850 -- contact</td>
<td>-- augite porphyry breccia; hoodoo structures; pyroclastic rocks; minor angular unconformity</td>
<td>Springbrook F.</td>
</tr>
<tr>
<td>2550</td>
<td>-- well-bedded conglomerate; dips range from zero to 22° east</td>
<td></td>
</tr>
<tr>
<td>2390</td>
<td>-- possible fault</td>
<td>poor</td>
</tr>
<tr>
<td>2150 -- contact</td>
<td>chert breccia</td>
<td>exposure -- unconformity</td>
</tr>
<tr>
<td>1980</td>
<td>-- base of exposure</td>
<td>massive black chert</td>
</tr>
</tbody>
</table>
Plate 2.2  Springbrook beds, two miles west of Green Ranch
Figure 2.2 Grain Analyses of Springbrook Sediment

(A Typical Conglomeratic Sandstone)

A. Size Frequency Histogram

B. Composition of Sand Fraction

Grain Size (Phi Scale)

Specific Gravity

altered feldspar quartz
Figure 2.3 Size Frequency Cumulative Curve of Springbrook Sediment

(A Typical Conglomeratic Sandstone)
d. Age

Bostock published conflicting information on the age of the Springbrook Formation. On map 628A (G.S.C.), he indicates that the upper beds "contain plants of early Tertiary, perhaps Paleocene age"; on map 341A (G.S.C.) he states that "these beds contain plants of presumably late Eocene age." Although both maps were published in 1941, the former (628A) has a higher series number and is, therefore, considered to be Bostock's most recent interpretation. Until a more comprehensive study is made, however, the present author tentatively assigns middle Eocene age to the Springbrook Formation in keeping with K-Ar dates obtained on similar rocks in southern British Columbia (Mathews, 1964).

e. Correlation

The following basal Tertiary sedimentary units of the region are tentatively correlated with the Springbrook Formation:

Kettle River Formation (Daly, 1912; Midway area).
Curry Creek Formation (Reinecke, 1915; Beaverdell area).
Coldwater Formation (Dawson, 1878; Kamloops area).
Allenby Formation (Rice, 1952; Princeton area).
O'Brien Creek Formation (Muessig, 1962; Republic area).

The Kettle River Formation is one of the most widely distributed units. It was recently redescribed by Little and Monger (1966, p. 67):

"The Kettle River Formation of Middle Eocene age unconformably overlies -- (pre-Tertiary rocks) --, and consists of a discontinuous basal conglomerate, above which is a white to buff, locally plant-bearing, arkosic sandstone, siltstone, and minor shale and conglomerate, all largely derived from acid volcanic and granitic rocks. The sedimentary rocks grade upward into a grey-green volcanic sandstone, gradational with, and in part contemporaneous with, the lower part of -- (Midway lavas) --. Nowhere in the map-area does the Kettle River Formation appear to be missing, with overlying -- (Midway lavas) -- resting directly upon basement, although it shows considerable variation in thickness, from at least 1,500 feet in the northwest of the map-area, where it is coarse and conglomeratic, to a few hundred feet in the east-central part of the map-area."

Although the Kettle River Formation is lithologically different, containing large volumes of fine-grained sediment not present in the Springbrook Formation, these units are probably of similar age since both are overlain directly by thick deposits of markedly similar volcanic rocks.
B. MARRON FORMATION

The name Marron Formation was applied by Bostock (1941) to the early Tertiary volcanic rocks underlying a large area in the central part of combined 15 minute quadrangle maps, Olalla, B.C. (G.S.C. map 628A) and Okanagan Falls, B.C. (G.S.C. map 627A). His brief description of these rocks on map 627A is as follows:

"The volcanic rocks of the Marron Formation were extruded over hills of pre-Tertiary rocks into valleys partly filled by the Springbrook Formation. They filled these valleys and accumulated to a thickness over 4,000 feet and are believed to have covered all parts of the map-area. The formation consists mainly of lava flows 10 to 200 feet thick, but in places there are large masses of agglomerate. In the northeast part of the map-area the lower flows are highly feldspathic. To the northwest some fine grained acid types were observed. In places, notably northwest of White Lake, there are thin interbeds of conglomerate, sandstone and soil."

Mapping by the writer provides the basis for a six-fold division of these rocks. The name Marron Formation is used in this study in reference to the lowest five divisions (members), a succession of conformable or nearly conformable beds.

The type-section of the Marron Formation is located near Yellow Lake, parallel to structure cross-section A-B (see map 100). At the base of this section, 0.8 miles west of Yellow Lake at elevation 3,000 feet, the lowermost member of the Marron Formation rests with slight angular unconformity on Springbrook conglomeratic beds (see Plate 2.3). At the top of the section, 0.7 miles west of 'B' at 3,700 feet, lavas of uppermost member of Marron Formation are overlain unconformably by younger volcanic rocks. (In the type-section, Marron rocks dip 5 to 25 degrees easterly. The aggregate thickness of the strata is about 5,000 feet.)

In the type section the lowermost Marron unit, here termed the 'Yellow Lake porphyry member', is well exposed near 'A' (see map 100). At 0.8 miles west of Yellow Lake and elevation 3,000 feet, these rocks rest on the Springbrook Formation; at elevation 4,400 feet in the same area, the Yellow Lake porphyry member is overlain by the 'clot-porphyry member' (see Plate 2.6). Clot-porphyry rocks are exposed in the type-section between 'A', at elevation 4,600 feet, and at a point 2.5 miles west of 'B' at elevation 2,700 feet. The 'Basaltic andesite member' is a relatively thin unit near the middle of the Marron succession and
Plate 2.3  Contact between Marron and Springbrook beds, near Yellow Lake
is exposed about a half mile east of Yellow Lake midway between points 'A' and 'B'. Younger rocks, here termed the 'rosette-porphyry member', are present near Trout Lake cropping out in the area 0.5 to 1.8 miles east of Yellow Lake in A-B section. The 'Park Rill andesite member', the uppermost unit of the Marron Formation overlies rosette-porphyry rocks one mile west of 'B' at an elevation of 3,300 feet and is overlain by a younger volcanic formation 0.7 miles west of 'B' at elevation 3,700 feet.

The refractive index of glass prepared from powdered rock samples is helpful in distinguishing lavas characteristic of various Marron members. These data are shown in Figure 2.4.

Complete chemical analyses of these rocks, including some data on minor elements, are tabulated in Appendix 'A', and detailed petrographic descriptions are given in Appendix 'C'.

Yellow Lake Porphyry Member

The name Yellow Lake porphyry member is applied to alkali-rich volcanic rocks that form the lowermost unit of the Marron Formation. ('Porphyry' is used as a textural term with no inference concerning the structure of the rocks.) The petrography of these rocks is briefly described by Church (1963) and more fully by Bird (1965).

a. Distribution and Thickness

Yellow Lake porphyries are well exposed on bluffs in the western extremity of the map-area, in the north near Marron Lake and the switchback in Highway 3, and in the southeast part of the map-area, near Mahoney Lake. Although these rocks form only about 10 percent of the total rocks exposed, probably they underlie an additional 80 percent of the map-area.

The thickness of this member varies. Near Marron Lake and Mahoney Lake, in the north and southeast parts of the map-area respectively, the unit is at least 1,000 feet thick. In the western part of the map-area the thickness varies from about 1,800 feet, near the west end of Yellow Lake, to about 500 feet, 1.5 miles northwest of Yellow Lake.
b. Lithology

The appearance of these rocks varies greatly within the map-area but most, if not all varieties can be broadly classified as anorthoclase-augite porphyry. Many rocks contain rhomb-shaped phenocrysts of anorthoclase which may serve as a useful guide for field mapping.

Near Mahoney Lake, the rocks are readily divisible into two sub-units; an upper small-rhomb-porphry lava, and a lower large-anorthoclase-augite porphyry lava and breccia. The lower unit contains many xenoliths of chert, argillite, granite, and other pre-Tertiary rocks, and thin discontinuous lenses of chert pebble conglomerate.

East of Marron Lake large-anorthoclase-augite porphyry lavas are observed; in the vicinity of switchback on Highway 3 and areas immediately south small-porphry lavas are present.

Near Yellow Lake the rocks are not easily divisible into large- and small-porphry units. Rhomb-porphries are poorly-developed and the lavas are lighter coloured and more amygdaloidal than those found at other localities.

On bluffs two miles west of Green Ranch, the rocks consist of about 350 feet of volcanic breccia overlain by about 600 feet of lavas. In places these rocks are cut by columnar jointed rhomb-porphry dikes.

Where the rocks are amygdaloidal, as near Yellow Lake, they contain much calcite, natrolite, some thomsonite, and, rarely, brewsterite. Cracks and fissures contain calcite, laumontite-leonhardite, and mordenite.

The major oxide-composition of two specimens from Yellow Lake porphyries is shown in Table 2.2. The composition of average rhomb-porphry rock published by Daly (1933) is similar to these analyses.

Clot-Porphry Member

The clot-porphry member consists of feldspar-porphry lavas and minor pyroclastic rocks, mainly of trachytic and trachyandesitic composition, conformably overlying Yellow Lake porphyry member (see Plate 2.6).
Table 2.2 Composition of Yellow Lake Porphyries

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>56.8</td>
<td>55.2</td>
<td>57.9</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>22.6</td>
<td>21.9</td>
<td>20.6</td>
</tr>
<tr>
<td>FeO</td>
<td>5.3</td>
<td>5.5</td>
<td>4.7</td>
</tr>
<tr>
<td>MgO</td>
<td>1.0</td>
<td>2.5</td>
<td>1.2</td>
</tr>
<tr>
<td>CaO</td>
<td>4.7</td>
<td>5.0</td>
<td>2.8</td>
</tr>
<tr>
<td>Na₂O</td>
<td>6.5</td>
<td>4.9</td>
<td>7.8</td>
</tr>
<tr>
<td>K₂O</td>
<td>3.1</td>
<td>5.0</td>
<td>5.0</td>
</tr>
</tbody>
</table>

1. Columnar rhomb-porphyry dike, N64-B, (station no.1, map 100)
2. Small rhomb-porphyry lava, N64-20-K, (station no.2, map 100)
3. Average composition of rhomb-porphyry lava, Daly (1933)

(total iron is calculated as FeO)
Plate 2.4  Blocky top of rhomb-porphyry lava flow
a. Distribution and Thickness

Clot-porphyry rocks are extensively exposed in the western part of the map-area, particularly on mountain-tops and ridge-crests. Smaller areas of exposure are to be seen at the north end of Marron Lake, near the junction of Highways 3 and 97 and to the south, and on the hill side west of Kitley Lake and the low hills and valleys to the southeast. Other exposures of this unit are found west and northwest of Mahoney Lake (see map 100).

Approximately three-quarters of the map-area is underlain by clot-porphyry rocks at varying depth, but less than 15 percent contains exposed rocks of this unit.

The clot-porphyry member has a more or less uniform thickness of about 1,000 feet.

b. Lithology

Clot-porphyry rocks form conspicuous, thick lava flows in the lower part of the Marron Formation. In the western part of the map-area, where best exposed, the rocks are typified by vertical slab-like pillars which locally form cliffs more than 100 feet high (see Plate 2.5).

Lavas are commonly non-vesicular and yellowish where fresh; where badly weathered, they are mottled with brownish-red hues or dark grey with bleached white feldspar phenocrysts.

The most widely distributed type of clot-porphyry rock contains discrete tabular crystals and polygonal clusters of feldspar phenocrysts measuring 3 to 6 millimeters in diameter, some small pyroxene grains, and few biotite flakes embedded in fine crystalline matrix. Plagioclase is the dominant feldspar but sanidine is abundant in some rocks, occurring as discrete glassy laths or forming jackets on plagioclase.

West of Mahoney Lake, the upper part of the formation is a 'clot-lath porphyry' about 400 feet thick. This rock contains both laths and anhedral clots of feldspar 2 to 6 millimeters in diameter set in a buff coloured, micro-crystalline matrix. Ferromagnesian minerals are virtually absent.

Also, at this locality, the lower part of the formation consists of a thin zone of small-feldspar-porphyry. The rock is characterized by a high content of small equant crystals and clusters of feldspar phenocrysts,
Plate 2.5  Slabby pillars, clot-porphyry lava
2 to 4 millimeters in diameter, embedded in a fine-grained matrix.

Many fractures in the clot-porphyry rocks contain fillings of calcite, some laumontite-leonhardite, and rarely heulandite.

Major oxide compositions of two clot-porphyry rocks, given in Table 2.3, are bracketed by Daly's average trachyte and trachyandesite.

Basaltic Andesite Member

Basaltic andesite occurs, with apparent conformity, near the middle part of the Marron succession.

a. Distribution and Thickness

Although widely distributed, the basaltic andesite is poorly exposed; outcrops form less than 2 percent of the total map-area. The largest area of exposure is found on valley slopes south of T.L. Ranch; small exposures may be seen east of Yellow Lake and near Mahoney Lake (see map 100).

The unit attains its maximum thickness, about 400 feet, west of Mahoney Lake.

b. Lithology

The unit consists mainly of basaltic andesite lava and flow breccia, commonly dark brown and markedly vesicular. Most rocks contain abundant pyroxene phenocrysts and a few scattered laths of plagioclase.

Basaltic andesite is easily weathered and eroded. Areas underlain by this unit are generally low lying and covered with a brown, granular regolith.

Most vesicles are filled with chlorite, some chalcedony, and minor calcite. Fire opal found north of the map-area probably occur in these rocks.

Rosette-Porphyry Member

The rosette-porphyries are chemically similar to the clot-porphyries (trachyte and trachyandesite) but differ in texture and stratigraphic position. They form the upper middle part of Marron Formation overlying the basaltic andesite unit with apparent conformity.
Table 2.3 Composition of Clot-Porphyries

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>58.4</td>
<td>63.3</td>
<td>59.9</td>
<td>62.1</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>19.9</td>
<td>16.8</td>
<td>17.9</td>
<td>18.2</td>
</tr>
<tr>
<td>FeO</td>
<td>5.1</td>
<td>3.9</td>
<td>7.0</td>
<td>5.2</td>
</tr>
<tr>
<td>MgO</td>
<td>1.9</td>
<td>1.5</td>
<td>1.3</td>
<td>1.1</td>
</tr>
<tr>
<td>CaO</td>
<td>4.8</td>
<td>4.0</td>
<td>4.3</td>
<td>3.1</td>
</tr>
<tr>
<td>Na₂O</td>
<td>4.7</td>
<td>10.5</td>
<td>5.9</td>
<td>4.5</td>
</tr>
<tr>
<td>K₂O</td>
<td>5.2</td>
<td>3.7</td>
<td>5.8</td>
<td></td>
</tr>
</tbody>
</table>

1. Feldspar porphyry, N64-21-5, (station no.4, map 100)
2. Feldspar porphyry, CC-5, (station no.5, map 100)
3. Average composition of trachyandesite, Daly (1933)
4. Average composition of trachyte, Daly (1914)

(total iron is calculated as FeO)
a. Distribution and Thickness

Rosette-porphyry beds are exposed continuously for several miles on slopes southeast and north of T.L. Ranch, between points 0.5 and 3.5 miles east of Yellow Lake on Highway 3 and adjacent slopes, and on northeast-facing slopes located south of Highway 3 in line between Marron Lake and Prather Lake.

Rosette-porphyry underlies roughly half of the map-area, though less than 15 percent is outcrop.

Rosette-porphyry, about 1,000 feet thick, is exposed on bluffs north of T.L. Ranch; in a few places west of Mahoney Lake the unit appears to be less than 200 feet thick.

b. Lithology

Rosette-porphyries form bluff and bench-topography in central part of the map-area where the thickest deposits are observed. Bluffs vary in height from 50 to more than 200 feet, each corresponding approximately to the thickness of one or more lava flows.

These rocks are commonly yellowish, where fresh, nonvesicular, and contain scattered small phenocrysts of pyroxene and radiating plagioclase glomerophenocrysts set in a fine crystalline matrix. Some flows contain minor biotite and sanidine.

Most of the rocks are homogeneous; constituent minerals varying only slightly in composition and abundance.

Pyroclastic deposits are generally thin and discontinuous; however, near Prather Lake the unit contains abundant agglomerate and some tuff.

In places west of Mahoney Lake, rosette-porphyries are intermixed with light coloured, aphanitic volcanic breccias.

The chemical composition of rosette-porphyry is similar to Daly's average analyses of trachytic lavas (see Table 2.4).

Park Rill Andesite Member

The name Park Rill andesite is applied to the uppermost member of the Marron Formation which rests conformably on the rosette-porphyry member (see Plate 2.7). The rock is distinct from the basaltic andesite unit in
Table 2.4 Composition of Rosette-Porphyries

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>59.4</td>
<td>59.9</td>
<td>62.1</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>18.9</td>
<td>17.9</td>
<td>18.2</td>
</tr>
<tr>
<td>FeO</td>
<td>5.0</td>
<td>7.0</td>
<td>5.2</td>
</tr>
<tr>
<td>MgO</td>
<td>1.1</td>
<td>1.3</td>
<td>1.1</td>
</tr>
<tr>
<td>CaO</td>
<td>4.3</td>
<td>4.3</td>
<td>3.1</td>
</tr>
<tr>
<td>Na₂O</td>
<td>4.6</td>
<td>5.9</td>
<td>4.5</td>
</tr>
<tr>
<td>K₂O</td>
<td>6.7</td>
<td>3.7</td>
<td>5.8</td>
</tr>
</tbody>
</table>

1. Rosette-porphyry lava, N64-24-2 (station no. 6, map 100)
2. Average composition of trachyandesite, Daly (1933)
3. Average composition of trachyte, Daly (1914)

(total iron is calculated as FeO)
stratigraphic position, textural appearance, and probably chemical com­
position,(see Figure 2.4).
a. Distribution and Thickness

Park Rill andesites are exposed mostly in the central and southern parts of the map-area. Thick deposits are to be seen on slopes west and south of Stewart Ranch and west and east of Dorfler Ranch near Park Rill. A relatively thin but continuous deposit crops out high on the north flank of the hill between Prather Lake and T.L. Ranch. Other important exposures are present near Mahoney Lake, on the ridge east of Prather Lake, and southwest of Marron Lake (see map 100).

The lateral extent of the Park Rill andesite amounts to about 30 percent of the map-area, but less than half of this area is occupied by bed-rock exposure.

The unit varies markedly in thickness. Near the south boundary of the map-area and east of Prather Lake, these beds are about 1,500 feet thick, but only 200 feet thick on the hill side west of Kitley Lake.

b. Lithology

The Park Rill andesite is mostly dark brown, nonvesicular lava. The unit is generally massive, and individual flows are distinguished only with difficulty.

The rock is typically merocrystalline, containing about equal parts glass and crystals measuring about one millimeter in diameter. A phase of this unit cropping out south and on the ridge east of Prather Lake is especially glassy; some specimens containing less than five percent crystals.

The composition of Park Rill andesite is comparable with that of average analyses of andesite given by Daly and Nockolds (see Table 2.5).

Structure

Marron rocks show important variations in attitude throughout the map-area. On the west, the rocks are almost horizontal or dip gently east; in the central and southeast parts, they underlie younger beds of the White Lake syncline; in the north-central part, they are unwarped over a broad southeast-trending anticlinal axis that forms a local structural high adjacent to the White Lake syncline.
Table 2.5 Composition of Park Rill Andesite

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO\textsubscript{2}</td>
<td>61.0</td>
<td>60.3</td>
<td>65.5</td>
<td>57.5</td>
<td>61.3</td>
<td>55.8</td>
</tr>
<tr>
<td>Al\textsubscript{2}O\textsubscript{3}</td>
<td>16.2</td>
<td>16.4</td>
<td>15.9</td>
<td>17.3</td>
<td>17.8</td>
<td>17.7</td>
</tr>
<tr>
<td>FeO</td>
<td>6.1</td>
<td>6.0</td>
<td>4.9</td>
<td>7.3</td>
<td>6.3</td>
<td>8.9</td>
</tr>
<tr>
<td>MgO</td>
<td>4.2</td>
<td>4.0</td>
<td>3.4</td>
<td>5.1</td>
<td>2.8</td>
<td>4.5</td>
</tr>
<tr>
<td>CaO</td>
<td>5.4</td>
<td>5.2</td>
<td>6.6</td>
<td>6.5</td>
<td>6.0</td>
<td>8.2</td>
</tr>
<tr>
<td>Na\textsubscript{2}O</td>
<td>4.0</td>
<td>4.1</td>
<td>3.7</td>
<td>4.0</td>
<td>3.7</td>
<td>3.8</td>
</tr>
<tr>
<td>K\textsubscript{2}O</td>
<td>3.1</td>
<td>4.0</td>
<td>2.3</td>
<td>2.1</td>
<td>1.1</td>
<td>1.1</td>
</tr>
</tbody>
</table>

1. Park Rill andesite, merocrystalline lava, N64-25A-2a, (station no. 8, map 100)
2. " " " " weathered lava, N64-11-15 (station no. 10, map 100)
3. Park Rill andesite, merocrystalline lava, CC-7 (station no. 11, map 100)
4. Park Rill andesite, vitric lava, N64-3-1 (station no. 9, map 100)
5. Average composition of andesite, Daly (1933)
6. Average composition of andesite, Nockolds (1954)

(total iron is calculated as FeO)
Plate 2.6  Conformable clot-porphyry and Yellow Lake porphyry lavas, north of Yellow Lake

Plate 2.7  Conformable Park Rill andesite and rosette-porphyry lavas, south of Park Rill near T.L. Ranch
The dip of the Marron beds in the map-area rarely exceeds 30 degrees except in areas of severe fault disturbance such as west of Mahoney Lake where some beds are almost vertical.

The beds are cut by numerous faults many of which are of gravity-type and show large vertical displacement. This is exemplified immediately north of Yellow Lake (see Plates 2.8, 2.9, and 2.10). Here the main movement has been along three north-trending faults spaced across about a half mile of gently dipping Marron beds. The total vertical displacement is more than 1,500 feet with relative downward movement on the east.

In the central and southern parts of the map-area, similar faults are present; here, however, the downthrows are on the west. Between south pasture of T.L. Ranch and Dorfler Ranch many faults run sub-parallel to the strike of beds which dip about 30 degrees east. Relative downward displacement of beds in up dip direction causes repetition of strata in this area. Between Dorfler Ranch and Mahoney Lake the fault pattern is somewhat complex. Here, north trending faults cut Marron beds at sharp angles. A few important faults immediately west of Mahoney Lake pass subparallel to the strike of the beds causing relative downward displacement to the southwest.

**Correlation and Age**

Marron beds are comparable with the Midway Group. Recent studies by Little and Monger (1966) of the Tertiary rocks near Midway B.C. reveal much about the internal structure of the Midway Group. Three divisions composed mainly of porphyritic lava are recognized: a basal division consisting of 300 to 1,000 feet of rhomb-porphyry and related alkali-rich rocks; a middle division, 200 to 1,000 feet thick, with two parts - a lower discontinuous unit composed mainly of andesite and an upper, widespread unit composed of trachyte and trachyandesite; an upper division, at least 800 feet thick, composed of andesite. This Midway succession bears a marked resemblance to the Marron Formation as shown in Table 2.6. No significant Midway unit is without a Marron equivalent; however, rocks of clot-porphyry type are not recognized in the Midway assemblage.
Plate 2.8

Plate 2.9

Plate 2.10

Gravity fault displacements of Marron rocks north of Yellow Lake (numbers indicate geographic positions)
<table>
<thead>
<tr>
<th>Marron Members</th>
<th>Thickness Range</th>
<th>Divisions of Midway Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Park Rill Andesite</td>
<td>200 - 1500</td>
<td>Upper Division andesite</td>
</tr>
<tr>
<td>Rosette-porphyry</td>
<td>400 - 1000</td>
<td>trachyandesite</td>
</tr>
<tr>
<td>Basaltic andesite</td>
<td>0 - 400</td>
<td>Middle Division andesite</td>
</tr>
<tr>
<td>Clot-porphyry</td>
<td>1000</td>
<td></td>
</tr>
<tr>
<td>Yellow Lake porphyry</td>
<td>500 - 1800</td>
<td>Lower Division rhomb-porphyries</td>
</tr>
</tbody>
</table>
Mathews (1964) gives two K-Ar ages for Midway rocks; 'pulaskite porphyry' 48 million years and Rock Creek ash 49 million years (Middle Eocene). Description of rocks and sample locations suggest that 'pulaskite porphyry' corresponds to Midway trachyandesite lava (equivalent to the rosette-porphyry member of Marron Formation); 'Rock Creek ash' immediately underlies the trachyandesite lava.

Age correlation of Midway Group with volcanic rocks of the Kamloops and Princeton Groups is established by Mathews (1964) on the basis of K-Ar work; however, details concerning the internal structure and composition of the Princeton and Kamloops deposits are unknown.

C. MARAMA FORMATION

The Marama Formation consists mainly of rhyolitic and rhyodacitic rocks.

The type-section lies near the crest of the mountain south of Marama Creek, near point 'B' in structure sections A-B and B-C (see map 100). At the base of type-section, 0.7 miles west of 'B' at elevation 3,700 feet, Marama pyroclastic rocks unconformably overlie Park Rill andesite lavas. At the top of the type-section, 1.4 miles southeast of 'B' at elevation 2,700 feet, Marama lavas and flow breccias are overlain unconformably by younger sedimentary rocks. (In the line of section, the Marama rocks dip 10 to 25 degrees southeast and reach a thickness, mainly lavas, of 700 feet.)

a. Distribution and Thickness

The Marama Formation is most widely distributed in the central and northern parts of the map-area where they form precipitous bluffs several hundred feet high (see Plate 2.11). The thickest deposits cap the ridge northwest of Marama Creek, slopes north of Stewart Ranch, and the ridge northeast of Prather Lake. Other important areas of exposure are on slopes immediately west of Green Ranch near Twin Lakes, west of Skaha Lake, and east of Okanagan Falls. A thin broken belt of rhyodacite breccia and pebble conglomerate extends for about a mile in an easterly direction from the main road near Dorfler Ranch. Also, small bodies of this rock crop out near the base of the White Lake Formation northeast of the Observatory Site (see map 100). Two small
Plate 2.11 Marama Formation, west of Highway 3 near Marama Creek
deposits of conglomerate and pyroclastic rocks, 1.5 miles northeast of Prather Lake, are tentatively assigned to this unit.

The Marama Formation probably underlies about 30 percent of the map-area but less than half of this is exposed below younger formations.

The maximum observed thickness of the Marama Formation, on slopes northwest of Marama Creek, is about 1,000 feet. However, beds are generally discontinuous and, in places, younger volcanic and sedimentary rocks, such as found about 1.5 miles southeast of White Lake, rest directly on Marron strata.

b. Stratigraphy and Lithology

The lowermost beds of the Marama Formation consist of conglomerate, minor sandstone and shale with seams of pyroclastic rocks intercalated throughout. Such deposits, northeast of Prather Lake, are about 50 feet thick but crop out only a few thousand feet along strike. These beds rest on the clot-porphyry member of the Marron Formation and contain many pebbles of feldspar porphyry. The beds appear to be overlain by rhyodacite volcanic breccia and massive lava to the east; contact between the units is, however, obscured by soil and talus cover.

Volcanic breccia and tuff deposits form the lowermost Marama beds on the mountain slopes north of Stewart Ranch and the ridge northwest of Marama Creek. On the mountainside immediately west of Green Ranch, the lowermost beds consist of chalky white pyroclastic accumulations and rhyolite lava.

Thick rhyodacite lavas constitute the upper part and bulk of the Marama Formation. Generally, the rocks are varicoloured in shades of grey, light brown, and cream. Some weathered, light brown phases of rhyodacite resemble vitric Park Rill andesite, but determinations on glass beads show much lower refractive indices for rhyodacite than for andesite (see Figure 2.4).

Rhyodacite is commonly brittle, nonvesicular, and tends to cleave into thin plates perpendicular to bedding surface. Most of the lavas are glassy but some contain as much as 30 percent microlites, mainly feldspar, some quartz, and minor pyroxene and hornblende.

The chemical composition of Marama lavas agrees well with Norkold's averages for rhyolite and rhyodacite (see Table 2.7).
Figure 2.4 Glass Bead Refractive Indices of Marron and Marama Lavas

(More specific information about the refractive indices of different types of lavas and their respective average and range values are detailed in the diagram.)
Table 2.7 Composition of Marama Rocks

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>69.3</td>
<td>75.6</td>
<td>67.8</td>
<td>74.4</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>17.5</td>
<td>14.9</td>
<td>15.9</td>
<td>13.8</td>
</tr>
<tr>
<td>FeO</td>
<td>2.3</td>
<td>0.6</td>
<td>3.9</td>
<td>2.0</td>
</tr>
<tr>
<td>MgO</td>
<td>0.1</td>
<td>0.1</td>
<td>1.6</td>
<td>0.3</td>
</tr>
<tr>
<td>CaO</td>
<td>3.0</td>
<td>1.2</td>
<td>3.7</td>
<td>1.1</td>
</tr>
<tr>
<td>Na₂O</td>
<td>4.7</td>
<td>4.6</td>
<td>3.9</td>
<td>3.0</td>
</tr>
<tr>
<td>K₂O</td>
<td>3.1</td>
<td>3.0</td>
<td>3.2</td>
<td>5.4</td>
</tr>
</tbody>
</table>

1. Rhyodacite lava, N64-8-9 (station no. 12, map 100)
2. Rhyolite lava, N64-2-8 (station no. 13, map 100)
3. Average composition of rhyodacite, Nockolds (1954)
4. Average composition of rhyolite, Nockolds (1954)

(total iron is calculated as FeO)
c. Structure

Marama rocks rest with angular unconformity on the Marron Formation. In the central and southeast parts of the map-area, the Marama rocks overlie Park Rill andesite; in the west and northeast parts, they overlie clot-porphyry rocks. Marron beds were undoubtedly subjected to marked erosion prior to deposition of the Marama rocks.

In the central part of the map-area, north of Stewart Ranch, beds vary in dip from nearly horizontal at the top of the mountain to about 30 degrees southeast near the contact with younger sedimentary rocks. In this area, Marama and Marron rocks are cut by north-trending normal faults, some of which show downthrow of several hundred feet to the west.

Northwest of Highway 3, between Trout Lake and Marron Lake, Marama rocks dip gently east and are downfaulted in the northeasterly trending Trout Lake graben (see Figure 2.5).

Immediately east of Prather Lake, Marama Formation is in contact with southeasterly dipping Marron rocks along an east-trending fault zone.

A northeasterly dipping belt of Marama rocks trends northwest about 3 miles from an area of exposure east of Okanagan Falls to a point west of Skaha Lake near the north boundary of the map-area. These rocks are overlain by younger beds on the east and are in fault contact with the same beds on the west. (This fault appears to have reverse movement and may be the result of concentric folding of thick volcanic deposits in this area.) The belt appears to be offset about one-half mile to the west along an east-trending fault near the north boundary of the map-area.

Northeast of the Dorfler Ranch, a thin easterly trending belt of Marama rocks shows lateral offset of about 2,000 feet along several south- and southeast-trending faults. Dips varying from 69 degrees north to 42 and 85 degrees northeast are determined on beds within this belt.

d. Correlation

Marama rocks are comparable to lavas cropping out on Mt. Boucherie near Kelowna. The Boucherie lavas are cut by basalt dikes, thought to
Figure 2.5 Trout Lake Graben

Legend:
Fault zone, approx. (tick on downthrow side)
Marama rocks
Graben

Horizontal scale:
0 1 Mile

(see map 100 for complete geology)
feeders of Miocene 'Plateau' lavas, and they rest on conglomerate beds which in turn appear to rest on a surface deeply eroded in older lavas similar to the clot-porphyry rocks of the Marron Formation.

Also, Marama beds resemble the silica-rich 'Sanpoil Volcanics' in northeastern Washington State, described by Muessig (1962), Staaz (1964), and Parker and Calkins (1964).

D. WHITE LAKE FORMATION

The White Lake Formation, named by Bostock (1941), consists of a thick succession of lake and stream sediments and volcanic rocks that overlap units of the older Tertiary volcanic pile and, in turn, are overlain unconformably by younger sediments and breccias.

a. Distribution and Thickness

The White Lake Formation is located in the east-central and northeast parts underlying about 25 percent of the map-area.

Most of the sediments lie west and north of White Lake, whereas the volcanic rocks are centered east and northeast of White Lake and near Okanagan Falls. The thickest section of White Lake strata, about 3,500 feet thick, is to be seen near Observatory Site. Between White Lake and Mahoney Lake the beds are thin, and, in places, younger rocks rest directly on pre-Tertiary formations.

b. Stratigraphy and Lithology

White Lake beds exposed near White Lake are divisible into three members (see map 200). The lower and middle members contain interdigitated sedimentary and volcanic deposits; the upper member consists mainly of volcanic rocks with some intercalated sediments.

Sedimentary Rocks

The stratigraphy of the sedimentary rocks, cropping out near Kearns Creek on north limb of White Lake syncline, is summarized by Camseall (1913, p. 214):

(lower member)

"A section along the valley of Prather creek (Kearns Creek) on the north side of the basin was measured, which gave a thickness of about 2,000 feet of beds. It is very
likely, however, that this thickness is not uniform throughout the whole area: but, because of conditions under which the beds were deposited, must vary greatly from one side of the area to the other. It is possible also that the 2,000 feet thickness in the section represents more than the actual thickness of the beds for, while there is no apparent duplication of the beds by faulting, it is very probable that there has been some slipping or faulting along the planes of bedding so as to give to the section an apparent thickness greater than actual.

A study of the measured section shows that the whole series can roughly be divided on lithological grounds into three parts. The lowest third of the section contains a preponderance of black and grey shales with a minor amount of sandstone. The shales are associated in places with seams of coal. The middle third contains chiefly sandstones with some bands of grey shales. The uppermost third consists wholly of tuffaceous sandstones.

(middle member)

In the central part of the area (south of Observatory Site near Kearns Creek?) some grey shales and two narrow seams of coal outcrop. These beds are not contained in the section measured and probably overlie it and constitute the topmost members of the series."

Data compiled during the present study for section E-F (see Figure 2.6 and map 100), located immediately east of Kearns Creek, coincide well with Camsell's description of the lower member; thick beds of fine-grained sediments in the lower part of the section are overlain by equally thick deposits of coarse sediments, possibly indicating large-scale infilling of Tertiary White Lake. However, the exposed section proves to be 2,400 feet thick - about 400 feet thicker than Camsell's estimate. Probably Camsell obtained his data from a section immediately west of Kearns Creek, on the side of the creek opposite E-F - here a bed of volcanic rock, thickening westward and occurring about 1950 feet above base of the formation, terminates the exposed section. This same volcanic bed can be traced to the south limb of White Lake syncline and serves as a good marker-zone for the top of the lower sedimentary member (see Figure 2.6).

Data compiled from a diamond drill hole in lower sedimentary member are summarized and illustrated in Figure 2.7. Selected samples of core were petrographically described by Ward (1954).

East of section E-F along strike, White Lake sediments pass into a predominantly volcanic succession (see map 200 and section W-X).
McEvoy (1915) briefly describes White Lake beds near the coal mine site about half-way between section E-F and W-X:

(lower member)

"In the lower part of the series the volcanic beds are fairly thick and the interbedded sediments contain carbonaceous shales, but only thin seams of coal; so far no greater thickness than 12 inches of clean coal has been uncovered. Some portions of this lower part of the section have not been uncovered and may contain seams of importance; but this is not probable.

(middle member)

In the upper part of the series, for a thickness of 1,000 feet the shales and sandstones predominate. In the shales in this part seven seams of coal were uncovered, four of which did not contain more than one foot of clean coal."

Lithology of White Lake sediments is diverse.

The sediments are intercalated with many lenses and layers of pyroclastic rock. The tuffaceous layers are generally non-fissile and light coloured. Thinly bedded sediments are commonly folded and compressed below thick pyroclastic deposits probably owing to sudden deposition and loading.

Medium and coarse clastic sediments are prominently exposed on ridge-crests and bluffs. These rocks are commonly massive but locally thinly bedded or flaggy. Crossbeds, most commonly of festoon type, are well developed in some sandstones.

The modal composition of 10 White Lake sandstones is shown in Figure 2.8. These rocks contain a high percentage of volcanic fragments, commonly more than 10 percent argillaceous matrix, minor quartz, chert, quartzite, and feldspar. According to Gilbert's (1955) classification, the term 'volcanic wacke' best describes this type of rock.

Mudstones comprise much of the sedimentary facies of White Lake Formation but, because of their non-resistant nature, they are commonly poorly exposed. The rocks are thinly bedded and range in colour from light to dark grey - commonly dark colour is indication of high content of carbonaceous matter. Some mudstones are turbid showing little evidence of planar fabric; on the other hand, well-laminated zones and graded beds are not uncommon.
Small-scale infilling is observed in some places. A good example is near the 600-foot level of section 'G' on the south limb of White Lake syncline (see Plate 2.12, Figure 2.6, and map 100). A complete infill-cycle consists of about 55 feet of strata. Lithological change in the cycle can be roughly broken down as follows: at the base massive sandstone is abruptly overlain by 30 feet of thinly bedded mudstone, followed by 10 feet of flaggy sandstone with intercalated mudstone, overlain in turn by 15 feet of massive sandstone.

Wood, stems, and leaf fossils are abundant in these rocks, especially in mudstones. Needle-bearing branches identified as *Metasequoia* sp. are common, also some fern-like *Comptonia* sp., a great variety of broad-leaf foliage is observed, legume pods, and an assortment of other fruiting bodies are present.

**Volcanic Rocks**

In the north limb of the White Lake syncline (see map 200 and accompanying W-X structure section) volcanic rocks have a total thickness of about 3,000 feet. The lowest member, about 1,500 feet thick, consists of thin feldspar-porphyry lava flows and abundant lahar and pyroclastic deposits containing some accidental fragments of Marama rhyodacite. The middle member, about 1,200 feet thick, consists of a few feldspar porphyry lava flows and much lahar and agglomerate. Characteristically, the clastic rocks contain exotic fragments of Yellow Lake porphyry. The upper member, about 300 feet thick, consists mainly of brown augite-porphyry lava and breccia containing small quartz xenoliths and a few blocks of granite.

Immediately southeast of White Lake the middle member shows compositional change. Here beds containing xenoliths of Yellow Lake porphyry interdigitate with lahars and pyroclastic deposits containing blocks of Park Rill andesite (see Plate 2.13).

In the area 0.5 to 2 miles southeast of White Lake the lower and middle members wedge out so that the upper member laps directly onto Yellow Lake porphyries (see map 200 and accompanying S-T structure section). Here the upper member consists of buff coloured volcanic debris, the 'Indian Head breccia', pyroclastic rocks, and some volcanic sandstone.
Figure 2.6 Generalized Columnar Sections of White Lake Beds

North Limb of Syncline

South Limb of Syncline

E-F

G H

Measured Sections

Legend

- Mudstone
- Mudstone, minor sandstone
- Sandstone, minor mudstone
- Sandstone
- Conglomerate
- Pyroclastic rock
- Rhyodacite (Marama F.)
- Correlated horizon

(Positions of measured sections are shown on map 100)
Plate 2.12 A, B  Small infill cycle, White Lake sediments, south limb of White Lake syncline
Plate 2.13 Interbedded lahar and pyroclastic deposits, White Lake volcanic rocks near White Lake,
1 - beds rich in xenoliths of Park Rill andesite,
2 - beds rich in xenoliths of Yellow Lake porphyry

Plate 2.14 Bluffs of White Lake volcanic rocks, near White Lake
Feldspar-porphyry lavas are interspersed throughout all members of White Lake volcanic succession. Commonly these rocks are light grey or yellowish coloured and contain many feldspar laths and glomerophenocrysts. Biotite and pyroxene are the main ferromagnesian minerals. These rocks have a broad trachyte -- trachyandesite composition range, showing general trend from basic to acid character toward top of the formation (see Figure 2.9).

Augite-porphyry is very limited in distribution, occurring only in the upper member and, to some extent, in the overlying younger beds. In addition to the thin zone of this rock about a mile east of the Observatory Site (in W-X section) there are several small exposures about one-half mile southwest of The Hole (see map 200).

Detailed petrographic descriptions are given in Appendix 'C'.

Structure

Except near Skaha Lake, where underlying Marama rocks are as much as several hundred feet thick in places, White Lake beds appear to have been deposited on a deeply eroded surface. In places north of the Observatory Site and west of White Lake the sediments rest directly on Park Rill andesite; about a mile northwest of Mahoney Lake they overlie Yellow Lake porphyries with pronounced angular unconformity.

White Lake beds are folded and cut by many faults. Near White Lake itself the beds are folded into the broad 'White Lake syncline', plunging about 25 degrees east. These rocks are more or less detached from White Lake strata near Skaha Lake by a fault zone along the west side of Okanagan Valley.

White Lake beds are generally more steeply inclined than older Tertiary rocks in adjacent areas. For example, measurements from surface exposure and diamond drill core from north limb of syncline show the average dip of beds to be 50 degrees (see Figure 2.10), whereas Marron rocks cropping out north of drill-hole site dip 30 degrees or less. These older rocks may have steep dips under White Lake beds, or alternatively, the fold form changes with depth; shallow dips in Marron rocks may persist at depth in spite of steep inclination of the overlying White Lake beds if the beds are concentrically folded.
White Lake beds are possibly accommodated in the core of a concentric fold by reverse faulting or thrust movement subparallel to bedding.

Reverse faulting is observed on the north limb of the syncline. About one mile northeast of the Observatory Site, for example, a body of Marama rhyodacite is thrust upward through several hundred feet of White Lake beds (see map 200). Evidence of important movement subparallel to bedding near the base of the White Lake Formation is also in diamond drill core (see Figure 2.7).

Figure 2.11 shows a hypothetical structure section through concentric folds of east-trending anticline and syncline.

Data presented in a preceding section shows that most White Lake sediments are the product of erosion of Tertiary volcanic rocks. Chert, quartz, granite, greenstone, gneiss, schist, and other pre-Tertiary debris are scarce.

Observations by Camsell (1913) suggest that the sediments were deposited from east-flowing streams (p. 215);

"The sandstones are all grey in colour and vary in the coarseness and angularity of grains from the east to the west side of the area. On the east the grains are more rounded and waterworn while on the west they are very angular, showing proximity to their original source."

However, cross-bedding measurements shown in Figure 2.12 provide some evidence that streams flowed in a northerly direction. This is supported by the fact that numerous exotic blocks in the middle member of White Lake volcanic succession were derived, at least in part, from Marron rocks underlying the southeast part of map-area.

Age and Correlation

The White Lake beds overlie Marron and Marama rocks with angular unconformity and are probably Eocene but may be Oligocene age. They bear marked structural and lithological similarity to the lower unit of the Klondike Mountain Formation north of Republic in Washington State (Parker and Calkins, 1964). Some characteristic features of the lower part of Klondike Mountain Formation are as follows:

1 - Lower beds rest with angular unconformity on Sanpoil Volcanic and older rocks.
Figure 2.7 Structure Section of White Lake Beds on North Limb of Syncline

Mean sea level

Assumed fault zone

Legend:
- Mudstone
- Mudstone, minor sandstone
- Sandstone, minor mudstone
- Sandstone
- Conglomerate
- Pyroclastic rocks
- Rhyodacite (Marama F.)

Vertical - Horizontal Scale
0 500 feet

(Position of section is shown on map 200)
Figure 2.8 Composition of White Lake Sandstones

(open circle indicates position of sample station)
Figure 2.9 Refractive Index Variation of White Lake Volcanic Rocks

Aug. Porph.
Indian Head Breccia

Upper Volc. Member

25 samples

Distance from Base of White Lake Formation

Relative Position of Samples in W-X Section
(see map 200)

Frequency Percent

Refractive Index of Samples

Histogram
Figure 2.10 Resultant Vector Diagram for Dip of White Lake Beds
Measured from D.D.H. Core

Measurements taken approximately every fifty feet along length of core.

after Ward, 1964
Figure 2.11 Diagrammatic Structure Section of Concentric Folds and Related Faults
Figure 2.12 Cross-bedding Directions in White Lake Sediments

(Arrow indicates current direction, corrected for fold and plunge)
2 - Strata are warped forming a shallow synclinal structure.

3 - The rocks are composed mainly of tuffaceous conglomerate, sandstone, and mudstone; thin flows of porphyritic latite; local concentration of older Tertiary and pre-Tertiary fragments; also, local volcanic mudflow deposits.

4 - Plant fossils include *Metasequoia occidentalis*, *Pinus sp.*, and *Comptonia columbiana*, an assemblage considered by Brown (Parker and Calkins, 1964, p. 66) to be Oligocene.

Allenby sediments near Princeton and Tranquille sediments near Kamloops are thick fluvo-lacustrine deposits intercalated with volcanic rocks similar in general aspect to rocks of the White Lake Formation. Mathews (1964) has dated these as Middle Eocene. (*Comptonia sp.* is included in a collection of fossil leaves from the Allenby Formation - Rouse, 1966, personal communication.)

E. SKAHA FORMATION

Skaha Formation is the name given in this study to the youngest Tertiary beds of the map-area. These rocks crop out in about five percent of the map-area) centered about 2 miles southwest of Skaha Lake.

The following description, by Bostock (G.S.C. map 627A, 1941), applies to Skaha beds and, in part, to Marron rocks west of Mahoney Lake and White Lake volcanic rocks immediately east of White Lake:

"Volcanic rocks, consisting mainly of breccia and agglomerate, lie unconformably over the southeastern part of the White Lake syncline. They are roughly stratified and dip easterly or southerly. In places a large proportion of the fragments are from the Old Tom, Shoemaker, and Vaseaux formations and from the granitic intrusives of the map-area. The fragments are up to 20 feet long. North of Mahoney Lake is a group of strata in which there is more evidence of sorting and stratification and in which volcanic materials are less abundant. Overlying them are beds of nearly flat lying conglomerate."

The present study shows that the Skaha Formation consists of two members, a lower one composed mainly of slide-breccia and some volcanic rock, and an upper one composed of coarse boulder block-conglomerate (fanglomerate). The typical stratigraphic relations of these members are shown in section S-T (accompanying Map 200).

Lower Member

The lower member consists of three units; 'basal breccias', 'augite-porphyry', and 'granite breccia'. The breccias appear to be the
product of several slides originating in terrain underlain by pre-
Tertiary rock near the southeast part of the map-area. The cause of
slides is unknown but they may have been the result of fault disturbance
and uplift accompanied by eruption of augite-porphyry.

'Basal Breccias'

'Basal breccias' are composed mainly of fragments of Shoemaker,
Old Tom, and Vaseaux Formations. These rocks rest with varying degree
of angular unconformity on older Tertiary and pre-Tertiary rocks.

a. Distribution and Thickness

'Basal breccias' occur roughly within the area lying between
Observatory Site, Mahoney Lake, White Lake, and east boundary of map-
area (see map 100).

These rocks have a maximum thickness of about 300 feet on the
ridge one-half mile east of White Lake; elsewhere they thin and wedge
out under younger beds.

b. Lithology

'Basal breccias' consist of a chaotic mixture of coarse and finely
broken rocks, massive blocks of chert and greenstone, and some conglomo-
merate; the unit varies in detail from place to place.

At Indian Head, about one-half mile east of White Lake, blocks
of dark chert, some greenstone, together with fine chert-breccia form
a thick cap on light coloured White Lake pyroclastic beds (see Plate
2.15). Generally, the contact between the 'basal breccias' and White Lake
rocks is abrupt. In a few places, however, thin zones of boulder
conglomerate are found immediately below the breccias (see Plate 2.16).

Immediately east of Kearns Creek near The Hole, 'basal breccias'
form a nearly horizontal layer, about 15 feet thick, overlying White
Lake volcanic rocks. 'Basal breccias' are roughly bedded and consist
mainly of intensely broken chert (see Plate 2.17).

Similar deposits of chert breccia are centered about 1,000 feet
northwest - and 2,000 feet south of The Hole. In places, the rock has
a rough and craggy habit with many holes and caves developed where
loose particles have been removed by erosion (see Plate 2.18).

Fragments are commonly less than two inches in diameter and are mostly
Plate 2.15  Skaha 'basal breccias' (mainly dark chert) overlying White Lake beds (mainly light coloured pyroclastic rocks), Indian Head

Plate 2.16  Conglomeratic zone immediately below 'basal breccias' at Indian Head
Plate 2.17  'Basal breccias' (highly fragmented bedded chert breccia) overlying White Lake volcanic rocks, canyon of Kearns Creek west of The Hole

Plate 2.18  Highly fragmented chert breccia, 'basal breccias'
cemented together by silica, some carbonate, and minor iron oxides. A
disaggregated sample of chert breccia shows little sorting; size distri-
bution of fragments resembles mechanically crushed quartz (see Figure
2.14).

A deposit of massive chert, some greenstone, and dike rocks
underlies about one-half square mile east and southeast of White Lake.
Although dikes and host rocks are locally crushed and sheared, the
deposit is generally intact and could easily be mistaken for Shoemaker
or Old Tom Formations in place. However, evidence indicates that this
body of rock actually consists of large rafted slabs. For example, at
many widely spaced points White Lake beds strike under this deposit (see
map 200 and accompanying sections S-T and X-Y). Pulaskite dikes are
traced without appreciable offset along strike for hundreds of feet,
indicating the size of some slabs. None of the dikes cut White Lake
rocks. (Correlation of pulaskite dikes with White Lake or Marron
trachyte-trachyandesite lava is inconclusive on basis of glass bead
refractive index work; see Figure 2.13).

In areas north of The Hole and Mahoney Lake, 'basal breccias'
consist mainly of large lumps of chert and greenstone in matrix of
similar composition. Blocks of feldspar porphyry, limestone, and
phylite are locally abundant. The exact size of the blocks is difficult
to determine because of internal shattering and irregular margins;
however, many exceed 5 feet in diameter. Some large blocks, which have
survived curshing, contain deep embayments and fissures filled tightly
with brecciated matrix.

Mixed boulder conglomerate and coarse talus-like breccia beds are
found southeast of The Hole. Boulders and blocks are mainly chert,
greenstone, phylite, quartz gneiss, feldspar-porphyries (including
rhomb-porphyry), some rusty quartzite, and granite. These beds are markedly
disturbed and dip steeply in places. Locally the rocks are sheared by
fault movement and are intruded by augite-porphyry dikes and tongue-
like bodies of fine chert breccia (see Plate 2.19).

'Augite-Porphyry'

Augite-porphyry lava (tephrite) is present in a small area cen-
tered between Kearns Creek and The Hole (see map 200), accompanied by
Minor light coloured sediments and pyroclastic rocks (see Plate 2.20).
Figure 2.13 Comparison of Refractive Indices of Pulaskite Dikes and Trachyte-Trachyandesite Lavas

(Open circle is average refractive index of glass, bar represents approximate standard deviation.)
Figure 2.14  Size Distribution of Skaha Chert Breccia

Cumulative Weight Percent

Probability Scale (Rosin's Law)

Regression Curve for Crushed Quartz (Kittleman, 1964)

Skaha Chert Breccia

Weight Percent

Size Frequency Histogram

Grain Size (Phi Scale)
Plate 2.19 Intrusive chert breccia in conglomerate beds, lower member Skaha Formation
Plate 2.20 Augite-porphyry lava (tephrite) overlying cross-bedded sandstone, near The Hole
The augite-porphyry is massive, dense, dark brown and contains characteristic large euhedral augite crystals embedded in a fine-grained matrix. Structures such as columnar jointing, flow breccia, and amygdales are only locally well developed. In a few places dikes of similar rock cut Skaha basal breccia unit and older deposits (see Plate 2.21).

Augite-porphyry has a basic alkali-rich composition similar to appinites analysed by Bowes et al. (1963) - see Table 2.8, this study. High volatile content of the original magma is indicated by the abundance of biotite and apatite (see petrographic description of augite-porphyry, Appendix 'C').

Bowes et al. find correlation between basic alkali rocks, like the augite-porphyry of this study, and explosion breccias. Although no direct evidence is available, it is possible that the curious bodies of intrusive chert breccia, described in the preceding section (see Plates 2.19 and 2.21), are simply slide debris remobilized by steam explosions which may have accompanied eruption of augite-porphyry following deposition of the basal breccia unit.

'Granite Breccia'

The 'granite breccia' unit consists of slide debris, mainly slabs and blocks of granite and some aplite, and a few beds of granite boulder conglomerate and arkose.

These rocks rest discordantly on basal Skaha slide debris. It appears that 'augite-porphyry' was locally removed by erosion before emplacement of 'granite breccia'.

a. Distribution and Thickness

'Granite breccia' forms only about one-quarter of the total outcrop area of Skaha Formation.

The main body of 'granite breccia' is found on Mt. Hawthorn. East of The Hole the deposit is about 200 feet thick and appears to fill a pre-existing valley developed in Skaha basal breccias (see Plate 2.31). Also, a thin veneer of crushed and highly fragmented granite blocks forms an isolated deposit cropping out on the ridge crest immediately north and northwest of The Hole.
Plate 2.21 Augite-porphyry dike and intrusive chert breccia in conglomerate, lower member Skaha Formation
Table 2.8 Composition of Augite-porphyry

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>51.0</td>
<td>51.4</td>
<td>49.0</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>16.6</td>
<td>17.2</td>
<td>14.9</td>
</tr>
<tr>
<td>FeO</td>
<td>7.6</td>
<td>10.5</td>
<td>10.9</td>
</tr>
<tr>
<td>MgO</td>
<td>6.9</td>
<td>4.2</td>
<td>10.3</td>
</tr>
<tr>
<td>CaO</td>
<td>9.2</td>
<td>10.4</td>
<td>9.5</td>
</tr>
<tr>
<td>Na₂O</td>
<td>3.4</td>
<td>2.7</td>
<td>2.9</td>
</tr>
<tr>
<td>K₂O</td>
<td>5.3</td>
<td>3.6</td>
<td>2.5</td>
</tr>
</tbody>
</table>

1. Composition of augite-porphyry 93C1
2. Average composition of tephrite, (Daly, 1933).
3. Average appinite, (Bowes et al., 1963)

(total iron is calculated as FeO)
b. Lithology

The granite is leucocratic containing a somewhat variable percentage of quartz (30 ± 5%), plagioclase (45 ± 5%), perthite-orthoclase (20 ± 5%), and accessory mica and magnetite. Two textural phases are commonly observed: a medium- to fine-grained, delicately foliated phase, and a non-foliated phase containing large potassic feldspar phenocrysts. Smoky quartz 'eyes' are observed in both phases (see Plates 2.22 and 2.23).

A variety of internal structures is found in the 'granite breccia' unit. In places large granite blocks grade into zones of 'autobreccia' or 'frictional breccia'. It appears that granite blocks several hundred feet in diameter were rafted into place on a highly comminuted and mobile mass of breccia (termed frictional breccia) of similar composition. Locally, the granite blocks are internally shattered forming a mosaic of fragments as if crushed under their own weight (autobreccia).

An example of these structures is to be found in the area north of The Hole (see Figure 2.15) where granite blocks several hundred feet in diameter can be observed. In places foliation and quartz veins can be traced tens of feet along strike, testifying to the relatively unbroken character of the blocks (see Plate 2.24). Elsewhere in the same area, granite is intensely fractured and crushed. Locally, brecciated feldspar-porphyry dikes in the granite pinch and swell irregularly indicating intensity of deformation and crushing (see Plates 2.25 and 2.26).

A good example of 'friction breccia' is to be seen on bluffs about 1,500 feet east of The Hole, where granite and feldspar-porphyry dike rocks are markedly broken with fragments mobilized and arranged in nearly horizontal layers (see Plate 2.27). A few thin seams and lenses of rusty material, possibly tuff, are interbedded with the breccias.

North of Green Lake and near the crest of Mt. Hawthorn, the unit consists mainly of coarse granite slide breccias, some granite boulder conglomerate, and thin beds of arkosic sandstones (see Plates 2.28 and 2.29). The conglomerate and sandstone probably resulted from stream re-working of slide deposits.

The granite breccia unit is intruded by a few small, irregular igneous bodies. These intrusions are aphanitic and generally light
Plate 2.22 Porphyritic granite; potassic feldspar (stained yellow), plagioclase (white), quartz (smoky).

Plate 2.23 Aphanitic granite with quartz eyes (smoky) set in matrix of fine grained potassic feldspar (stained yellow) and plagioclase (white); a weak foliation trends normal to length of the ruler.
Figure 2.15 Internal Structure of Part of Granite Breccia Unit

Legend:
- attitude of quartz vein

Scale
- 0 - 500 feet

The Hole

(see map 200 for geological setting)
Plate 2.24  Uncrushed granite typical of large slabs, 'granite breccia zone'
Plate 2.25  Granite 'autobreccia' with crushed dike

Plate 2.26  Internal structure of 'autobrecciated' dike
Plate 2.27 'Frictional breccia', layered deposits of mobilized granite and dike rock breccia, east of The Hole (folder and hammer circled for scale)
Plate 2.28  Granite-block conglomerate cemented by arkose

Plate 2.29  Arkosic sandstone bed in granite-boulder conglomerate
coloured and mottled with rusty stains. The refractive index of glass beads is high (1.585) suggesting a basic composition. Wall rocks adjacent to these intrusions are somewhat chloritized and show loss of primary textures probably owing to thermal metamorphism and metasomatism (see Plate 2.30).

The relationship of these intrusions to tuffs interbedded with granite breccia or augite-porphyry units is not known, however, there appears to have been continuous igneous activity (if not continuous volcanism) during deposition of the lower member of the Skaha Formation.

Upper Member

The upper member of the Skaha Formation is the youngest Tertiary unit in the map-area and consists of coarse clastic sediments of mixed provenance. It rests on an erosion surface of moderate to low relief overlying Skaha 'basal breccias', 'augite-porphyry' unit, and upper beds of White Lake Formation. 'Granite breccia' beds are not found in contact with the upper member and were probably topographically high standing during deposition of these younger beds.

a. Distribution and Thickness

The main deposit occurs near Mahoney Lake capping the south spur of Mt. Hawthorn. Here beds form prominent bluffs and have a maximum thickness of about 600 feet (see Plate 2.31). Small exposures of similar rock are present near Kearns Creek and northeast of The Hole.

b. Lithology

The unit is a thick-bedded mixed boulder- and block-conglomerate. It contains fragments measuring as much as 6 feet in diameter, but commonly less than one foot, composed of older Tertiary and pre-Tertiary rocks. The mean size of the fragments varies considerably between beds; however, fine-grained sediments are scarce. The general aspect of the deposit is that of an alluvial fan developed near a fault scarp or relatively high standing terrain.

Chert and greenstone boulders are most common and were probably derived from Shoemaker and Old Tom Formations to the south. The presence of a few lumps of chert breccia suggests that some material was eroded from the lower member of Skaha Formation. Lumps of augite-
Plate 2.30 Igneous intrusion in breccias, lower member Skaha Formation
Plate 2.31 Skaha beds east of The Hole
porphyry are present, some very large, petrographically identical with augite-porphyry from the Skaha and White Lake Formations from which they were almost certainly eroded. (A complete description of the boulders is given in Table 2.9). These fragments are enclosed in relatively clean pebbly and sandy matrix cemented by carbonate and some iron oxide (see Plates 2.32 and 2.33).

Sandstone beds are generally very thin and discontinuous. The rock is grey and speckled with black chert; it is best described petrographically as a lithic arenite (see Figure 2.16).

Although about 10 percent of the fragments in the upper member are of volcanic origin, primary volcanic deposits are not found in this unit.

Except for local pebble imbrication and channel features (see Plate 2.34) little internal structure is found in the upper member, at least when viewed closely. Typically, the rock is only moderately well indurated and joint fractures tend to pass around pebbles and boulders rather than through them. Generally, the rocks weather easily forming hoodoo structures and caves on steep hill sides (see Plate 2.35).

**Structure**

The Skaha beds have undergone marked deformation. They lie north of The Hole, dip to the south and are roughly parallel to the north limb of the White Lake syncline. Reverse faulting along a northeast trending zone (probably related to concentric folding) has severed the northern part of the formation, mainly chert breccia beds, from the main body of similar rock lying immediately to the south (see structure section X-Y). South of The Hole, the Skaha beds dip easterly. (In this area Tertiary beds are relatively thin and are not simply related to fold structures to the north where beds are thick.) Here, Skaha beds are displaced by steep northerly-trending gravity faults similar to those found in southern and western parts of map-area (see description of Marron Formation and structure sections C-D on map 100 and S-T accompanying map 200).

Slickensides and cleavages are locally well developed east of White Lake providing evidence of relatively late movement. These structures occur in Skaha, White Lake, and Marron rocks with some
<table>
<thead>
<tr>
<th>Type of Fragment</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chert and Greenstone</td>
<td>Angular and subrounded fragments up to four feet in diameter, very common occurrence, probably derived from lower slide complex or Shoemaker F. and Old Tom F.</td>
</tr>
<tr>
<td>Feldspar-porphyries</td>
<td>Angular fragments up to five feet in diameter, very common occurrence, probably derived from Marron clotporphyrries and White Lake feldspar-porphyries.</td>
</tr>
<tr>
<td>Arkose</td>
<td>Rounded fragments up to six feet in diameter, leucocratic granite source possibly from upper slide complex.</td>
</tr>
<tr>
<td>Vein quartz</td>
<td>Angular fragments up to eight inches in diameter, probably derived upper slide complex.</td>
</tr>
<tr>
<td>Augite-porphyry</td>
<td>Angular blocks up to six feet in diameter, derived from augite-porphyry unit of upper White Lake F. or Skaha F.</td>
</tr>
<tr>
<td>Phyllite</td>
<td>Sub-rounded fragments up to two feet in diameter, probably derived from lower slide complex or Vaseaux F.</td>
</tr>
<tr>
<td>Granite and Aplite</td>
<td>Sub-rounded fragments up to three feet in diameter, probably derived from upper slide complex.</td>
</tr>
</tbody>
</table>
Plate 2.32 Boulder of arkosic sandstone in upper member, Skaha Formation

Plate 2.33 Chert block in upper member, Skaha Formation
Figure 2.16 Composition of Skaha Sandstones

Average of 3 Samples

Average of 2 Samples

Modal Percent

Lithic Arenite
Upper Conglomerate

Arkosic Arenite
Upper Siltite Complex

Quartz
Chert, Quartzite
Feldspar
Mica, Unstable Rock
Heavy Minerals
Plate 2.35 Hoodoo structure in conglomerate, upper member Skaha Formation

Plate 2.34 Channel deposit in upper member, Skaha Formation
directional consistency. Generally, cleavages strike northeast and dip steeply; slickenside lineations plunge, at low angles, in two main directions - northeasterly, approximately coincident with mean cleavage plane, and southeasterly roughly parallel to strike of main faults of the Okanagan system (see Figures 2.17 and 2.18). Figure 2.19 shows a hypothetical relation of structures in conjugate shear plan indicating north as the approximate direction of maximum stress.

Age and Correlation

The Skaha Formation is just slightly younger than White Lake Formation; this is suggested by the fact that Skaha beds overlie White Lake rocks with minor unconformity and have undergone similar deformation.

The only other deposit described to date in southern British Columbia resembling the Skaha rocks occurs in the Flathead area, about 225 miles east of White Lake. This deposit, known as the Kishenehn Formation, consists partly of coarse conglomerate containing boulders commonly one foot and some as large as four feet in diameter. According to Price (1966), this material was eroded from high terrain underlain by Paleozoic rocks and deposited as a 'fanglomerate' on the downthrow, west side of Flathead fault in late Eocene or early Oligocene time.

3. RÉSUMÉ OF GENERAL STRUCTURE

Tertiary rocks in vicinity of White Lake map-area are intersected by important gravity faults. The region is divided into three structural zones by the Marron fault system which follows Marron Valley southeasterly to Marron Lake; here it splits into a weak easterly-trending branch which passes into Okanagan Valley, and a strong southwesterly-trending branch which passes near Twin Lakes and extends into Similkameen Valley (see Figure 2.20).

Structural zone 'A', the area west of Marron fault and Twin Lake branch, is relatively simple. Typically, the strata here are thin, dip gently east, and are displaced mainly by northerly-trending gravity faults with easterly downthrow. Small grabens, such as Trout Lake graben (see Figure 2.4), occur along the eastern margin of the zone adjacent to the Marron fault system, which shows antithetic displacement.
Figure 2.17  Some Late Structures in Rocks East of White Lake

A. Slickenside Pattern

B. Cleavage Pattern

Legend:
- Short bar, angle cleavage measurement
- Long bar, average of similar cleavage structures in small quadrants
- 'N' number of measurements averaged
- 'D' angular dispersion of averaged measurements
- Only strikes of cleavage will also show (not QP projected)

(Coordinates are the same as on map 2023)
Figure 2.18 Equal Area Diagrams

A. Plot of Slickensides

B. Plot of Cleavages

Contour

- > 2.0%

95 Poles

Contours

- <0.5%
- 0.5-1.0%
- 1.0-2.0%
- 2.0-5.0%
- 5.0-7.0%
- > 7.0%

338 Poles
Figure 2.19 Possible Stress Scheme for Late Movement, Area Near White Lake
Figure 2.20 Structural Subdivisions of Map-area and Adjacent Region

Legend
Tertiary rock
Map-area boundary
Fault zone, approx.;
tick on downthrow side
Anticline, plunging
Syncline, plunging
Strata trend

Scale: 0 — 4 Miles
Zone 'B', the area between Twin Lake branch and easterly-trending branch of Marron fault system, is somewhat complex. In general, the strata here are folded to form 'White Lake syncline' which is open and plunges gently to the east. The beds are cut by gravity faults of widely varying trends which show mainly westerly or northerly downthrow. Reverse faults, probably related to concentric folding, are developed where strata are especially thick such as on the north limb of White Lake syncline. Some northerly-trending faults in the southeast part of zone 'B' show strike-slip displacement.

Rocks only in the southern part of zone 'C', the area east of Marron fault and north of zone 'B', were examined by the writer but some structural features are evident. In general, the Tertiary pile is thin on the west along the axis of an anticline and thick near the south end of Skaha Lake, site of the 'Okanagan Falls syncline'. Both folds are open and plunge southeastward. A northerly trending reverse fault, immediately west of south end of Skaha Lake, is possibly due to concentric folding of thick strata.

In summary, the main structural features are as follows:
1. The area underlain by Tertiary rocks is mostly bounded by gravity faults.
2. The Tertiary pile is thickest and structurally lowest near the Okanagan Valley.
3. Beds commonly dip in an easterly direction - westerly dipping beds are few.

The structure section A-B-C-D (see Figure 2.21) across the main belt of Tertiary rocks shows the typical deformation. It is proposed that a trapdoor-like downward rotation along west-dipping faults of the Okanagan system produced easterly dips and marked subsidence of strata near Okanagan Valley. Also, although details of the structural history are uncertain, this type of movement may have been influential in localizing Skaha and White Lake beds in the east part of the area. (see section on historical geology in Chapter IV of this report.).

Folds are only locally important and are best developed where Tertiary deposits appear to be thickest. Concentrically folded beds of White Lake and Okanagan Falls synclines probably reflect simpler underlying structures, possibly titled fault blocks.
Figure 2.21 Cross Section of White Lake Basin

(Looking Northeasterly)

Legend:
- Skaha F.
- White Lake F.
sediments/volcanic rocks
- Marron F.
- Springbrook F.

Scale:

(see map 100 for location of cross section)
GLACIAL GEOLOGY

Ice Thickness and Movement

According to the Glacial Map of Canada (1962), the Wisconsin ice sheet moved southerly from an ice divide north of Kamloops and attained a maximum elevation in excess of 7,000 feet in the southern Okanagan.

Two sets of glacial striae are observed in the map-area; a southerly trending set with presumably southerly sense, and an easterly trending set with sense of ice movement unknown.

East of White Lake, where the rocks were examined in detail, 16 of a total of 18 striae measurements trend southerly, 2 trend easterly. The presence of large blocks of granite breccia in gravel deposits west of Mahoney Lake establishes a southerly sense for the most recent ice advance, since the source of these blocks is about 1.5 miles north, on the ridge north of The Hole (see Figure 2.22).

A series of small closed depressions (site of ephemeral ponds) southeast of White Lake were probably formed by 'eddies' set up in southerly flowing ice in response to local topographic features. These depressions are mostly located on the south sides of knolls and bluffs where the thickest ice would accumulate and erode in a manner analogous to the formation of tarns and paternoster depressions such as commonly found in glaciated rugged terrain.

Meltwater Drainage and Glacial Deposits

According to Nasmith (1962), during the retreat of the Wisconsin ice sheet, meltwater discharging into the Similkameen valley excavated two significant channels, one containing Yellow Lake and the other located southwest of Twin Lakes. Pitted outwash deposits near Twin Lakes were laid down during this initial retreat of the ice.

At a later stage, meltwaters flowed south and east through White Lake basin to Okanagan Valley via Kearns Creek. Significant outwash deposits were formed at this time in the vicinity of Marron Lake and White Lake. Unable to pass directly south across the White Lake basin, probably because of ice damming near Dorfler Ranch, the meltwaters flowed southeast of the Observatory Site downslope along a surface of resistant chert breccia beds of Skaha Formation. Between Indian Head and The Hole, the western margin of augite-porphyry unit
Figure 2.22 Plot of Ice Movement in Area East of White Lake

Scale: 0 - 2000 Feet

(c-ordinates are the same as on map 200)
closely parallels the present course of Kearns Creek suggesting that the contact between this rock and chert breccia beds locally controlled the course of a stream prior to entrenchment of meltwaters and formation of present valley in this area (see Figure 2.23). Further south, the meltwater channel was controlled in part by north trending fault zone (see map 200).

At a later stage, when Okanagan ice lobe retreated north of Okanagan Falls, the Kearns Creek course was abandoned and meltwaters flowed eastward to glacial Lake Penticton following the present course of Marron Creek. A considerable volume of white silt (delta deposit) was laid down by this stream west of Okanagan Falls.
Figure 2.23 Topographic Section Showing Glacial Features in Vicinity of The Hole

- Indian Head

- Kearns Creek

- initial channel (subsequent)

- projected contact

- augite-porphyry

- chert breccia

- meltwater entrenchment

- line of section

- feet above m.s.l.

- Horizontal Scale:

  0  500  1000 Feet
The object of this chapter is to elucidate the petrographic and chemical nature and mode of origin of the Tertiary igneous rocks of the White Lake area.

**MAIN PETROGRAPHIC FEATURES**

A variety of early Tertiary effusive rocks is found in south-central British Columbia and northern Washington State as shown by petrographic descriptions and chemical analyses of LeRoy (1912), Daly (1912), Drysdale (1915), Church (1963), Staaz (1964), and Bostock (1966). (A comprehensive tabulation of chemical analyses is given in Appendix 'A'.) The rock assemblage includes andesite, rhyolite, trachyandesite, trachyte, tephrite (augite-porphyry), and phonolite (commonly with rhomb-shaped anorthoclase phenocrysts).

A similar spectrum of rock types is present in the White Lake area. The order of extrusion of these rocks is as follows:

8. tephrite .................. White Lake and Skaha F.
7. trachyte, trachyandesite ............ White Lake F.
6. rhyolite, rhyodacite ............ Marama F.
5. andesite .................. Marron F.
4. trachyte, trachyandesite ............ "
3. basaltic andesite ............ "
2. trachyte, trachyandesite ............ "
1. phonolite .................. "

(The normative composition of analysed rocks is given in Appendix 'B' and detailed petrographic descriptions of selected rocks are given in Appendix 'C'.)

Trachytes and trachyandesites are found in three stratigraphic zones (2, 4, and 7). Characteristically, these rocks contain two feldspars; plagioclase, which forms laths and clots or star-shaped glomerophenocrysts, and potassic feldspar, which occurs mainly as thin
rims or jackets on plagioclase crystals, or less commonly as discrete phenocrysts, and in the fine-grained groundmass. Generally the most basic rocks of this group, the trachyandesites, contain some normative nepheline, whereas the trachytes have some normative quartz. Although feldspathoidal minerals have not been detected in these rocks, quartz was observed in the fine-grained matrix of some trachytes.

The lowermost and uppermost lavas in the succession, phonolites and tephrites respectively, are markedly undersaturated in silica and contain important amounts of normative nepheline and olivine. X-ray analysis shows abundant analcite in the matrix of many of these rocks. Only a few grains of serpentine, pseudomorphic after olivine, are found. Potassic feldspar is abundant, occurring as distinctive rhomb-shaped (anorthoclase) phenocrysts in many lava flows. Plagioclase is scarce and generally restricted to the fine-grained groundmass of these rocks.

In contrast, andesite and rhyolite-rhyodacite rocks, which occur near the middle of the succession (3, 5, and 6), are rich in normative quartz. Also, unlike the rocks described above which are commonly holocrystalline, the andesites and rhyodacites are vitrophyric. Plagioclase phenocrysts are abundant in most of these rocks, whereas, phenocrysts of potassic feldspar are scarce and found only in some rhyolites.

In spite of the many differences in the felsic composition of these rocks, the mafic minerals show little variety. Diopsidic augite and biotite are widely distributed, varying only in relative abundance. Except for rhyolite and some trachytes, modal biotite is less abundant than pyroxene.

Accessory minerals include magnetite, apatite, and hypersthene. Magnetite occurs as small grains disseminated in the matrix of holocrystalline rocks or as small phenocrysts in vitrophyric rocks or constituent grains in glomerophenocrysts. Apatite occurs in the matrix of most rocks examined but is especially abundant and forms unusually large crystals in tephrite (augite-porphyry) and phonolite (rhomb-porphyry). (Prismatic cleavage traces are commonly observed in this apatite.) Hypersthene is found in some andesites but only amounts to a small percentage of the total pyroxene content.
CHEMICAL VARIATIONS

Murata (1960) has provided a graphical method of illustrating chemical variations in igneous rock series. Major oxides, such as lime and magnesia, are simply plotted against alumina-to-silica ratios. The utility of Murata-type plots is three-fold:

1- With these plots, rock series are readily delineated, as demonstrated by Murata in the case of Hawaiian tholoiitic and alkalic basalts.
2- Only partial chemical analyses are required.
3- Chemical variations are easily compared with important phase equilibria diagrams.

Important chemical differences in the igneous rock groups of this study are brought out with the plot - total iron oxide versus alumina-to-silica ratios (see Figure 3.1). Andesite - rhyodacite rocks, designated 'A' series, have relatively small alumina-to-silica ratios but large iron oxide range; high iron oxide values for andesites and low values for rhyodacites and rhyolites. Tephrite (augite-porphyry) and phonolite (rhomb-porphyry) rocks, designated 'C' series, typically have large alumina-to-silica ratios and high iron oxide content. Iron oxide is higher in tephrite rocks compared to phonolitic members of the series but range of values is less than exhibited by 'A' series. Trachyte - trachyandesite rocks, designated 'B' series, are intermediate in composition between 'A' and 'C' series. Generally, the most basic members of the series, the trachyandesites, have higher iron content than the acid members, the trachytes.

It is interesting to note (see Figure 3.1) that the line of silica-saturation bisects the composition field of 'B' series, whereas, 'A' and 'C' series fall, respectively, on the oversaturated and undersaturated side of the line. It will be shown in a later section that the position of this line is important in considering the genesis of the rocks of each series.

Refractive indices of glass of artificially fused rocks of 'A', 'B', and 'C' series are found by Church (1963) to be a suitable scale on which to base main chemical variations. The chemistry of analysed rocks is illustrated in Figures 3.2, 3.3, and 3.4. Refractive index histograms for a total of 137 samples, representing the three series, show relative abundance of the various rock types.
Figure 3.1 Early Tertiary Igneous Rock Series

open circles, analyses of lavas of White Lake map-area
solid circles, analyses of effusive rocks of south-central British Columbia and northern Wash.
areas within solid lines indicate approximate composition range for rock series

(see Table 3.1, key to analyses)
### Table 3.0 Key to Analyses, Figure 3.1

<table>
<thead>
<tr>
<th>Analysis No.</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Feeder dike to Midway andesite lava, LeRoy 1912 (see Appendix Table A-3, no. 5)</td>
</tr>
<tr>
<td>2.</td>
<td>Park Rill andesite, Marron F. (see Appendix Table B-1, no. 1)</td>
</tr>
<tr>
<td>3.</td>
<td>Andesite, Midway lava, Church 1963 (see Appendix Table A-3, no. 1)</td>
</tr>
<tr>
<td>4.</td>
<td>Rhyodacite, Kelowna area, Church 1963 (see Appendix Table A-3, no. 2)</td>
</tr>
<tr>
<td>5.</td>
<td>Sanpoil lava, Staaz 1964 (see Appendix Table A-4, no. 2)</td>
</tr>
<tr>
<td>6.</td>
<td>Sanpoil lava, Parker and Calkins 1964 (see Appendix Table A-4, no. 3)</td>
</tr>
<tr>
<td>7.</td>
<td>Marama lava (see Appendix Table B-1, no. 2)</td>
</tr>
<tr>
<td>8.</td>
<td>Shingle Creek porphyry (see Appendix Table A-3, no. 9)</td>
</tr>
<tr>
<td>9.</td>
<td>Pulaskite dike, feeder to Midway lava, LeRoy 1912 (see Appendix Table A-3, no. 6)</td>
</tr>
<tr>
<td>10.</td>
<td>Rosette-porphyry, Marron F. (see Appendix Table B-1, no. 3)</td>
</tr>
<tr>
<td>11.</td>
<td>Marron lava, Bostock 1966 (see Appendix Table A-3, no. 10)</td>
</tr>
<tr>
<td>12.</td>
<td>Clot-porphyry, Marron F. (see Appendix Table B-1, no. 4)</td>
</tr>
<tr>
<td>13.</td>
<td>Trachyte, Midway lava, Drysdale 1915 (see Appendix Table A-3, no. 7)</td>
</tr>
<tr>
<td>14.</td>
<td>Pulaskite dike, feeder to Midway lavas (see Appendix Table A-3, no. 3)</td>
</tr>
<tr>
<td>15.</td>
<td>Trachyte, Kelowna area, Church 1963 (see Appendix Table A-4, no. 4)</td>
</tr>
<tr>
<td>16.</td>
<td>Augite-porphyry, Midway lava, Drysdale 1915, (see Appendix Table A-3, no. 8)</td>
</tr>
<tr>
<td>17.</td>
<td>Augite - porphyry lava, Skaha F. (see Appendix Table B-1, no. 5)</td>
</tr>
<tr>
<td>18.</td>
<td>Marron lava, Bostock 1966 (see Appendix Table A-4, no. 1)</td>
</tr>
<tr>
<td>19.</td>
<td>Rhomb-porphyry, Midway volcanic rocks, Daly 1912 (see Appendix Table A-4, no. 5)</td>
</tr>
<tr>
<td>20.</td>
<td>Yellow Lake rhomb-porphyry, Marron F. (see Appendix Table B-1, no. 6)</td>
</tr>
<tr>
<td>21.</td>
<td>Rhomb-porphyry, Midway lava, LeRoy 1912, (see Appendix Table A-3, no. 4)</td>
</tr>
<tr>
<td>22.</td>
<td>Indian Head breccia (weathered), White Lake F. (see Appendix Table A-1, sample CC-18)</td>
</tr>
</tbody>
</table>
Figure 3.2 Variation Diagram, 'A' Series

- Open circles, analyses this study (see Table 3.1)
- Solid circles, analyses Church 1963

Frequency Percent

54 Samples

Glass Beads

Histogram

Refractive Index of Samples

1.570 1.560 1.550 1.540 1.530 1.520 1.510 1.500 1.490

50 40 30 20 10 0

SiO₂ %

FeO %

CaO %

Al₂O₃ %

MgO %

K₂O+Na₂O %
Figure 3.3 Variation Diagram, 'B' Series

open circles, analyses this study (see Table 3.1)
solid circles, analyses Church 1963
open circles, analyses this study (see Table 3.1)
solid circles, analyses Church 1963
Table 3.1  Key to Analyses (Figs. 3.2, 3.3, 3.4)

<table>
<thead>
<tr>
<th>Analyses Nos.</th>
<th>Field No.</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>'A' 1.</td>
<td>N64-3-1</td>
<td>andesite</td>
</tr>
<tr>
<td>Series 2.</td>
<td>N64-11-15</td>
<td>andesite</td>
</tr>
<tr>
<td>3.</td>
<td>N64-25A-2</td>
<td>andesite</td>
</tr>
<tr>
<td>4.</td>
<td>N64-8-9</td>
<td>rhyodacite</td>
</tr>
<tr>
<td>5.</td>
<td>N64-2-8</td>
<td>rhyolite</td>
</tr>
<tr>
<td>'B' 1.</td>
<td>N64-24-2</td>
<td>trachyandesite</td>
</tr>
<tr>
<td>Series 2.</td>
<td>N64-21-5</td>
<td>trachyte</td>
</tr>
<tr>
<td>'C' 1.</td>
<td>93C1</td>
<td>augite-porphyry</td>
</tr>
<tr>
<td>Series 2.</td>
<td>N64-B</td>
<td>rhomb-porphyry</td>
</tr>
<tr>
<td>3.</td>
<td>N64-20-K</td>
<td>rhomb-porphyry</td>
</tr>
</tbody>
</table>

(Complete chemical data for these rocks is given in Appendix Table A-1)
In summary, the main chemical characteristics of the series are as follows:

1- In all series silica increases with decreasing refractive index; silica values are generally lower in 'C' series showing smaller rate of increase than in 'A' or 'B' series.

2- Alumina is markedly variable; 'C' series shows sharp increase in alumina content passing from basic to acid rocks, however, the reverse is true for 'B' series. In contrast to both 'B' and 'C' series, the overall alumina content in rocks of 'A' series is low with little variation between basic and acid rocks.

3- Lime, magnesia, and iron oxide, the most refractory major constituents, decrease with increasing acidity (decreasing refractive index).

4- Total alkali composition (soda plus potash) of 'B' and 'C' series is relatively high showing little difference between basic and acid rocks. Alkali composition of 'A' series increases somewhat with acidity but is generally lower than 'B' or 'C' levels. Average potash-to-soda ratios of rocks analysed for the present study are as follows:

<table>
<thead>
<tr>
<th>Series</th>
<th>Composition</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>'A'</td>
<td>andesite</td>
<td>0.77</td>
</tr>
<tr>
<td></td>
<td>rhyolite - rhyodacite</td>
<td>0.66</td>
</tr>
<tr>
<td>'B'</td>
<td>trachyte - trachyandesite</td>
<td>1.47</td>
</tr>
<tr>
<td>'C'</td>
<td>tephrite (augite-porphyry)</td>
<td>1.53</td>
</tr>
<tr>
<td></td>
<td>phonolite (rhomb-porphyry)</td>
<td>0.76</td>
</tr>
</tbody>
</table>

In general, 'A' series rocks are relatively soda-rich, 'B' series rocks are relatively potash-rich, and 'C' series rocks are mixed with basic rocks potash-rich and acid rocks soda-rich or intermediate.

Data are also available for a few important minor elements. Figure 3.5A shows good correlation between titania and iron oxide for analysed rocks. This correlation is not surprising since one of Goldschmidt's main rules of diadochy states (Mason, 1956, p. 114):

"When a minor element has a similar ionic radius but a higher charge than that of a major element, it is said to be captured by the crystal lattice containing the major element."

Ionic radii of iron and titanium are very similar (in six-fold coordination):

<table>
<thead>
<tr>
<th>Element</th>
<th>Ionic Radius</th>
</tr>
</thead>
<tbody>
<tr>
<td>Divalent iron</td>
<td>0.74 Å</td>
</tr>
<tr>
<td>Trivalent iron</td>
<td>0.64 Å</td>
</tr>
<tr>
<td>Trivalent titanium</td>
<td>0.76 Å</td>
</tr>
</tbody>
</table>
Twenty-eight strontium and barium determinations were made on these rocks for this study (see Appendix Table A-1) and by Church (1963, Table D.1). The average strontium-to-barium ratios are similar for these rocks:

<table>
<thead>
<tr>
<th>Series</th>
<th>Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>'A'</td>
<td>0.50</td>
</tr>
<tr>
<td>'B'</td>
<td>0.52</td>
</tr>
<tr>
<td>'C'</td>
<td>0.57</td>
</tr>
</tbody>
</table>

However, some differences in concentration levels of strontium and barium are noted (see Figure 3.5B). Average concentration of these elements in 'A' series is less than 2000 p.p.m. and in 'B' series less than 3000 p.p.m. Characteristically 'C' series has high strontium and barium concentrations - greater than 3000 p.p.m.

**Petrographic Provinces**

Figure 3.6 is a sketch map showing the main areas of volcanic rock in southern British Columbia and Washington State. Waters (1962) distinguishes two petrographic provinces of early Tertiary rock in western Washington; (1) a spilite province centered on the Olympic peninsula and coastal areas to the south, and (2) an andesite province south and east of Puget Sound, extending east to the axis of the Cascades. The andesites are, in part, overlain by the younger Columbia River basalts to the east and the much younger rocks of the Cascade volcanic complex.

As shown in the preceding section the early Tertiary volcanic assemblage of the White Lake map-area and, more generally, Okanagan and Boundary areas of southern British Columbia, have markedly mixed composition. Interlayering of diverse rocks, such as those of 'A', 'B', and 'C' series, is probably due to overlapping of adjacent petrographic provinces.

Rocks of 'A' series examined by the author are mainly andesites and minor silica-rich acid types (see histogram Figure 3.2) and are possibly correlative with similar early Tertiary lavas of Kamloops and Princeton areas (see Stevenson, 1939, p.446, and description of Kamloops
Figure 3.5 Some Minor Element Variations

A TiO_2 - FeO Correlation

B Sr - Ba Dispersion

(data includes analyses by Church 1963)
Group by Daly, 1915, p. 126-130; and description of Princeton lavas by Rice, 1947, p. 29, and Shaw, 1952, p. 6, Camsell, 1913, p. 83). This 'andesitic' suite of volcanic rocks crop out in a broad belt trending northward from northern Washington through south-central British Columbia. The belt may represent a partly eroded northerly extension of the andesite province (2) of the Puget Sound area.

Rocks of 'B' and 'C' series are alkali-rich and resemble the Coryell batholith in both composition and age. The inference by Daly (1912, p. 419) that the Coryell intrusions are simply the plutonic equivalents of some of these early Tertiary volcanic rocks is now well founded. Table 3.2 shows the average chemical composition of two phases of the main intrusions of the Coryell batholith near Trail and Lower Arrow Lake, British Columbia. The most acid rocks of 'B' series (no. 15 of Figure 3.1) are similar to the quartz syenite phase, and tephrite of 'C' series (no. 17 of Figure 3.1) corresponds well with the shonkinite phase of the Coryell batholith. Also, the age of the Midway volcanic rocks determined by Mathews (1964), 48 and 49 m.y., is similar to the age of the Coryell rocks determined by Baadsgaard et al. (1961), 54 and 58 m.y.

The area of thickest volcanic deposits and largest exposed intrusions of these rocks, termed the 'alkalic magma province' (3), is roughly outlined in Figure 3.6. Some early Tertiary trachyte flows and alkali-rich intrusions are reported to occur in the Princeton and Kamloops areas to the west (Rice, 1929; Dawson, 1896) but these are comparatively small bodies possibly related to alkaline centers remote from the Okanagan - Boundary region. Knowledge of early Tertiary volcanic outliers and intrusions to the southwest and northeast is incomplete and the boundaries of province (3) are more or less arbitrarily drawn.

To the southeast, the 'Petrographic Province of Central Montana', made famous by the work of Pirsson (1905) and Larsen (1940), contains an assemblage of alkali-rich Tertiary intrusions (shonkinites) and volcanic rocks (mafic phonolites) bearing some
Figure 3.6 Cenozoic Petrographic Regions of Southern British Columbia and Washington State

Explanation

PLIOcene to RECENt
Cascade Volcanic Complex

MIocene - PlIOCene
Columbia River and 'Plateau' Basalt

EARLY TERTIARY

1. Spilite Province
2. Andesite Province
3. Alkali Magma Province
   Coryell Intrusions

(geology of Washington State simplified from Waters 1962)
Table 3.2 Composition of Main Phases of Coryell Batholith and Similar Rocks of 'B' and 'C' Series

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>63.2</td>
<td>63.7</td>
<td>60.4</td>
<td>53.4</td>
<td>51.0</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>17.0</td>
<td>17.1</td>
<td>18.5</td>
<td>16.6</td>
<td>16.6</td>
</tr>
<tr>
<td>FeO</td>
<td>4.3</td>
<td>3.5</td>
<td>4.7</td>
<td>8.5</td>
<td>7.6</td>
</tr>
<tr>
<td>MgO</td>
<td>2.0</td>
<td>0.7</td>
<td>1.5</td>
<td>5.8</td>
<td>6.9</td>
</tr>
<tr>
<td>CaO</td>
<td>2.8</td>
<td>3.4</td>
<td>4.4</td>
<td>8.0</td>
<td>9.2</td>
</tr>
<tr>
<td>Na₂O</td>
<td>4.9</td>
<td>11.6</td>
<td>4.6</td>
<td>3.4</td>
<td>3.4</td>
</tr>
<tr>
<td>K₂O</td>
<td>5.8</td>
<td>5.9</td>
<td>4.3</td>
<td>5.3</td>
<td></td>
</tr>
</tbody>
</table>

1. Average composition of Coryell 'quartz syenite' (see Little 1960, Table I, nos. K and L; Table III, no. 1)
2. Trachyte, Kelowna area (see Appendix Table A-4, no. 4)
3. Average trachyte-trachyandesite, Marron F. (see Table 2.4, no. 3; Table 2.5, no. 1)
4. Average composition of Coryell 'monzonites and shonkonites' (see Little 1960, Table I nos. M and N; Table III, no. 2)
5. Augite-porphyry, Skaha F. (see Table 2.9, no. 1)

(total iron is calculated as FeO)
resemblance to the alkali-rich rocks of the Okanagan-Boundary region. These are best developed in the Highwood Mountains of Montana and are typically potassic and rich in strontium and barium. Alumina content, however, is generally less than that in rocks of 'B' and 'C' series of the Okanagan-Boundary area and rhomb-porphyry rocks are not found.

PETROGENESIS

Fractional crystallization of parental andesite and shonkinite magmas appears to account for the rocks of the 'A' and 'C' series, respectively. Mixing of 'A' and 'C' magmas best explains the 'B' series and the transition from undersaturated to oversaturated compositions. Migration of potash from 'C' to 'B' magmas may have accompanied this mixing process, possibly aided by volatile transfer.

The magmas of the 'A' and 'C' series probably approached a silica-rich rhyolite eutectic and a soda-rich phonolite (rhomb-porphyry) eutectic, respectively, along separate composition and thermal lines of descent. These lines are diagrammatically represented in the system diopside-nepheline-silica (see Figure 3.7A) which contains important normative minerals of the 'A' and 'C' series.

Subtraction diagrams, Figures 3.8 and 3.9, show quantitatively how the acid magmas of 'A' and 'C' series, respectively, may have been produced.

In the case of the 'A' series, subtraction (fractionation) of a mineral aggregate, 'x' (composed mostly of plagioclase, some pyroxene, biotite, and minor magnetite), from Park Rill andesite, '1', can produce a silica-rich composition similar to average Marama lava, '2'. Roughly, fractionation of andesite '1' yields 60 percent crystal accumulate 'x' and 40 percent rhyolitic magma '2'.

In the case of the 'C' series, subtraction of aggregate 'y' (composed largely of pyroxene, some biotite, and minor potash) from Skaha augite-porphyry, '5', produces a composition similar to average Yellow Lake lava, '6'. Rough calculations show that fractionation of augite-porphyry yields 40 percent crystal accumulate plus minor
fugitive potash and 60 percent phonolitic magma '6'.

The magmas of 'B' series, as previously indicated, include silica-saturated and undersaturated types. The thermal divide between undersaturated and oversaturated magmas is breached, theoretically, by fractionation of undersaturated minerals or mixing of silica-poor and silica-rich magmas (see Tilley, 1958).

In consideration of the first case, that of separation of undersaturated minerals, biotite is present as phenocrysts in some rocks of the 'B' series; however, magnetite is the only abundant undersaturated mineral. Osborn (1959) shows that fractionation of magnetite from wet magmas with high partial pressure of oxygen can lead to enrichment in silica. Also, Bailey and Schairer (1966) show that crystal fractionation in highly oxidized undersaturated systems can yield oversaturated iron-poor residuals (see Figure 3.7B). However, in view of the relatively high iron content of even the most acid rocks of 'B' series (see Figure 3.1) it seems unlikely that magnetite-fractionation played any important role in the generation of these rocks. Also, determination of co-existing plagioclase and potassic feldspars in a number of rocks of 'B' series shows that feldspar pairs are joined by relatively steep tie lines (see Figure 3.10); this feature, according to Yoder et al. (1957), is characteristic of shallow-seated magmas (low pressure and high temperature). Escape of water through the roof of the magma chamber would reduce the oxygen content of the magma, thereby inhibiting formation of magnetite.

A more adequate explanation of the origin of the 'B' series is simply mixing of 'A' and 'C' magmas. Variation diagram, Figure 3.11, shows mostly regular chemical change from 'i', a composition intermediate in 'C' series (see Figure 3.9), through undersaturated and saturated rocks of 'B' series, nos. '3.' and '4.' and average 'k', average Kelowna trachyte (see Appendix Table A-4, no. 4), to no. '2.', average Marama lava. Roughly, rosette-porphyries and clot-porphyries of 'B' series represent mixtures of 'i' and '2.' of about 2:1; average Kelowna trachyte 'k' is mixed about 1:2.

Relatively high concentration of potash in 'B' series shown in
Figure 3.7 Phase Diagrams

A. Silica - Diopside - Nepheline System

B. Silica - Acmite - Nepheline System

Ab - Albite
Cg - Carnegieite
Di - Diopside
Fo - Forsterite
He - Hematite
Ne - Nepheline
Pl - Plagioclase
Si - Silica
Figure 3.8 Subtraction Diagram, 'A' Series

(see Table B-1)

Kalsilite
Quartz
Orthoclase
Albite
Anorthite
Hypersthene
Diopside
Orthopyroxene
Clinopyroxene
Magnetite
3Ks + 6Hy → 2Biotite + Or

Normative Composition

Frequency Percent
Mineral Frequency in Accumulate x

Relative Frequency of Phenocryst in 1'

Plagioclase
Pyroxene
Biottite
Magnetite

Park Rill andesite
Marama lava

(total iron is calculated as FeO)
Figure 3.9 Subtraction Diagram, 'C' Series

'y' consists of crystal accumulate clinopyroxene 68% and biotite 27% and fugitive potash 5%
(total iron is calculated as FeO)

'i' composition intermediate in 'C' series, see Figure 3.11
Table 3.3 Normative Calculations, 'y' as Pyroxene, Biotite, and Potash Residual

<table>
<thead>
<tr>
<th>Formula positions of cations</th>
<th>Z</th>
<th>Y</th>
<th>X</th>
<th>W</th>
<th>totals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composition of 'y', cation molecular percent</td>
<td>Si</td>
<td>Al</td>
<td>Fe&quot;</td>
<td>Fe&quot;</td>
<td>Mg</td>
</tr>
<tr>
<td>Clinopyroxene (Wo&lt;sub&gt;45&lt;/sub&gt;En&lt;sub&gt;35&lt;/sub&gt;Fs&lt;sub&gt;20&lt;/sub&gt;) %</td>
<td>29.1</td>
<td>4.9</td>
<td>6.8</td>
<td>11.9</td>
<td>15.3</td>
</tr>
<tr>
<td>general formula cation proportions</td>
<td>1.7</td>
<td>0.3</td>
<td>0.3</td>
<td>0.1</td>
<td>0.7</td>
</tr>
<tr>
<td>W(X,Y)Z&lt;sub&gt;2&lt;/sub&gt;O&lt;sub&gt;6&lt;/sub&gt; charge</td>
<td>+6.8</td>
<td>+0.9</td>
<td>+0.9</td>
<td>+0.2</td>
<td>+1.4</td>
</tr>
<tr>
<td>Biotite %</td>
<td>10.6</td>
<td>3.6</td>
<td>1.4</td>
<td>8.0</td>
<td>3.5</td>
</tr>
<tr>
<td>general formula cation proportions</td>
<td>3.0</td>
<td>1.0</td>
<td>0.4</td>
<td>2.3</td>
<td>1.0</td>
</tr>
<tr>
<td>W(X,Y)&lt;sub&gt;3&lt;/sub&gt;Z&lt;sub&gt;4&lt;/sub&gt;0&lt;sub&gt;10&lt;/sub&gt;(OH)&lt;sub&gt;2&lt;/sub&gt; charge</td>
<td>+12.0</td>
<td>+3.0</td>
<td>+1.4</td>
<td>+4.6</td>
<td>+1.0</td>
</tr>
<tr>
<td>Residual %</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(Composition Wo<sub>45</sub>En<sub>35</sub>Fs<sub>20</sub> is determined optically for pyroxene in Skaha augite-porphyry)
Figure 3.10 Co-existing Plagioclase and Potassic Feldspar in Two-Feldspar Rocks

\[ \text{An} \% \text{ in Plagioclase (oil immersion determinations)} \]

\[ \text{Or} \% \text{ in Potassic Feldspar (201 X-ray determinations)} \]

- **'A' Series**
  1. Rhyolite (Kelowna Area)
  2. Trachyte (Kelowna Area)
  3. Trachyandesite (Midway Area)

- **'B' Series**
  4. Trachyte (Midway Area)

- determinations, this study
- determinations, Church 1963
Figure 3.11, is not accounted for by the mixing hypothesis outlined above. Source of this extra potash may be 'C' magmas since, as previously indicated, some potash is lost from 'C' during magmatic evolution. High apatite content in these rocks suggests that the magmas were volatile-rich and that possibly transfer of potash from 'C' to 'B' magmas is achieved by volatile movement.

Concentration differences of Sr and Ba in rocks and minerals support the fractionation and mixing hypotheses outlined above. Church (1963, Table 4.8) shows average plagioclase much richer in Sr and Ba than clinopyroxene (plagioclase, 3300 ppm. Sr and 1260 ppm. Ba, average of 4 analyses, clinopyroxene, 174 ppm. Sr and 90 ppm. Ba, average of 6 analyses). High Sr and Ba content of 'C' compared to 'A' series rocks (see Figure 3.5B) is possibly due to partitioning of these elements between crystal and liquid phases such that marked fractionation of pyroxene from 'C' magmas leaves residual liquid enriched in Sr and Ba, whereas, fractionation of large amounts of plagioclase in the case of 'A' series leaves residual liquids impoverished in these elements. Average concentration of Sr and Ba in 'B' series is intermediate to 'A' and 'C' supporting the mixing hypothesis.
Figure 3.11 Mixing Diagram

(see Table A-4, no. 4)

(total iron is calculated as FeO)
CHAPTER IV
SUMMARY AND CONCLUSIONS

GEOLOGICAL HISTORY

A summary of Cenozoic geological events in southern interior of British Columbia is given in Table 4.0, based mainly on publications by Schofield (1943), Russell (1954), Mathews (1964), and Bally et al. (1966).

In the light of fossil evidence and stratigraphic correlations, outlined in preceding chapters, it seems likely that most of the rocks of the White Lake map-area were deposited during a short interval of geological time, probably not extending much beyond the Eocene epoch. A generalized columnar section of the Tertiary strata is shown in Figure 4.1.

The earliest recorded Tertiary event in the area was marked by deposition of Springbrook valley-talus and stream gravels. This was followed by slight eastward tilting of the Springbrook beds and a period of intense volcanic activity, during which the Marron rocks were deposited.

Five volcanic events are recognized in the Marron succession, each marked by deposition of distinctive rocks. The lowermost rocks are, typically, anorthoclase porphyries. These are overlain, in order, by trachyte-trachyandesite, basaltic andesite, trachyte-trachyandesite, and, uppermost, andesite. These lavas, mostly products of fissure extrusions, buried pre-existing valleys and hill tops to form thick sheet-like deposits, so that local topographic relief was greatly reduced.

Volcanic activity resumed with renewed vigor with extrusion of Marama rhyolite and rhyodacite, but not before erosion had cut deeply into the upper Marron rocks. Viscous lavas flooded valleys burying thin gravel deposits and, locally, overtopped ridge-crests.

An interval of erosion and gravity faulting followed. At this time, Okanagan Valley was probably a prominent geomorphological feature containing an important stream course.
<table>
<thead>
<tr>
<th>Epochs</th>
<th>K-Ar Age</th>
<th>Main Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recent</td>
<td></td>
<td>uplift and downcutting of streams; development of river terraces, deposition of alluvial fans in main valleys</td>
</tr>
<tr>
<td></td>
<td>1 m.y.</td>
<td>Pleistocene extensive glaciation, general beveling of topography and widening and deepening of valleys by ice action, formation of melt water channels; deposition of tills and drift, deposition of white silts of Kamloops and Okanagan valleys</td>
</tr>
<tr>
<td></td>
<td>10 m.y.</td>
<td>Pliocene uplift and dissection of landscape followed by local volcanic eruptions, 'valley basalt'</td>
</tr>
<tr>
<td></td>
<td>25 m.y.</td>
<td>Miocene short period of widespread volcanic eruption 'plateau basalts'</td>
</tr>
<tr>
<td></td>
<td>38 m.y.</td>
<td>Oligocene uplift followed by development of late mature erosion surface</td>
</tr>
<tr>
<td></td>
<td>57 m.y.</td>
<td>Eocene extensive and prolonged volcanic eruption; deposition of lake and stream sediments and some coal</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Paleocene record in Rocky Mountain area - end of imbricate thrusting and molasse-type deposition</td>
</tr>
</tbody>
</table>

K-Ar dates for epoch boundaries, average from Holmes (1959), Kulp (1961), and Geol. Soc. London (1964)
Figure 4.1 Generalized Columnar Section

<table>
<thead>
<tr>
<th>Formations</th>
<th>Main Deposits</th>
<th>Erosional and Tectonic Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skaha F.</td>
<td>glacial deposits</td>
<td>erosion - faulting - folding</td>
</tr>
<tr>
<td></td>
<td>fanglomerate</td>
<td>erosion</td>
</tr>
<tr>
<td></td>
<td>slide breccias</td>
<td>faulting</td>
</tr>
<tr>
<td>White Lake F.</td>
<td>volcanic rocks</td>
<td>erosion - faulting</td>
</tr>
<tr>
<td></td>
<td>interdigitated with sediments</td>
<td>faulting</td>
</tr>
<tr>
<td>Marama F.</td>
<td>rhyolite - rhyodacite</td>
<td>erosion - faulting</td>
</tr>
<tr>
<td></td>
<td>conglomerate</td>
<td>faulting</td>
</tr>
<tr>
<td></td>
<td>andesite</td>
<td>erosion</td>
</tr>
<tr>
<td></td>
<td>trachyte - trachyandesite</td>
<td>faulting</td>
</tr>
<tr>
<td>Marron F.</td>
<td>basaltic andesite</td>
<td>erosion - faulting</td>
</tr>
<tr>
<td></td>
<td>trachyte - trachyandesite</td>
<td>faulting</td>
</tr>
<tr>
<td></td>
<td>rhomb-porphyry</td>
<td>erosion</td>
</tr>
<tr>
<td>Springbrook F.</td>
<td>conglomerate</td>
<td>faulting</td>
</tr>
<tr>
<td></td>
<td>talus</td>
<td>erosion - faulting</td>
</tr>
<tr>
<td></td>
<td>pre-Tertiary</td>
<td>folding</td>
</tr>
<tr>
<td></td>
<td>metamorphic rocks</td>
<td>erosion - faulting - folding</td>
</tr>
</tbody>
</table>

(maximum thickness of units shown)
Deposition of White Lake sediments coincided with the eruption of trachyte and trachyandesite lavas from vents centered near the Okanagan Valley. In this area, a northerly flowing stream was probably dammed by volcanic debris forming a lake several miles in diameter (Tertiary White Lake). Large volumes of laharc and pyroclastic material were periodically ejected from water-filled vents spilling debris into Okanagan Valley and the nearby lake. The lake was filled by considerable thickness of shale, sandstone, and some coal. Extrusion of a small amount of tephrite lava marked the climax of volcanic activity.

Normal faulting followed and continued during deposition of the Skaha beds. These consist, in the lower part, of slide-breccias with intercalated tephrite lava and, in the upper part, of coarse fanglomerates. The gross nature of the clastic rocks reflects the dynamic conditions under which they were deposited. The slide-breccias were derived from high terrain, underlain mainly by Mesozoic chert, greenstone, and granite near the southeast part of map-area. The breccias were deposited on both Tertiary and pre-Tertiary rocks, possibly at the base of a fault scarp. They disrupted local drainage and were partly eroded and reworked by stream action. The uppermost beds, the fanglomerates, were derived partly from older Tertiary rocks and from the same high terrain that was a source for the slide-breccias. This material rests on eroded slide-breccias and locally onlaps White Lake rocks.

Deformation postdating the events described above, include folding (probably pre-Miocene), gravity and strike-slip fault movement (age unknown).

The late mature erosion surface, typical of central interior British Columbia, is preserved, in places, in the western part of the map-area; however, no Miocene Plateau Basalts overlie this surface as they do elsewhere.

**PETROLOGY**

A wide spectrum of lavas is present in the Tertiary stratigraphic
succession of the White Lake area. Three rock series are recognized from mineral and chemical evidence; 'A', rhyolite-andesite; 'B', trachyte-trachyandesite; 'C', phonolite (rhomb-porphyry) - tephrite (shonkinite).

Some important mineral differences are found. For example feldspar compositions vary markedly. Typically 'A' series rocks contain plagioclase phenocrysts in the range An\textsuperscript{0}_{20} to An\textsuperscript{0}_{60}; potassic feldspar is scarce. Commonly 'B' series rocks are two feldspar-bearing with coexisting andesine and sanidine phenocrysts. The rocks of 'C' series contain anorthoclase or, less commonly, sanidine; but very little plagioclase.

Apatite shown important variations. Apatite crystals are generally small and scarce in 'A' rocks, small but common in 'B' rocks, and large and abundant in 'C' rocks.

Marked chemical differences are also found. The composition of 'A' rocks contrasts sharply with that of 'C' rocks; generally, 'B' rocks are chemically intermediate to 'A' and 'C'. 'A' rocks commonly contain normative quartz and have small alumina-to-silica ratios, low strontium and barium content, and show a large range in iron concentration. In contrast, 'C' rocks contain normative nepheline and have large alumina-to-silica ratios, high strontium and barium content, and are iron-rich.

Details on the origin of these rocks are uncertain but probably they were derived from plutonic bodies formed from the melting of sialic and possibly some carbonate substratum. Absence of basalt suggests that this rock played little or no role in formation of the lavas of the White Lake area.

Rocks of 'A' series form part of an early Tertiary 'andesite' belt that extends through the central interior of British Columbia and northern and western Washington state. These lavas were probably extruded from large granodiorite batholiths flanking the axis of the Cascade Mountains.

Rocks of 'B' and 'C' series are probably derived from the Coryell Batholith (or satellite stock) which is similar in age and
composition. The main lobe of the Coryell Batholith, near Trail in south-central British Columbia, appears to be a high level intrusion unroofed by erosion after late Tertiary uplift. Coryell intrusions together with the lavas of the 'B' and 'C' series form an alkalic petrographic province centered immediately north of the International Boundary, extending from Okanagan Valley area on the west to Kootenay Lake on the east.

Evidence from experimental petrology suggests that two processes were mainly responsible for genesis and diversification of these rocks:

1- Rocks of the 'A' and 'C' series were formed by crystal fractionation of andesitic and shonkinitic parent magmas, respectively.

2- Rocks of the 'B' series were formed by mixing of 'A' and 'C' liquid differentiates.

Removal of mineral aggregates similar to actual phenocrysts of basic rocks of 'A' and 'C' series yields residuals similar in composition to acid rocks of the series. For example, subtraction of mainly plagioclase and some pyroxene and biotite from typical andesite of the 'A' series yields a rhyolitic composition; also, subtraction of the mainly pyroxene and some biotite from tephrite (augite-porphyry of the 'C' series) yields phonolitic composition (like the rhomb-porphyry rocks of 'C' series).

Similarly, it is possible to show, using a mixing diagram, that 'B' rocks have bulk compositions intermediate between the 'A' and 'C' series. Details on the mixing process are uncertain, however; scarcity of country rock xenoliths in 'B' lavas favours the view that liquid mixing was achieved without much solid assimilation.

In view of the high apatite content of 'B' and 'C' rocks it is likely that volatiles were influential in their evolution. For example, the high potash content of 'B' rocks is not accounted for by simple mixing of 'A' and 'C' magmas which are mostly soda-rich. Also, calculations show that excess potash results from crystal fractionations of 'C' magmas - probably this excess potash was boiled off with volatiles, to be gained, in part, by subjacent 'B' magmas.

Finally, in the light of recent work by Bowes and others, the
association of intrusion breccias and basic alkali-rich rock, such as found in the Skaha Formation, may not be coincidental. Possibly volatiles generated by crystallization of augite-porphyry magma caused explosions and remobilization of bedded rocks, such as Skaha slide debris, to form intrusion breccias. However, no conclusive evidence was found to support this theory during the present study.

SUGGESTIONS FOR FUTURE WORK

The present study provides a basis for future work on stratigraphy, structure, mineralogy, and chemistry of Tertiary rocks of the White Lake area.

The following studies are proposed to amplify stratigraphic data for purposes of correlation:

1- Radiometric age-dating. Most lavas of the White Lake area contain fresh biotite suitable for potassium-argon determinations.

2- Paliobotanical studies. Springbrook beds and especially White Lake beds contain abundant leaf fossils. Some microfossils, spores and pollen grains were obtained from White Lake sediments.

3- Paleomagnetic studies. According to some authors, magnetic reversals serve as marker zones for correlation in some otherwise undifferentiated lava successions.

Additional research is suggested on the structure of the Tertiary pile in the complex area near White Lake. A wealth of information could be obtained from seismic records of the Dominion Observatory station at White Lake.

Mineral studies might profitably be extended to include major and minor element analyses using X-ray fluorescent or emission spectrographic methods. Detailed information is especially scarce on zeolites, alkali feldspars, and apatite, all of which are fresh minerals commonly occurring in abundance in the Tertiary rocks of the White Lake area.

Finally, to complete chemical data, it is suggested that major oxide analyses be obtained for Marron basaltic andesite and White Lake trachyte and trachyandesite lavas.


Bostock, H.S., 1940, Keremeos, British Columbia; Geol. Survey, Canada, Map 341A.

_________, 1941, Okanagan Falls, British Columbia; Geol. Survey, Canada, Map 627A.

_________, 1941, Olalla, British Columbia; Geol. Survey, Canada, Map 628A.


__________, 1940, Kettle River (West Half), B.C.; Geol. Survey, Canada, Map 538A.


Carr, J.M., 1962, Geology of the Princeton, Merritt, Kamloops area of southern British Columbia; Western Miner and Oil Rev., v. 35, p. 46-49.


Dawson, G.M., 1879, Preliminary report on the physical and geological features of the southern portion of the interior of British Columbia; Geol. Survey, Canada, Rept. Progress 1877-1878.


Drysdale, C.W., 1915, Geology of Franklin Mining Camp, British Columbia; Geol. Survey, Canada, Mem. 56, 246p.

Emmons, R.C., 1943, The universal stage; Geol. Soc. America, Mem. 8, 205p.


Geological Association of Canada, 1958, Glacial map of Canada.


———, 1939, A descriptive petrography of igneous rocks (Volume 1); Univ. Chicago Press, Chicago, 267p.


Little, H.W., 1957, Geology of Kettle River (east half), British Columbia; Geol. Survey, Canada, Map 6-1957.

———., 1960, Nelson map-area (west half), British Columbia; Geol. Survey, Canada, Mem. 308, 205p.


Moxham, R.L., 1961, Minor element distribution in some metamorphic pyroxenes; Canadian Mineralogist, v. 6, p. 522-545.


Slemmons, D.B., 1962, Determination of volcanic and plutonic plagioclases using a three or four axis universal stage; Geol. Soc. America, Special Paper 69, 64p.


Tuttle, O.F., and Bowen, N.L., 1958, Origin of granite in the lights of experimental studies in the system NaAlSi$_3$O$_8$ - KAlSi$_3$O$_8$ - SiO$_2$ - H$_2$O; Geol. Soc. America, Mem. 74, 153p.


### Table A-1 Chemical Composition of Rocks, White Lake Map-area

<table>
<thead>
<tr>
<th></th>
<th>1.</th>
<th>2.</th>
<th>3.</th>
<th>4.</th>
<th>5.</th>
<th>6.</th>
<th>7.</th>
<th>8.</th>
<th>9.</th>
<th>10.</th>
<th>11.</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>74.9</td>
<td>67.6</td>
<td>53.8</td>
<td>54.6</td>
<td>58.1</td>
<td>49.7</td>
<td>54.9</td>
<td>55.0</td>
<td>51.7</td>
<td>52.0</td>
<td>46.8</td>
</tr>
<tr>
<td>TiO₂</td>
<td>0.18</td>
<td>0.41</td>
<td>1.46</td>
<td>0.94</td>
<td>0.86</td>
<td>0.60</td>
<td>0.90</td>
<td>0.98</td>
<td>0.78</td>
<td>0.94</td>
<td>1.04</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>14.7</td>
<td>17.2</td>
<td>16.2</td>
<td>14.8</td>
<td>15.4</td>
<td>17.5</td>
<td>18.8</td>
<td>17.5</td>
<td>20.5</td>
<td>20.6</td>
<td>15.3</td>
</tr>
<tr>
<td>MnO</td>
<td>0.07</td>
<td>0.06</td>
<td>0.14</td>
<td>0.08</td>
<td>0.11</td>
<td>0.09</td>
<td>0.10</td>
<td>0.18</td>
<td>0.11</td>
<td>0.10</td>
<td>0.14</td>
</tr>
<tr>
<td>FeO</td>
<td>0.63</td>
<td>2.3</td>
<td>6.8</td>
<td>5.5</td>
<td>5.9</td>
<td>3.2</td>
<td>4.9</td>
<td>4.6</td>
<td>5.1</td>
<td>4.8</td>
<td>7.0</td>
</tr>
<tr>
<td>MgO</td>
<td>0.5</td>
<td>0.5</td>
<td>4.8</td>
<td>3.7</td>
<td>4.1</td>
<td>2.8</td>
<td>4.1</td>
<td>1.8</td>
<td>2.3</td>
<td>0.9</td>
<td>6.3</td>
</tr>
<tr>
<td>CaO</td>
<td>1.2</td>
<td>2.9</td>
<td>6.1</td>
<td>4.8</td>
<td>5.2</td>
<td>6.7</td>
<td>4.6</td>
<td>4.0</td>
<td>4.7</td>
<td>4.3</td>
<td>8.5</td>
</tr>
<tr>
<td>Na₂O</td>
<td>4.6</td>
<td>4.6</td>
<td>3.7</td>
<td>3.8</td>
<td>3.9</td>
<td>4.1</td>
<td>4.5</td>
<td>4.3</td>
<td>4.6</td>
<td>6.0</td>
<td>3.2</td>
</tr>
<tr>
<td>K₂O</td>
<td>2.97</td>
<td>3.08</td>
<td>2.11</td>
<td>3.70</td>
<td>2.95</td>
<td>5.21</td>
<td>4.94</td>
<td>6.17</td>
<td>4.73</td>
<td>2.86</td>
<td>4.90</td>
</tr>
<tr>
<td>SrO</td>
<td>0.015</td>
<td>0.045</td>
<td>0.070</td>
<td>0.130</td>
<td>0.118</td>
<td>0.177</td>
<td>0.390</td>
<td>0.189</td>
<td>0.602</td>
<td>0.402</td>
<td>0.580</td>
</tr>
<tr>
<td>BaO</td>
<td>0.202</td>
<td>0.224</td>
<td>0.0965</td>
<td>0.269</td>
<td>0.224</td>
<td>0.560</td>
<td>0.615</td>
<td>0.415</td>
<td>0.850</td>
<td>0.808</td>
<td>0.965</td>
</tr>
<tr>
<td>H₂O</td>
<td>0.6</td>
<td>0.9</td>
<td>2.7</td>
<td>3.3</td>
<td>1.7</td>
<td>1.8</td>
<td>2.0</td>
<td>1.6</td>
<td>2.7</td>
<td>4.9</td>
<td>2.0</td>
</tr>
<tr>
<td>CO₂</td>
<td>0.1</td>
<td>0.3</td>
<td>0.1</td>
<td>3.0</td>
<td>0.1</td>
<td>7.8</td>
<td>0.1</td>
<td>0.3</td>
<td>0.4</td>
<td>1.1</td>
<td>3.5</td>
</tr>
<tr>
<td>Total</td>
<td>100.7</td>
<td>100.1</td>
<td>98.1</td>
<td>98.6</td>
<td>98.7</td>
<td>100.2</td>
<td>98.5</td>
<td>96.2</td>
<td>99.1</td>
<td>99.7</td>
<td>100.2</td>
</tr>
<tr>
<td>R.I.</td>
<td>1.499</td>
<td>1.508</td>
<td>1.553</td>
<td>1.549</td>
<td>1.539</td>
<td>1.541</td>
<td>1.535</td>
<td>1.584</td>
<td>1.555</td>
<td>1.556</td>
<td>1.582</td>
</tr>
</tbody>
</table>

1. Rhyolite, Marama F. (field no. N64-2-8; Map 100 location no. 13)
2. Rhyodacite, Marama F. (field no. N64-8-9; Map 100 location no. 12)
3. Park Rill andesite, Marron F. (field no. N64-3-1; Map 100 location no. 9)
4. Park Rill andesite, Marron F. (field no. N64-11-15; Map 100 location no. 10)
5. Park Rill andesite, Marron F. (field no. N64-25A-a; Map 100 location no. 8)
6. Trachyandesite (weathered), White Lake F. (field no. CC-18; Map 100 location no. 14)
7. Clot-porphryite, Marron F. (field no. N64-21-5; Map 100 location no. 4)
8. Rosette-porphyry, Marron F. (field no. N64-24-2; Map 100 location no. 6)
9. Yellow Lake porphyry, Marron F. (field no. N64-20-K; Map 100 location no. 3)
10. Yellow Lake porphyry, Marron F. (field no. N64-B; Map 100 location no. 1)
11. Augite-porphyry, Skaha F. (field no. 93C1; Map 100 location no. 15)

(total iron is calculated as FeO)

Analyses by Geological Survey of Canada, Rapid Method
<table>
<thead>
<tr>
<th></th>
<th>1. Clot-porphyry, Marron F. (field no. CC-5; Map 100 location no. 5)</th>
<th>2. Park Rill andesite, Marron F. (field no. CC-7; Map 100 location no. 11)</th>
<th>3. Rosette-porphyry, Marron F. (field no. CC-6; Map 100 location no. 7)</th>
<th>4. Yellow Lake porphyry, Marron F. (field no. CC-1; Map 100 location no. 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>61.79</td>
<td>63.68</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TiO₂</td>
<td>0.74</td>
<td>0.91</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>16.52</td>
<td>15.47</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MnO</td>
<td>0.05</td>
<td>0.07</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FeO</td>
<td>3.78</td>
<td>4.81</td>
<td>5.20</td>
<td>4.30</td>
</tr>
<tr>
<td>MgO</td>
<td>1.50</td>
<td>3.30</td>
<td>3.30</td>
<td>2.40</td>
</tr>
<tr>
<td>CaO</td>
<td>3.90</td>
<td>6.40</td>
<td>6.20</td>
<td>4.20</td>
</tr>
<tr>
<td>SrO</td>
<td>0.15</td>
<td>0.15</td>
<td>0.165</td>
<td>0.310</td>
</tr>
<tr>
<td>BaO</td>
<td>0.28</td>
<td>0.16</td>
<td>0.260</td>
<td>0.550</td>
</tr>
<tr>
<td>P₂O₅</td>
<td>trace</td>
<td>0.30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H₂O</td>
<td>1.19</td>
<td>1.19</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>89.90</td>
<td>96.44</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R.I.</td>
<td>1.517</td>
<td>1.538</td>
<td>1.529</td>
<td>1.532</td>
</tr>
</tbody>
</table>

Table A-2 Partial Analyses of Rocks, White-Lake Map-area
Table A-3 Chemical Analyses from Other Studies

<table>
<thead>
<tr>
<th></th>
<th>1.</th>
<th>2.</th>
<th>3.</th>
<th>4.</th>
<th>5.</th>
<th>6.</th>
<th>7.</th>
<th>8.</th>
<th>9.</th>
<th>10.</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>59.7</td>
<td>65.6</td>
<td>63.8</td>
<td>55.9</td>
<td>58.4</td>
<td>58.7</td>
<td>61.4</td>
<td>53.0</td>
<td>72.5</td>
<td>59.5</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>15.4</td>
<td>15.4</td>
<td>18.1</td>
<td>22.0</td>
<td>16.2</td>
<td>17.8</td>
<td>18.4</td>
<td>15.8</td>
<td>15.1</td>
<td>20.4</td>
</tr>
<tr>
<td>FeO</td>
<td>6.2</td>
<td>3.5</td>
<td>3.5</td>
<td>4.7</td>
<td>6.7</td>
<td>5.7</td>
<td>4.1</td>
<td>8.1</td>
<td>1.7</td>
<td>4.2</td>
</tr>
<tr>
<td>MgO</td>
<td>5.1</td>
<td>1.8</td>
<td>1.0</td>
<td>1.7</td>
<td>4.9</td>
<td>2.8</td>
<td>1.4</td>
<td>8.1</td>
<td>0.8</td>
<td>1.8</td>
</tr>
<tr>
<td>CaO</td>
<td>8.6</td>
<td>4.2</td>
<td>1.8</td>
<td>4.2</td>
<td>6.1</td>
<td>4.3</td>
<td>1.8</td>
<td>8.2</td>
<td>1.5</td>
<td>3.9</td>
</tr>
<tr>
<td>Na₂O</td>
<td>5.0</td>
<td>9.5</td>
<td>4.9</td>
<td>5.1</td>
<td>3.0</td>
<td>4.6</td>
<td>5.4</td>
<td>2.9</td>
<td>4.1</td>
<td>4.3</td>
</tr>
<tr>
<td>K₂O</td>
<td>6.9</td>
<td>6.4</td>
<td>4.7</td>
<td>6.1</td>
<td>7.5</td>
<td>3.9</td>
<td>4.3</td>
<td>5.9</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(major oxides recalculated to 100 percent; total iron as FeO)

1. Average andesite, Midway Gp. (Church, 1963, Table D-3 analysis A1-4)
2. Rhyodacite, Kelowna area (Church, 1963, Table D-3 no. A.7)
3. Pulaskite dike, Midway area (Daly 1912, Table XXVII no. 1)
5. Feeder dike to Midway andesite (LeRoy 1912, analysis no. I, p. 49)
7. Trachyte, Midway Gp. (Drysdale 1915, analysis p. 126)
8. 'Alkalic basalt' (augite-porphyry), Midway Gp. (Drysdale 1915, analysis p. 128)
9. Average composition of Shingle Creek porphyry (Bostock 1966, Table IX, no. 5)
10. Trachyandesite, Marron Gp. (Bostock 1966, Table IX, no. 8)
<table>
<thead>
<tr>
<th></th>
<th>1.</th>
<th>2.</th>
<th>3.</th>
<th>4.</th>
<th>5.</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>56.2</td>
<td>68.1</td>
<td>64.8</td>
<td>63.7</td>
<td>56.0</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>18.9</td>
<td>15.8</td>
<td>16.8</td>
<td>17.1</td>
<td>20.5</td>
</tr>
<tr>
<td>FeO</td>
<td>6.0</td>
<td>3.3</td>
<td>4.5</td>
<td>3.5</td>
<td>5.8</td>
</tr>
<tr>
<td>MgO</td>
<td>4.5</td>
<td>1.9</td>
<td>2.7</td>
<td>0.7</td>
<td>2.6</td>
</tr>
<tr>
<td>CaO</td>
<td>3.5</td>
<td>3.8</td>
<td>4.7</td>
<td>3.4</td>
<td>4.5</td>
</tr>
<tr>
<td>Na₂O</td>
<td>5.1</td>
<td>4.0</td>
<td>4.1</td>
<td></td>
<td>6.1</td>
</tr>
<tr>
<td>K₂O</td>
<td>5.8</td>
<td>3.1</td>
<td>2.8</td>
<td>11.6</td>
<td>4.5</td>
</tr>
</tbody>
</table>

(major oxides recalculated to 100 percent; total iron as FeO)

1. Average 'rhomb-porphyry', Marron Gp. (Bostock 1966, Table IX, nos. 6 and 7)
2. Average lava, Sanpoil Volcanics (Staatz 1964, Table 5, nos 1, 2, and 3)
3. Average lava, Sanpoil Volcanics (Parker and Calkins, 1964, Table 3, nos. 1 and 2)
4. Average trachyte, Kelowna area (Church 1963, Table D-3, nos. B-5 and B-7)
5. Average rhomb-porphyry, Midway Gp. (Daly 1912, Table XXVI no. 3; no. 1064 p. 414)
APPENDIX 'B' CALCULATION OF NORMS

Norm calculations are performed using a method adapted from Barth (1959). Briefly, the procedure is as follows:

Major oxide composition is recalculated to cation proportions according to the following example for Al₂O₃:

molecular proportion = Wt.%/ Mol. Wt. = 18/102 = 0.176

cation proportion = 0.176 x 2 = 0.352

Cation proportions are summed and recast as percentages, then assigned to mineral molecules according to the schedule given below. Finally, constituent cations of each mineral are summed giving normative mineral composition expressed as molecular mineral percent.

Schedule for Assignment of Cations:

1. Orthoclase  1K, 1Al, 3Si
2. Albite 1Na, 1Al, 3Si
3. Anorthite 1Ca, 2Al, 2Si
4. Residual Al as corundum
5. Residual Ca in diopside augite 1Ca, 1(Mg + Fe), 2Si
6. Residual Mg in hypersthene 1Mg, 1Fe, 2Si
7. Residual Fe as magnetite
8. Residual Si as quartz
9. If there is a deficiency of Si, recalculate part or all of albite to nepheline (1Na, 1Al, 1Si) in the proportions:
   \[ x(\text{albite}) + y(\text{nepheline}) = \text{available Na} \]
   \[ 3x(\text{albite}) + y(\text{nepheline}) = \text{available Si} \]
10. If there is still a deficiency of Si after step 9 then recalculate part or all of hypersthene to olivine (1Mg, 1Fe, 1Si) in the proportions:
    \[ x(\text{hypersthene}) + y(\text{olivine}) = \text{available Mg, Fe} \]
    \[ x(\text{hypersthene}) + \frac{y}{2}(\text{olivine}) = \text{available Mg, Fe} \]

For purpose of simplification, minor rock constituents, including water, are ignored in calculations. As a result, biotite, which is a common modal hydrous mineral, is normatively represented by some of the orthoclase (or kalsilite) and iron oxide, and most of
the olivine and corundum. Similarly, analcite which is present in some undersaturated rocks of this study, is represented mainly by normative nepheline.

The norms of rocks of 'A', 'B', and 'C' series, occurring in the White Lake area, are given in Table B-1. Abbreviations for normative minerals are as follows:

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Minerals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Qtz</td>
<td>quartz</td>
</tr>
<tr>
<td>Or</td>
<td>orthoclase</td>
</tr>
<tr>
<td>Ab</td>
<td>albite</td>
</tr>
<tr>
<td>An</td>
<td>anorthite</td>
</tr>
<tr>
<td>Ne</td>
<td>nepheline</td>
</tr>
<tr>
<td>Cor</td>
<td>corundum</td>
</tr>
<tr>
<td>Di</td>
<td>diopsidic augite</td>
</tr>
<tr>
<td>Hy</td>
<td>hypersthenite</td>
</tr>
<tr>
<td>Olv</td>
<td>olivine</td>
</tr>
<tr>
<td>Mg</td>
<td>magnetite</td>
</tr>
</tbody>
</table>
Table B-1 Normative Compositions

<table>
<thead>
<tr>
<th></th>
<th>1.</th>
<th>2.</th>
<th>3.</th>
<th>4.</th>
<th>5.</th>
<th>6.</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO$_2$</td>
<td>61.0</td>
<td>72.4</td>
<td>59.4</td>
<td>60.9</td>
<td>51.0</td>
<td>56.0</td>
</tr>
<tr>
<td>Al$_2$O$_3$</td>
<td>16.2</td>
<td>16.2</td>
<td>18.9</td>
<td>18.4</td>
<td>16.6</td>
<td>22.3</td>
</tr>
<tr>
<td>FeO</td>
<td>6.1</td>
<td>1.5</td>
<td>5.0</td>
<td>4.5</td>
<td>7.6</td>
<td>5.4</td>
</tr>
<tr>
<td>MgO</td>
<td>4.2</td>
<td>0.1</td>
<td>1.1</td>
<td>1.7</td>
<td>6.9</td>
<td>1.8</td>
</tr>
<tr>
<td>CaO</td>
<td>5.4</td>
<td>2.1</td>
<td>4.3</td>
<td>4.4</td>
<td>9.2</td>
<td>4.8</td>
</tr>
<tr>
<td>Na$_2$O</td>
<td>4.0</td>
<td>4.7</td>
<td>4.6</td>
<td>4.8</td>
<td>3.4</td>
<td>5.7</td>
</tr>
<tr>
<td>K$_2$O</td>
<td>3.1</td>
<td>3.0</td>
<td>6.7</td>
<td>5.3</td>
<td>5.3</td>
<td>4.0</td>
</tr>
</tbody>
</table>

|          |        |        |        |        |        |        |
| Qtz      | 5.5    | 26.9   | -      | 1.9    | -      | -      |
| Or       | 18.2   | 18.1   | 39.1   | 30.8   | 30.7   | 23.0   |
| Ab       | 35.5   | 41.9   | 35.0   | 42.3   | 2.0    | 38.0   |
| An       | 16.9   | 10.0   | 11.0   | 12.8   | 14.0   | 22.9   |
| Ne       | -      | -      | 3.5    | -      | 16.7   | 7.1    |
| Cor      | -      | 1.5    | -      | -      | -      | -      |
| Di       | 7.7    | -      | 8.1    | 7.0    | 24.5   | 0.3    |
| Hy       | 15.3   | 0.6    | -      | 2.3    | -      | -      |
| Olv      | -      | --     | -      | -      | 9.5    | 7.0    |
| Mg       | 0.9    | 1.0    | 3.3    | 2.9    | 2.6    | 1.7    |

1. Fresh Park Rill andesite (field no. N64-25A-2)
2. Average Marama lava (field nos. N64-2-8, N64-8-9)
3. Fresh rosette-porphyry (field no. N64-24-2)
4. Average clot-porphyry (field nos. N64-21-5, CC-5)
5. Fresh Skaha augite-porphyry (field no. 93C1)
6. Average Yellow Lake lava (field nos. N64-20-k, N64-B)

(total iron is calculated as FeO)
APPENDIX 'C' PETROGRAPHIC DESCRIPTIONS

The following petrographic descriptions of distinctive lava types supplement data given in Chapters II and III. Descriptions are arranged according to the main rock series, as defined in Chapter III, then in order of relative stratigraphic position of the rocks.

Rock colour-names and symbols are adapted from the 'rock-color chart' distributed by Geological Society of America (1963). Textural terms are those suggested by Williams, Turner, and Gilbert (1955).

Methods used for determination of main minerals are as follows:
Potassic feldspar - 201 X-ray method (Tuttle and Bowen, 1958, p. 13)
Plagioclase - cleavage flake oil immersion method by Tsuboi (Winchell and Winchell, 1956, p. 281)
- refractive indices of plagioclase glass (Slemmons, 1962, Plate 12)

ROCKS OF 'A' SERIES

1. Basaltic Andesite

This rock occurs near the middle of the Marron Formation and is conveniently exposed in a road cut 0.4 miles east of Yellow Lake on Highway 3.

The rock is typically a pyroxene-porphyry and varies in colour from brownish grey (5YR4/1) on fresh surfaces to moderate brown (5YR3/4) where weathered.

Although no chemical analyses are available, relative high refractive indices of glass artificially prepared from several samples suggest a slightly more basic composition than that of typical andesites of 'A' series (see Figure 2.4).
The following modal composition is determined from four thin sections:

<table>
<thead>
<tr>
<th>Phenocrysts</th>
<th>Clinopyroxene - 10%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plagioclase</td>
<td>- 1%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Groundmass</th>
<th>Feldspar - 60%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Chlorite - 15%</td>
</tr>
<tr>
<td></td>
<td>Magnetite</td>
</tr>
<tr>
<td></td>
<td>Biotite - accessory</td>
</tr>
<tr>
<td></td>
<td>Apatite</td>
</tr>
<tr>
<td></td>
<td>Quartz</td>
</tr>
</tbody>
</table>

Clinopyroxene composition is about $\text{Wo}_{42}\text{En}_{39}\text{Fs}_{19}$ ($2V_\mu - 51^\circ$, $\text{ny} - 1.693$). Grains are commonly subhedral, slightly elongate in prismatic section, and rarely exceed 3.5mm. in maximum diameter. Alternate medium and pale green (oscillatory) zones are developed in many large crystals. Inclusions of small apatite rods, magnetite granules, and glass blebs are common in some phenocrysts.

Plagioclase phenocrysts range in composition between oligoclase and andesine (refractive index determinations on glass from fused plagioclase, $\text{n} - 1.513$, gives the composition $\text{Ab}_{70}\text{An}_{30}$). Large crystals are generally lath-shaped (as much as 4mm. long) but as a rule with some embayments or rounded outline.

The groundmass is composed of small (less than $\frac{1}{2}$mm. in diameter) interlocking equant grains of plagioclase, potassic feldspar, and chlorite. Magnetite granules are disseminated throughout the groundmass and are interstitial to slightly larger silicate minerals.

Quartz is scarce and is mainly concentrated in amygdales and along cracks.

Secondary alteration has severely affected plagioclase phenocrysts and groundmass constituents; however, primary textures are not destroyed. Plagioclase is replaced, in part, by mixtures of mica, clay minerals, and possibly some calcite. Chlorite has replaced a few small phenocrysts of pyroxene and almost all of the groundmass pyroxene and biotite.

2. Andesite

Typical andesite forms the uppermost unit of the Marron
Plate C.1  Hand specimen of typical basaltic andesite

Plate C.2  Photomicrograph (crossed nicols) of basaltic andesite showing plagioclase (Pl.) and clinopyroxene (Cpx.) phenocrysts set in microcrystalline groundmass
Formation and is given the local name 'Park Rill andesite'. Two textural phases can be distinguished in the field, a merocrystalline and a vitric phase. Merocrystalline andesite is distributed widely throughout the map-area but is most conveniently exposed immediately north of the gravel road about 0.8 miles northwest of Stewart Ranch. Vitric andesite, stratigraphically equivalent to merocrystalline andesite, is observed only on the north limb of the White Lake syncline. A fresh and readily accessible exposure of vitric andesite is located immediately east of the gravel road 1.1 miles north of Observatory Site.

The colour of these rocks is somewhat variable. Merocrystalline andesite is commonly dusky yellowish brown (10YR2/2) where fresh but moderate brown (5YR3/4) on rusted weathered surfaces. Altered (chloritized) andesite observed on the ridge south of Stewart Ranch is commonly greenish grey (5GY6/1) flecked with small white altered feldspar crystals. Vitric andesite is dark grey (N3) where fresh but yellowish brown (10YR4/2) on weathered surfaces.

Chemical analyses show merocrystalline andesite to be slightly more acidic in composition than vitric andesite (see Table 2.6). This is in keeping with slight differences noted in refractive indices of glass beads prepared from rock samples (average R.I. = 1.541, 4 samples of merocrystalline andesite; average R.I. = 1.548, 8 samples of vitric andesite). Smaller average density of vitric andesite (av. S.G. = 2.656, 15 samples) compared to merocrystalline andesite (av. S.G. = 2.669, 21 samples) is probably due to crystal-to-glass ratio differences.

Modal composition of fresh merocrystalline andesite, determined from eight thin sections, is as follows:

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Glass</td>
<td>60%</td>
</tr>
<tr>
<td>Plagioclase</td>
<td>25%</td>
</tr>
<tr>
<td>Clinopyroxene</td>
<td>15%</td>
</tr>
<tr>
<td>Magnetite</td>
<td>1%</td>
</tr>
<tr>
<td>Biotite</td>
<td>~1%</td>
</tr>
<tr>
<td>Orthopyroxene</td>
<td>trace</td>
</tr>
<tr>
<td>Apatite</td>
<td>trace</td>
</tr>
</tbody>
</table>

Plagioclase crystals commonly show oscillatory zoning and have
a composition-range of An\textsubscript{46} - An\textsubscript{53} (Tsuboi method) - (R.I. of plagioclase glass is 1.533 giving the approximate composition Ab\textsubscript{48} An\textsubscript{52}). Crystals are commonly solitary with rectangular habit of subhedral or euhedral outline. Crystals with diameters 0.5 to 1mm. are most abundant and few exceed 3.5mm. Most commonly, plagioclase is clear and contains a few apatite grains or glassy bleb inclusions; also, crystals are riddled with vermicular glass or blebs and grains of foreign material arranged concentrically in layers parallel to oscillatory zoning. Albite and Carlsbad type twinning is well developed in almost all plagioclase grains.

Clinopyroxene shows some oscillatory zoning and has the approximate composition Wo\textsubscript{47} En\textsubscript{33} Fs\textsubscript{20} (2V\textsubscript{\|} = 57°, ny = 1.697). Crystals are commonly solitary with stubby prismatic sections and anhedral or subhedral outlines. Most crystals are within the size range 0.25 to 0.5mm., few are greater than 3mm. in diameter. Crystals are pale green and clear; a few contain small apatite rods or magnetite grains.

Accessory minerals include magnetite, biotite, orthopyroxene, and apatite. Magnetite is relatively abundant forming anhedral grains (less than 0.25mm. in diam.) scattered randomly throughout the glassy groundmass or occurring in clusters with pyroxene. Biotite is less abundant and is observed as dark brown strongly pleochroic books (oxybiotite) ranging greatly in size from less than 0.5mm. to more than 3mm. in maximum length. Commonly, biotite is partly corroded and charged with magnetite dust but also occurs as fresh euhedral crystals. Apatite is not abundant and is found mainly as inclusions in silicate minerals. A strongly pleochroic variety of orthopyroxene, probably hypersthene (large optic axial angle) forms about 5 percent of the pyroxene concentrates separated from this rock.

Glass, which forms the bulk volume of this rock, is medium brown coloured and has a lower refractive index than Canada Balsam (1.540). Structurally, the glass has flow banding and, in some samples, is charged with tiny microlites.

Vitric andesite composition, estimated from 12 thin sections of fresh rock, is as follows:
Phenocrysts -  
Clinopyroxene  5%  
Orthopyroxene  1%  
Plagioclase  1%  

Groundmass -  
Glass plus  
microites  95%  

Clinopyroxene composition is estimated Wo<sub>49</sub> En<sub>39</sub> Fs<sub>12</sub>  
(2V<sub>y</sub> = 59°, ny = 1.688). These crystals are clear, almost colourless, anhedral, and commonly 0.25 to 0.5 mm. in diameter.

Orthopyroxene is distinguished from clinopyroxene with some difficulty. The mineral has pale green and pink pleochroism suggesting hypersthene composition, although no detailed optical data are available for positive identification.

The composition of plagioclase phenocrysts is in the range An<sub>45</sub> - An<sub>65</sub> (relatively high refractive index; positive optic axial angle). Phenocrystals are lath-shaped and small, generally less than 0.5 mm. long. Twinning is not highly developed.

The groundmass is composed mostly of grayish brown glass but is commonly charged with small, subparallel plagioclase laths (less than 0.2 mm. long) forming typical microlitic texture. Intergranular pyroxene and magnetite is disseminated throughout.

Secondary alteration of andesite, partly due to weathering, results in replacement of pyroxene by chlorite and of plagioclase by white mica, clay minerals, and calcite. Chemical analyses of both weathered and fresh merocrystalline andesite (see Appendix Table A-1, nos. 4 and 5) shows high total water and carbon dioxide in the weathered rock. Fresh and weathered rocks are almost chemically identical when major oxides, excluding water and carbon dioxide, are recalculated to 100 percent (see Table 2.6, nos. 1 and 2).

Normally, textures are well preserved even in the most severely altered rocks.

3. Rhyodacite

Rhyodacite lava comprises most of the Marama Formation and is intermixed with minor rhyolite lava and breccia. The rock is conveniently exposed in a road cut immediately east of Prather Lake.
Plate C.3  Photomicrograph (plain light) of merocrystalline andesite showing plagioclase (Pl.), pyroxene (Px.), and minor magnetite (opaque) phenocrysts set in glass

Plate C.4  Photomicrograph (plain light) of vitric andesite; the rock is composed largely of glass containing small laths of plagioclase and a few pyroxene (Px.) subhedra
The rock is varicoloured in tones of grey on fresh surfaces (N3 to N6) and brown (10YR6/2, 5YR5/2, and 5YR6/4) where weathered. Typically, partly weathered samples are mottled medium grey (N5) and dark yellowish brown (10YR4/2).

The rock has vitrophyric texture and is easily confused with vitric andesite in the field. However, rhyodacite is chemically distinctive (see Appendix Table A-1, no. 2) and has low refractive index (average R.I. on glass beads is 1.508, 10 samples) and specific gravity (average S.G. = 2.538, 14 samples).

Study of twenty thin sections shows that the rock consists of more than 85 percent glass, devitrified glass, and microlites. Phenocrysts are mainly plagioclase (less than 15%), some clinopyroxene (less than 5%) or, rarely, hornblende.

Plagioclase shows some normal and oscillatory zoning but has an average composition of approximately Ab$_{57}$An$_{43}$ (based on determination of plagioclase glass, R.I. = 1.525). Crystals are mainly lath-shaped with euhedral outlines and show complete size range between phenocrysts 1mm. in maximum length to cryptomicrolite dimensions.

Clinopyroxene crystals are observed only in about half the total thin section examined. The exact composition of this mineral is unknown but a large optic axial angle and almost colourless appearance suggests that it may be diopsidic augite. Crystals are small, less than 0.5mm. in diameter, with equant habit, and commonly subhedral or anhedral outline.

Hornblende is observed in only one thin section. Crystals are small, mostly less than 0.5mm. in length, and show subhedral outlines. Margins of some crystals are corroded and charged with opaque magnetite dust. Pleochroism is so strongly developed (commonly dark brown and greenish brown) that extinction angles and optic axis figures are difficult to measure, although Z to C values are small, in keeping with common hornblende compositions.

The glassy groundmass of rhyodacite is commonly light coloured and charged with plagioclase microlites and magnetite grains.
Plate C.5  Typical platy habit of rhyodacite lava

Plate C.6  Photomicrograph (crossed nicols) of rhyodacite showing plagioclase phenocrysts (Pl.) set in glassy groundmass - ferromagnesian minerals are scarce
Most samples of rhyodacite show signs of secondary alteration. The groundmass is commonly birefringent indicating devitrification and replacement by microcrystalline minerals. Calcite and minor chlorite have replaced phenocrysts and patches of groundmass in some of the rock.

4. Rhyolite

Rhyolite was observed only in the Marama Formation and is well exposed on the hill side immediately north of Green Ranch.

The rock is typically a light coloured (yellowish grey 5Y8/1) quartz-feldspar-porphyry.

Chemical analysis (see Appendix Table A-1, no. 1) shows unusually high silica content of rhyolite compared to other lavas of this study. Also, specific gravity and refractive index of rhyolite is relatively low (S.G. 2.33; R.I. 1.499).

Examination of one thin section of rhyolite shows the following modal composition:

Phenocrysts - Plagioclase 10%
                             Quartz 5%
                             Biotite 1%

Groundmass - mainly de-vitrified glass 85%

Plagioclase shows marked normal zoning; cores of large phenocrysts have the approximate composition Ab$_{65}$ An$_{35}$, microlites and outer zones of phenocrysts are about Ab$_{76}$ An$_{24}$ (determinations are based on the Tsuboi oil immersion method and extinction methods). Crystals are rectangular or polygonal in habit with subhedral outlines and vary in size from 4mm. in maximum length to less than 0.5mm.

Quartz crystals are water-clear and have equant habit showing rounded and embayed outlines. Inclusions are few and consist mainly of small rods of apatite, rutile(?), and vacuoles partly filled with liquid. Crystal sizes are variable but commonly range between 0.5 and 3mm. in diameter.
Plate C.7  Fluidal banding in rhyolite

Plate C.8  Photomicrograph (crossed nicols) of rhyolite showing plagioclase (Pl.), quartz (Qz.), and biotite (Bio.) set in groundmass of partly devitrified glass
Biotite is pleochroic in deep browns and appears fresh. Books are subhedral in outline and commonly less than 2mm. in diameter. Inclusions are few and consist mainly of magnetite and apatite grains.

The groundmass of this rock is composed almost entirely of quartz and feldspar. These crystals are interwoven in a mat-work of feathery cryptocrystalline clots. The clots are about 0.2mm. in diameter and may represent patches of devitrified and recrystallized glass.

Magnetite and other accessory heavy minerals are scarce.

Except for some rusted surfaces rhyolite is commonly fresh and appears to be more resistant to weathering than other lavas in the map-area.

ROCKS OF 'B' SERIES

1. Clot-Porphyries

The field name 'clot-porphyry' is a collective term used in reference to trachytic and trachyandesitic rocks with lath-shaped phenocrysts and glomerophenocrystic 'clots' of feldspar having equant or stout rectangular habit. These rocks occur in the lower middle part of the Marron Formation.

Clot-porphyry rocks are multicoloured, commonly dark yellowish brown (10YR4/2) and olive grey (5Y4/1) where fresh and brownish grey (5YR4/1) and medium grey (N-5) on weathered surfaces. Some severely weathered rocks have a blackish red matrix (5R2/2) and bleached white feldspar phenocrysts.

The chemical composition of two samples is given in Appendix Table A-1 (no. 7) and Appendix Table A-2 (no. 1), and the refractive index-range of glass of artificially fused samples is shown in Figure 2.4.

The most common variety of clot-porphyry rock is conveniently exposed in roadcuts along Highway 3 near the east end of Yellow Lake and near the junction of Highways 3 and 97. This rock also forms the middle part of the clot-porphyry section west of Mahoney Lake. Its
approximate mode is as follows:

<table>
<thead>
<tr>
<th>Phenocrysts</th>
<th>composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plagioclase</td>
<td>~25%</td>
</tr>
<tr>
<td>Sanidine</td>
<td></td>
</tr>
<tr>
<td>Clinopyroxene</td>
<td>~2%</td>
</tr>
<tr>
<td>Biotite</td>
<td></td>
</tr>
<tr>
<td>Magnetite</td>
<td>~1%</td>
</tr>
<tr>
<td>Apatite</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Groundmass</th>
<th>composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feldspar</td>
<td>~60%</td>
</tr>
<tr>
<td>Magnetite</td>
<td></td>
</tr>
<tr>
<td>Biotite</td>
<td></td>
</tr>
<tr>
<td>Pyroxene</td>
<td></td>
</tr>
<tr>
<td>Chlorite</td>
<td></td>
</tr>
<tr>
<td>Apatite</td>
<td></td>
</tr>
<tr>
<td>Quartz</td>
<td></td>
</tr>
</tbody>
</table>

The composition of plagioclase phenocrysts determined from two samples is \( \text{Ab}_{22} \text{An}_{48} \) and \( \text{Ab}_{45} \text{An}_{55} \) (\( \eta_x' = 1.553 \), \( \eta_x' = 1.551 \); Tsuboi method). Zoning is slight. Solitary crystals have tabular or lath-shaped habits, commonly \( \frac{1}{2} \) to 3 mm. in maximum diameter, with rounded or embayed outlines. Glomerophenocrysts commonly consist of five or six unsymmetrically arranged crystals joined along sinuous contacts. These 'clots' range from 3 to 7 mm. in diameter. Minor pyroxene, biotite, and magnetite are observed in some aggregates.

The texture of the feldspar clots suggests a xenolithic origin. Possibly the clots were derived from loose crystal-accumulates in a magma chamber. Xenoliths of country rock are uncommon in clot-porphyry lavas.

Sanidine phenocrysts are generally scarce. The compositions of slightly zoned crystals from two trachytes are \( (\text{Ab} + \text{An})_{6} \text{Or}_{94} \) and \( (\text{Ab} + \text{An})_{42} \text{Or}_{58} \) (201 X-ray method). The sanidine is commonly fresh and relatively free from inclusions and occurs as solitary laths as much as 2 cm. long or as jackets on plagioclase.

The clinopyroxene, determined from two samples, is \( \text{Wo}_{45} \text{En}_{35} \text{Fs}_{20} \) and \( \text{Wo}_{42} \text{En}_{40} \text{Fs}_{18} \) (\( 2V_p = 51^\circ \), \( \eta_y = 1.693 \); \( 2V_p = 54^\circ \), \( \eta_y = 1.696 \)). Phenocrysts are pale green, slightly zoned, and commonly have equant habits with subhedral outlines. Generally individual pyroxene crystals are small, \( \frac{1}{2} \) to 2 mm. in diameter, however, a few glomerophenocrysts are as much as 4 mm. in diameter.
Biotite is strongly pleochroic in shades of brown. Basal plates are generally darker than prismatic sections. Phenocrysts are commonly solitary showing subhedral or corroded amoeboid-like outline. The thin outermost shell of biotite books is usually charged with magnetite dust.

Magnetite and apatite phenocrysts are few and less than \(\frac{1}{2}\) mm. in diameter. Magnetite generally occurs as equant subhedral or anhedral grains, and apatite as subhedral prisms. Many of these minerals form poikilitic inclusions in pyroxene and biotite and, to a much lesser extent, in feldspar phenocrysts.

The groundmass is composed mainly of felted feldspar microlites with interstitial biotite, pyroxene, and disseminated magnetite grains. In a few rocks the microlites are arranged in subparallel fashion suggesting flowage.

The lowermost clot-porphyry beds, west of Mahoney Lake, are distinctive and are mapped separately (termed small feldspar porphyry on map 200). The modal composition of this rock is as follows:

Phenocrysts: Plagioclase 20%
Biotite trace

Groundmass: Feldspar 70%
Magnetite
Calcite pseudomorphic after pyroxene - accessory
Apatite

The low concentration of ferromagnesian minerals and relatively small size of feldspar-porphyry 'clots' (less than 4 mm. in diameter) are typical of this rock, distinguishing it from the 'normal' type of clot-porphyry described above.

The anomalously high sodic composition of plagioclase in this rock, Ab\(_{69}\) An\(_{31}\) (determination on plagioclase glass, R.I. - 1.518) is possibly due to deuteric action. Most plagioclase examined is bleached white and charged with finely disseminated clay minerals.

The upper part of the clot-porphyry rocks, west of Mahoney Lake, also forms a mappable unit (termed clot-lath feldspar porphyry on map
Plate C.9 Photomicrograph (crossed nichols) of clot-porphyry trachyte showing plagioclase glomerophenocrysts (Pl.) with sanidine jackets (San.) set in microcrystalline groundmass.

Plate C.10 Photomicrograph (crossed nichols) of clot-porphyry trachyandesite showing typical plagioclase 'clot' (xenolith)
The rock generally contains markedly fewer feldspar phenocrysts and has a lower ratio of glomeroporphyroblasts to solitary crystals than does that of normal clot-porphyry described previously. Plagioclase occurs mainly as plates (1 to 6 mm. in diameter) with broad equidimensional (010) faces and thin lath-shaped sections in zones normal to (010).

The rock is commonly deeply weathered and fresh phenocrysts are scarce. Determination of partly sericitized plagioclase using extinction methods is Ab_{72} An_{28}.

2. Rosette-Porphyries

The field name 'rosette-porphyry' applies to trachytic and trachyandesitic rocks that typically contain small glomerophenocrysts of radially oriented feldspar. These rocks occur in the upper middle part of the Marron Formation and are conveniently exposed in roadcuts along Highway 3 near Trout Lake.

Rosette-porphyry is typically dark yellowish brown (10YR 4/2) on fresh surfaces and commonly light olive grey (5Y 5/2) or greyish red (10R 4/2) where weathered.

Refractive indices and specific gravities of rosette-porphyry (R.I. = 1.527, av. of 10 samples; S.G. = 2.59, av. of 42 samples) and clot-porphyry (R.I. = 1.526, av. of 10 samples; S.G. = 2.59, average 46 samples) are markedly similar, as are their chemical compositions (see Appendix Table A-1, nos. 7 and 8).

Examination of 25 thin sections of fresh rock shows the following average composition:

<table>
<thead>
<tr>
<th>Phenocrysts</th>
<th>Plagioclase</th>
<th>~ 8%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sanidine</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clinopyroxene</td>
<td>~ 3%</td>
<td></td>
</tr>
<tr>
<td>Biotite</td>
<td></td>
<td>- trace</td>
</tr>
</tbody>
</table>
Groundmass - Feldspar ~ 70%
Glass ~ 10%
Biotite
Pyroxene
Magnetite - accessory
Apatite

In view of the low phenocryst-to-groundmass ratio, shown above, distinction between trachytes and trachyandesites is best made on the basis of chemical data. Since the most pronounced differences between rocks of this series is silica composition (see Chapter III), rocks containing normative quartz are arbitrarily called trachytes and undersaturated rocks with normative nepheline are termed trachyandesites.

Plagioclase phenocrysts are only slightly zoned. Their composition range, based on determination of feldspar from two rocks, is from Ab\(^{52}\) An\(^{18}\) to Ab\(^{44}\) An\(^{56}\) (\(n_v = 1.553\), and \(n_y = 1.558\); Tusboi method). Individual crystals are lath-shaped and most of them form glomeroporphyritic bursts 2 to 5 mm. in diameter. Carlsbad and polysynthetic albite twinning is displayed by most crystals. Inclusions are few and consist mainly of small apatite rods.

Sanidine is a soda-rich variety with compositions (Ab+An)\(^{42}\) Or\(^{58}\) and (Ab+An)\(^{46}\) Or\(^{54}\) (determined from two rocks by the \(\bar{2}01\) X-ray method). (The widely accepted boundary between sanidine and anorthoclase is about Ab\(^{65}\) Or\(^{35}\) based on the monoclinic - triclinic inversion point of these feldspars - see Smith and Mackenzie 1958, p. 874). Sanidine occurs as jackets on plagioclase or commonly as free-floating laths 2 to 6 mm. long. The crystals are clear, relatively free from inclusions and with subhedral or euhedral habits. The optic axial plane is oriented nearly parallel to the basal cleavage; optic axial angles are generally large for sanidine, 50 to 60 degrees. Most laths show Carlsbad twinning; grid twinning, typical of anorthoclase, is not observed.

The clinopyroxene is approximately Wo\(^{45}\) H\(^{35}\) Fs\(^{20}\) (\(2V_y = 54^\circ\), \(n_v = 1.696\)). Crystals are pale green in thin section and only slightly zoned. Most commonly it occurs as solitary crystals \(\frac{1}{2}\) to 1 mm. in diameter showing equant habits and subhedral outlines. Apatite and magnetite inclusions are common.

Biotite phenocrysts are generally few. They are pleochroic in yellowish browns, commonly corroded and charged with magnetite dust.
Plate C.11 Typical massive rosette-porphyry trachyte
Plate C.12  Photomicrograph (crossed nichols) of rosette-porphyry trachyandesite showing typical plagioclase glomerophenocryst

Plate C.13  Photomicrograph (crossed nicsls) of rosette-porphyry trachyte showing sanidine laths set in microcrystalline groundmass
The groundmass is composed mainly of felted feldspar microlites about 0.1mm. long. Interstices are filled mostly with a dark brown substance, probably devitrified glass, some biotite and pyroxene. Magnetite grains are disseminated uniformly throughout.

3. White Lake Feldspar Porphries

Feldspar-porphyries resembling 'clot-porphyry' rocks described previously, form the bulk of the volcanic facies of the White Lake Formation. These rocks are conveniently exposed in roadcuts immediately southwest of the bridge on Highway 97, near the village of Okanagan Falls, and on the bluffs near Indian Head about half a mile east of White Lake.

The rocks are commonly weathered, perhaps due to their fragmented character (see Chapter II), and they vary in colour from medium grey (N7) to greenish grey (5GY6/1) and moderate yellowish brown (10YR5/4) on rust-stained surfaces.

The refractive index of glass prepared from the White Lake feldspar-porphyry rocks indicates a marked composition range (see Figure 2.8). The chemical analysis of a weathered sample obtained near Indian Head resembles trachyte in composition except for low silica, and high lime and carbon dioxide (see Appendix Table A-1, no. 6).

The relative frequency of phenocrysts in these rocks is as follows (based on binocular examination and thin section studies):

<table>
<thead>
<tr>
<th>Phenocryst</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plagioclase</td>
<td>- 5 to 20%</td>
</tr>
<tr>
<td>Sanidine</td>
<td>- less than 5%</td>
</tr>
<tr>
<td>Biotite</td>
<td>- trace</td>
</tr>
<tr>
<td>Clinopyroxene</td>
<td></td>
</tr>
<tr>
<td>Magnetite</td>
<td></td>
</tr>
<tr>
<td>Apatite</td>
<td></td>
</tr>
</tbody>
</table>

The groundmass is markedly variable in composition and texture. In some of the most 'acid' rocks, such as those near Indian Head, the groundmass consists mainly of small feathery feldspar microlites (~75%), showing subparallel 'flow' arrangement (trachyte texture), and interstitial chlorite (~ 20%), possibly replacing glass, and disseminated magnetite grains (~ 5%). On the other hand, some of the most 'basic' rocks of this assemblage, such as some in the lower part of the White Lake Formation, are relatively glassy; i.e. -

<table>
<thead>
<tr>
<th>Component</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Groundmass</td>
<td>Glass and partially devitrified glass - 70%</td>
</tr>
<tr>
<td></td>
<td>Feldspar microlites - 25%</td>
</tr>
<tr>
<td></td>
<td>Ferromagnesian minerals - 5%</td>
</tr>
</tbody>
</table>
Plagioclase is commonly replaced by mica, calcite, or patches of sodic feldspar. Composition based on refractive index of glass prepared from a sample of this altered plagioclase is about Ab70 An30 (R.I. = 1.512). The mineral occurs both as single crystals and glomerophenocrysts, usually less than 5mm. in diameter, showing embayed and rounded outlines.

Sanidine amounts to less than ⅔ total modal feldspar phenocryst content in rocks examined. Composition of phenocrysts determined from a trachyandesite are about (An+Ab)50 Or95. Crystals are clear, except for minor alteration products, and occur as jackets on plagioclase or solitary laths.

Biotite is commonly present and is the dominant ferromagnesian constituent in trachytes and trachyte breccias near Indian Head. Generally biotite books are pleochroic in browns and reddish brown, subhedral in outline, ½ to 2mm. in diameter, and are relatively free of inclusions except for some magnetite dust near resorbed margins and a few apatite crystals. Biotite alters to weakly birefringent chlorite minerals and magnetite; also, in some rocks biotite is replaced by a bright green chlorite showing moderate birefringence.

Clinopyroxene is commonly replaced by calcite, chlorite, and iron oxide. The composition of fresh unzoned phenocrysts from a trachyandesite is Wo45 En37 Fs18 (2Vp = 54°; ny = 1.695). Crystals generally range from ½ to 2mm. in diameter and show subhedral outlines.

Magnetite and apatite crystals, which are less than ½mm. in maximum diameter and subhedral in outline, occur as solitary crystals or form glomeroporphyroblasts with pyroxene alteration products.

ROCKS OF 'C' SERIES

1. Rhomb-Porphyry (Phonolite)

Lavas bearing distinctive rhomb-shaped anorthoclase phenocrysts constitute most of the Yellow Lake porphyry beds, the basal unit of the Marron Formation. This rock is conveniently exposed in roadcuts on the north shore of Yellow Lake and near the switchback on Highway 3 about 1.7 miles west of Kaleden Junction. The best textural development of this rock is displayed by basal Marron lavas in the valley cut
Plate C.14 Photomicrograph (crossed nicols) of White Lake feldspar-porphyry trachyte showing plagioclase (Pl.) and sanidine (San.) phenocrysts set in microcrystalline groundmass
by Kearns Creek, about a half mile northwest of Mahoney Lake.

The rock is commonly light olive grey (5Y6/1) or dark grey (N3) on freshly broken surfaces and light olive grey (5Y5/2) where weathered.

The large range in refractive indices obtained on glass beads prepared from rocks (see Figure 2.4) suggests marked chemical variation; however, two non-amygdaloidal samples analysed are quite similar, showing relatively low silica and unusually high alumina content (see Appendix Table A-1, nos. 9 and 10).

Examination of 30 thin sections of fresh rock shows the following mineral:

| Phenocrysts | Anorthoclase (varying abundance) |
| Clinopyroxene (varying abundance) |
| Biotite (minor abundance) |
| Plagioclase (present in some rocks) |
| Analcite (uncommon as phenocrysts) |
| Olivine (uncommon; mainly altered to bowlingit) |
| Epidote (rare as phenocrysts) |
| Magnetite (rare as phenocrysts) |

| Groundmass | Feldspar (very abundant) |
| Pyroxene (common) |
| Biotite (common) |
| Epidote (common) |
| Magnetite (common) |
| Analcite (common in some rocks) |
| Glass (scarce) |

The textures exhibited by rhomb-porphyry rocks are markedly variable. For example, the lowermost lavas in the Yellow Lake succession commonly contain large and often well-formed phenocrysts (some as long as 2cm.) of anorthoclase (5 to 15%), dark green clinopyroxene (10 to 20%), and minor biotite suspended in a matrix composed mainly of felted feldspar microlites and scattered magnetite granules. In contrast, the uppermost Yellow Lake lavas are commonly microporphyritic and composed mostly of small subhedral crystals (mainly less than 2mm. in diameter) consisting mainly of anorthoclase (15 to 25%) and clinopyroxene (about 5%); the groundmass is commonly a felted intergrowth of feldspar and some pyroxene microlites, a few biotite flakes, and disseminated magnetite granules. Some rhomb-porphyrries are similar to the 'shackanite' lavas of the Midway area described by Daly (1912, p. 411-415); typically, the groundmass of these rocks contains many roundish or polygonal analcite crystals with average diameters of about 0.1mm. In
a few 'shackanites', there are analcite phenocrysts with diameters as large as 3mm.

The composition of anorthoclase from microporphyry is approximately \((\text{Ab+An}) \approx 80\) or 20 (201 X-ray determination). This is roughly in agreement with X-ray fluorescence determination of large anorthoclase phenocrysts by Bostock (1966, p. 13) from basal Marron flows, Shingle Creek B.C.

The usual habit of the anorthoclase is illustrated in Figure C.1. Goniometric measurements on two large crystals, obtained from basal lavas near Kearn's Creek, show that the characteristic rhomb-outline of (010) sections, faces, and cleavage plates is due to modifications of the type (110), (1\(\overline{1}0\)), and (201):

\[
\begin{align*}
110 & \wedge 010 \approx 58^\circ \\
110 & \wedge 001 \approx 68^\circ \\
20\overline{1} & \wedge 001 \approx 80^\circ \\
\beta & = 116^\circ \\
a:b:c & = 0.66 : 1 : 0.58
\end{align*}
\]

(see Daly 1912, p. 402).

Optical data obtained on the same large crystals are similar to common anorthoclase (see Figure C.1 and Deer et al., vol. 4, p. 57). It should be pointed out, however, that examination of many thin sections shows 2\(V_\phi\) range of 38 to 80 degrees and extinction angle with (001) cleavage trace on (010) plates, 3 to 14 degrees.

Many anorthoclase crystals examined in thin section show marked zoning. Cobaltinitrite stain-tests indicate that the thin outer zones of some crystals are rich in potassium. This is verified by X-ray determination on part of the outer shell of a large rhomb-shaped crystal which gives Or 90 (201 method). Also, the X-ray diffraction pattern of this outer shell is comparable to that of hyalophane, suggesting a significant content of barium (see Table C.1). (Since barium is commonly divalent and is markedly similar to potassium in ionic radius \((\text{Ba}^{2+} = 1.46, K^{+} = 1.45 \text{ Å})\) it is not surprising that this minor element is captured by potassium-rich zones in feldspar).

Grid twinning (combination of albite and pericline polysynthetic twinning) is observed on some anorthoclase crystals. Significantly, sections showing good grid twinning also show (001) and (010) cleavage
Figure C.1 Illustration of Habit and Optical Orientation of Rhomb-shaped Anorthoclase
Table C.1  Feldspar X-ray Diffraction Data

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th></th>
<th>2</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>dA</td>
<td>I</td>
<td>dA</td>
<td>I</td>
<td></td>
</tr>
<tr>
<td>6.48</td>
<td>5</td>
<td>6.53</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>5.90</td>
<td>5</td>
<td>5.87</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>4.678</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.216</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.027</td>
<td>5</td>
<td>4.01</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>3.798</td>
<td>25</td>
<td>3.93</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>3.675</td>
<td>5</td>
<td>3.77</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>3.457</td>
<td>7</td>
<td>3.60</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>3.318</td>
<td>100</td>
<td>3.46</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>3.190</td>
<td>70</td>
<td>3.30</td>
<td>90</td>
<td></td>
</tr>
<tr>
<td>2.993</td>
<td>20</td>
<td>3.22</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>2.904</td>
<td>15</td>
<td>2.98</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>2.765</td>
<td>7</td>
<td>2.901</td>
<td>70</td>
<td></td>
</tr>
<tr>
<td>2.576</td>
<td>40</td>
<td>2.759</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>2.393</td>
<td>7</td>
<td>2.572</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>2.322</td>
<td>5</td>
<td>2.427</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>2.167</td>
<td>15</td>
<td>2.319</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>2.126</td>
<td>10</td>
<td>2.162</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>2.065</td>
<td>5</td>
<td>2.113</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>2.009</td>
<td>5</td>
<td>2.057</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>1.973</td>
<td>5</td>
<td>2.004</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>1.932</td>
<td>5</td>
<td>1.969</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>1.849</td>
<td>5</td>
<td>1.920</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>1.792</td>
<td>30</td>
<td>1.852</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>1.729</td>
<td>80</td>
<td>1.796</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>1.620</td>
<td>3</td>
<td>1.763</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>1.587</td>
<td>3</td>
<td>1.626</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>1.562</td>
<td>3</td>
<td>1.570</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>1.534</td>
<td>3</td>
<td>1.529</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>1.498</td>
<td>15</td>
<td>1.494</td>
<td>70</td>
<td></td>
</tr>
</tbody>
</table>

1. Potassic feldspar from outer shell of large rhomb-shaped anorthoclase crystal.

2. 'Hyalophane' containing 3.8% BaO (Vermaas, 1953)
Plate C.15 Typical rhomb-shaped anorthoclase phenocryst from Yellow Lake lava
Plate C.16 Photomicrograph (plain light) of Yellow Lake lava with anorthoclase (Anorth.), clinopyroxene (Cpx.), biotite (Bi.), and apatite (Ap.) phenocrysts. The groundmass is finely crystalline and contains many round grains of analcite.

Plate C.17 Photomicrograph (crossed nicols) of apatite crystal, in rhomb-porphyry lava, showing basal parting and well developed (1010) cleavage.
Plate C.18 Photomicrograph (crossed nicols) of (010) section of anorthoclase showing rhomb-shaped outline of crystals and (001) cleavage trace.

Plate C.19 Photomicrograph (crossed nicols) of (001) section of anorthoclase showing grid-twinning and (010) cleavage trace.
traces and generally squarish or equant rather than rhomb-shaped outlines. Chemical compositions of rhomb-shaped anorthoclase crystals from Midway area, British Columbia, and Mount Erebus, Ross Island Antarctica, are given in Table C.2.

Plagioclase phenocrysts are infrequent; however, when present they are commonly corroded and mantled with potassic feldspar. The estimated composition of the plagioclase, based on relative relief and extinction angles, is An $\text{An}^{35}$.

The clinopyroxene composition is Wo$_{50}$ Hy$_{35}$ Fs$_{15}$ (2$V^\prime_\alpha$ = 60°, ny= 1.694; average of three similar determinations). Phenocrysts show oscillatory zoning and variations in light and medium green colours. Large crystals are prismatic, commonly with euhedral outline; however, microporphyries generally contain stubby subhedral crystals.

Although some rhomb-porphyry rocks are soda-rich, sodic pyroxenes are not observed.

Biotite is strongly pleochroic in browns and orange-brown, and generally the margins of the biotite books show evidence of magmatic corrosion.

Apatite and magnetite are relatively abundant in rhomb-porphyry rocks and from a few crystals as large as 2mm. in diameter. These minerals occur in the groundmass and as inclusions in feldspar, pyroxene, and biotite phenocrysts. Prismatic cleavage (1010) is commonly well developed in apatite.

Fresh olivine is not found in rhomb-porphyries even though these rocks contain significant normative olivine. A greenish-brown mineral (bowlingite?) was observed in several thin sections pseudomorphic after a small equant mineral with well developed pyramid terminations - possibly olivine.

2. Augite-Porphyry (Tephrite)

Augite-porphyry is a basic alkali-rich rock similar in composition to tephrite, the extrusive equivalent of shonkinite. It occurs in two stratigraphic zones in the map-area; at the top of the White Lake Formation and near the middle of the Skaha Formation. The rock from the White Lake Formation is typically a microporphyry containing many xenoliths (mainly quartz grains, and lumps of granite and shale). Skaha augite-porphyry is relatively coarse, fresh, and free from
### Table C.2 Analyses of Rhomb-shaped Anorthoclase

<table>
<thead>
<tr>
<th></th>
<th>1.</th>
<th>2.</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>56.16</td>
<td>62.61</td>
</tr>
<tr>
<td>TiO₂</td>
<td>0.62</td>
<td>-</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>22.80</td>
<td>21.98</td>
</tr>
<tr>
<td>FeO</td>
<td>2.06</td>
<td>0.33</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>-</td>
<td>0.86</td>
</tr>
<tr>
<td>MgO</td>
<td>1.34</td>
<td>0.08</td>
</tr>
<tr>
<td>CaO</td>
<td>4.75</td>
<td>3.75</td>
</tr>
<tr>
<td>Na₂O</td>
<td>4.59</td>
<td>7.27</td>
</tr>
<tr>
<td>K₂O</td>
<td>5.74</td>
<td>3.12</td>
</tr>
<tr>
<td>B₂O₅</td>
<td>1.12</td>
<td>-</td>
</tr>
<tr>
<td>SrO</td>
<td>0.82</td>
<td>-</td>
</tr>
<tr>
<td>φ</td>
<td>-</td>
<td>1.536</td>
</tr>
<tr>
<td>ϒ</td>
<td>-</td>
<td>1.541</td>
</tr>
<tr>
<td>2V</td>
<td>40° to 50°(-)</td>
<td>62°(-)</td>
</tr>
<tr>
<td>x'001</td>
<td>2° to 14°</td>
<td>2° to 5°</td>
</tr>
<tr>
<td>S.G.</td>
<td>-</td>
<td>2.620</td>
</tr>
<tr>
<td>Mol. %</td>
<td>(Ab+An)₆₀Or₄₀</td>
<td>(Ab+An)₂₂Or₁₈</td>
</tr>
</tbody>
</table>

1. Anorthoclase from Rock Creek Chonolith, near Midway B.C. (Daly, 1912)

2. Anorthoclase from ash deposit, crater of Mt. Erebus, Ross Island Antartica (Mountain, 1925)
xenoliths. A good exposure of this rock is to be seen beside the logging road about a mile southeast of the Observatory Site.

The rock is olive grey (5Y4/1) where fresh, and moderate brown (5YR4/4) or greyish brown (5YR3/2) on weathered surfaces.

A xenolith-free variety has relatively high specific gravity (~2.820) and refractive index of glass beads (~1.580). These values decrease with increasing degree of xenolith contamination.

The modal composition of fresh, xenolith-free rock (based on examination of three thin sections) is comparable to the normative composition calculated from chemical analysis of the same rock using the Barth method (see Barth 1959, p. 82; and Appendix Table B-1, no. 5).

<table>
<thead>
<tr>
<th>Mode</th>
<th>Norm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potassic Feldspar (and Plagioclase)</td>
<td>Or 30.7%</td>
</tr>
<tr>
<td></td>
<td>Ab 2.0%</td>
</tr>
<tr>
<td></td>
<td>An 14.0%</td>
</tr>
<tr>
<td>Analcite</td>
<td>Ne 16.7%</td>
</tr>
<tr>
<td>Clinopyroxene</td>
<td>Di 24.5%</td>
</tr>
<tr>
<td>Biotite</td>
<td>Olv 9.5%</td>
</tr>
<tr>
<td>Magnetite</td>
<td>Mg 2.6%</td>
</tr>
<tr>
<td>Apatite</td>
<td>2%</td>
</tr>
</tbody>
</table>

63.4%

Clinopyroxene shows oscillatory zoning indicating somewhat variable composition; however, many optical measurements give an average of Wo45 En35 Fs20 (2Vp= 55°; ny= 1.696). Crystals commonly have prismatic elongation, euhedral outline, and range in length between 0.25mm. and 1.5cm. They vary in colour from medium to very pale green and display high second order interference colours under crossed nicols. Inclusions are mainly magnetite and apatite, some biotite, feldspar, and glass.

The groundmass is composed mainly of grains less than 0.5mm. in diameter including the felsic minerals, most of the biotite, and the accessories, magnetite and apatite. Potassic feldspar, plagioclase, and biotite occur as randomly oriented laths and plate Angular interstices between these minerals are filled mainly with analcite and some glass (?). Rounded grains of magnetite and euhedral apatite, probably early-formed minerals, are scattered throughout the groundmass commonly occurring as inclusions in other minerals.

Partial replacement of plagioclase by secondary minerals prevents accurate determinations, however, relatively high normative anorthite content of the rock suggests a calcic composition.
Fresh olivine is not observed in augite-porphyry; however, a few patches of serpentine-like substance in the goundmass appear to be pseudomorphous after this mineral. The relatively high normative olivine composition of the rock is probably accounted for by the presence of biotite which is, in part, chemically equivalent to olivine.
Plate C.20  Hand specimen of White Lake augite-porphyry (tephrite) charged with granite xenoliths

Plate C.21  Photomicrograph (plain light) of Skaha augite-porphyry lava showing large clinopyroxene euhedra (Cpx.) and some biotite (Bi.) plates set in a groundmass of feldspar, analcite, biotite, and magnetite.
Geology of White Lake Basin

Legend

Early Tertiary Rocks
- Skaha Formation
- Park Rill Andesite Mbr.
- Rosette - Porphyry Mbr.
- Basaltic Andesite Mbr.
- Clot - Porphyry Mbr.
- Yellow Lake Porphyry Mbr.

Springbrook Formation

White Lake Formation

Pre-Tertiary Rocks
- Aa, Old Tom Formation
- Ab, Shoemaker Formation
- Ac, Vaseaux Formation

Symbols
- Drift-covered area
- Geological boundary (approximate)
- Bedding (horizontal, inclined)
- Syncline (plunging)
- Anticline
- Fault (approximate, assumed)
- Topographical contour (interval 500 feet)
- Structure section
- Boundary of map 200
- Stream
- Main road
- Secondary road
- Glacial striae
- Chemical analysis station

Structure Sections

Geology by N. Church, 1967
Detailed Geology near White Lake
(map 201)

Legend

Glacial and Recent Deposits

Early Tertiary Rocks

WHITE LAKE FORMATION

Upper Member:
10a, agglomerate, tuff, sediments;
10b, Indian Head volcanic breccia;
10c, augite-porphyry (tephrite);
10d, mainly shale, possibly equivalent to 9 or 12;
Middle and Lower Members:
9, White Lake sediments, mudstone, sandstone, conglomerate, coal, and pyroclastics;
Middle Member:
8a, pyroclastic rocks and lahars with abundant xenoliths of 12;
8b, pyroclastic rocks and lahars with abundant xenoliths of 6;
Lower Member:
8, trachyte and trachyandesite lavas ond pyroclastic rocks;

SPRINGBROOK FORMATION

1, undivided conglomerate and basal breccia;

Pre-Tertiary Rocks

1, Old Tom Formation;
2, Shoemaker Formation;
3, Vaseaux Formation;

Symbols

Bedrock exposure
Geological boundary
Boundary of detailed mapping
Bedrock
Post (approximate position)
Minor displacement
Major displacement
Transitional contact (below, 50 feet)
Structure section
Bedrock unit
East-west
Road
Lake
Wash
Stream
Granite
Agglomerate
Limestone

Scale
1000
500
0
1000 feet

Geology by N. Church, 1967