ALKALIC VOLCANISM AND COPPER DEPOSITS OF THE HOSREFLY AREA, CENTRAL BRITISH COLUMBIA

by

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Carleton University
Ottawa, Ontario
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A thesis submitted to the Faculty of
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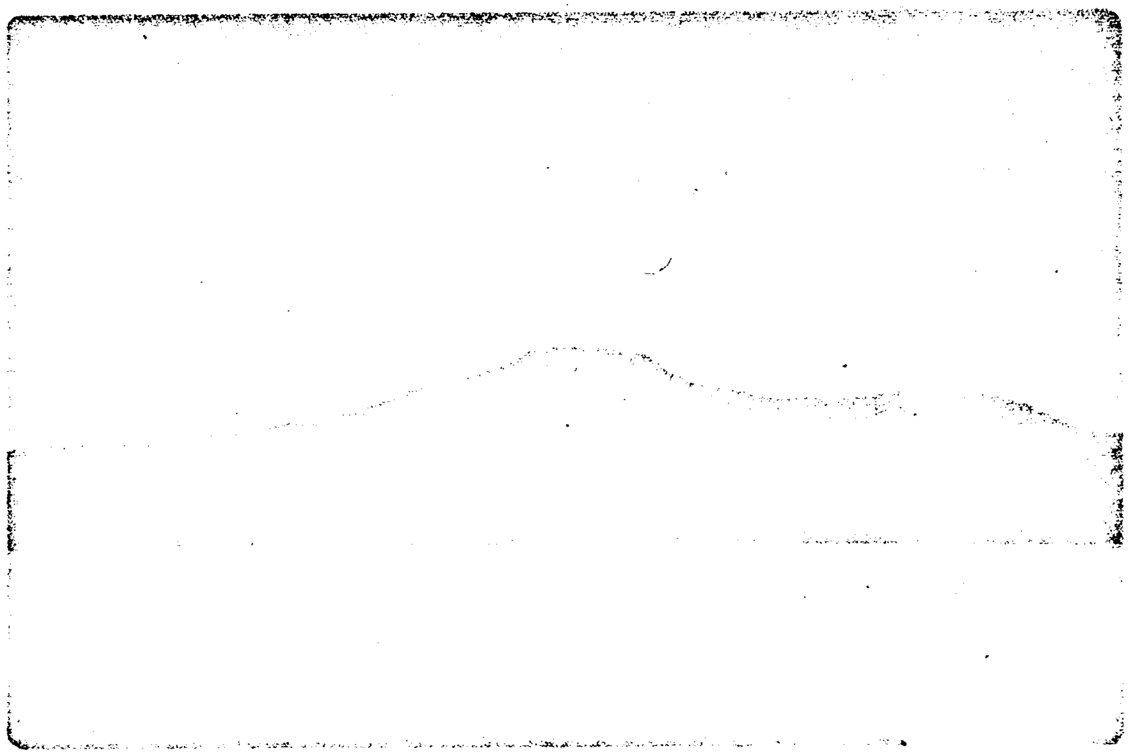

I

Plate I: View eastward down Horsefly Lake looking towards Viewland Mountain, a syenodiorite intrusive breccia that represents the remnant of a Mesozoic volcanic neck.

The undersigned hereby recommend to the Faculty of Graduate Studies acceptance of this thesis, submitted by Ronald Lee Morton, B.Sc., M.Sc., in partial fulfilment of the requirements for the degree of Doctor of Philosophy.

Abstract

In the Horsefly area Lower Jurassic alkalic rocks form a central volcanic belt that varies from 8-38 km in width, composed of a complex succession of flow and pyroclastic rocks, intrusive and flow breccias, laharic deposits, stocks, dykes, sills, and coarse-grained volcaniclastic rocks. Volcanic and intrusive rocks are subdivided into three lithologically and mineralogically distinct successions, each believed to represent part of a continuous cycle of volcanism.

The oldest cycle ranges in composition from ankaramite and alkali-olivine basalt to trachyte with accompanying intrusions of olivine gabbro to syenite. Rocks of the second cycle contain 5 to 25% modal nepheline. They vary from basalt to trachybasalt with phaneritic intrusions of tephrite, syenodiorite, and monzonite. Analcite-bearing flow, pyroclastic, and intrusive rocks form the youngest cycle. Analcite is considered to be of magmatic origin on the basis of field, textural, and petrographic relationships.

Spatially and genetically-related volcanic, intrusive, and pyroclastic rocks are grouped into five volcanic complexes, intruded through and built upon thick successions of alkali-olivine and alkali basalt. The complexes vary in size, depth of erosion, and type of associated rock units; they are separated by block faults or thick successions of flow and volcaniclastic rocks.

Volcanic and intrusive rocks of each cycle are strongly undersaturated with respect to silica, contain normative nepheline and olivine, and belong to the mildly potassic suite of alkalic rocks. Major and trace element abundances and trends are similar to those of volcanic rocks from islands situated close to the Mid-Atlantic Ridge: Tristan da Cunha, Gough, and St. Helena.

The relatively smooth curves of major and trace element variation, presence of cumulative rocks, zoning of mineral phases, and the abundance of mafic rocks compared to intermediate and salic types indicate that the descents, olivine basalt-trachyte and nepheline basalt-monzonite, have resulted from fractional crystallization of alkali-olivine basalt and nepheline basalt parent magmas. The origin of the analcitic rocks remains speculative.

Genetically associated with rocks of Cycle I are porphyry and pyrometasomatic copper-gold prespects. Prospects are zoned with respect to sulphide and alteration assemblages which reflect the basic and undersaturated solutions from which they were derived.

The alkalic rocks and associated copper deposits are believed to have formed as a result of uplift and rifting of the Permo-Triassic Cache Creek Group. Rifting was initiated by structural readjustment of the oceanic Cache Creek rocks as a result of collision or overriding by the leading edge of the North American continent.

Acknowledgements

Field work for the thesis was carried out while the writer was employed by Hudson's Bay Oil and Gas Company, Limited. Hudson's Bay Oil and Gas provided base maps and thin sections for the study, and financed the chemical analyses. The writer is extremely grateful for their active and enthusiastic support. In particular appreciation is expressed to Dr. D. Pollock and Mr. M. Hegge for their encouragement and counsel.

Competent assistance in the field was given in 1973 and 1974 by Mr. E. A. Schink.

Long standing appreciation is expressed to Dr. P. E. Fox who, through the past several years, provided many hours of valuable discussion, new ideas, and constructive criticism on the mapping of volcanic rocks within the Quesnel Trough and the classification of ore deposits in British Columbia.

Dr. C. J. Hodgson of Queen's University visited the field area and provided constructive criticism of the project.

Mrs. M. Legros and J. Bennett drafted the field maps, and Mrs. L. Bureau assisted with the drafting of figures. Mrs. L. Collins performed the X-ray analyses of the feldspathoidal minerals.

The thesis was supervised by Dr. J. M. Moore, Jr. and the writer is indebted to him for his criticism and valuable suggestions.

Dr. D. H. Watkinson critically reviewed the preliminary manuscript and Dr. K. Bell provided helpful suggestions concerning the chemistry of alkalic rocks.

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I: Introduction

General Statement

This thesis presents the results of a detailed study of Lower to Middle (?) Jurassic volcanic and synvolcanic intrusive rocks of the Horsefly area, British Columbia. Stratigraphic relationships, petrology, chemistry, origin of the volcanic rocks, and volcanic mineral deposits formed are discussed. The study serves to define and outline a new alkalic rock province.

Spatially associated with the alkalic intrusive and volcanic rocks are numerous copper occurrences and related alteration assemblages. This association appears to be unusual because abundant copper has rarely been reported in association with such rocks. Selected sulphide deposits were studied to establish their relationship, not only spatially but temporally, to specific events in the formation of the volcanic succession.

Location and Access

The Horsefly area is situated near the eastern margin of the Interior Plateau Region of British Columbia, between longitude 121° 10' and 121° 35' W and latitude 52° 16' and 52° 29' N. Geological mapping covered 480 square km near Horsefly, a small village located 48 km east of Williams Lake and 368 km northeast of Vancouver, British Columbia (Figure 1).

Access is via highway 97 to 150 Mile House, then by an all-weather gravel road northeast to Horsefly, a distance of 61 km.

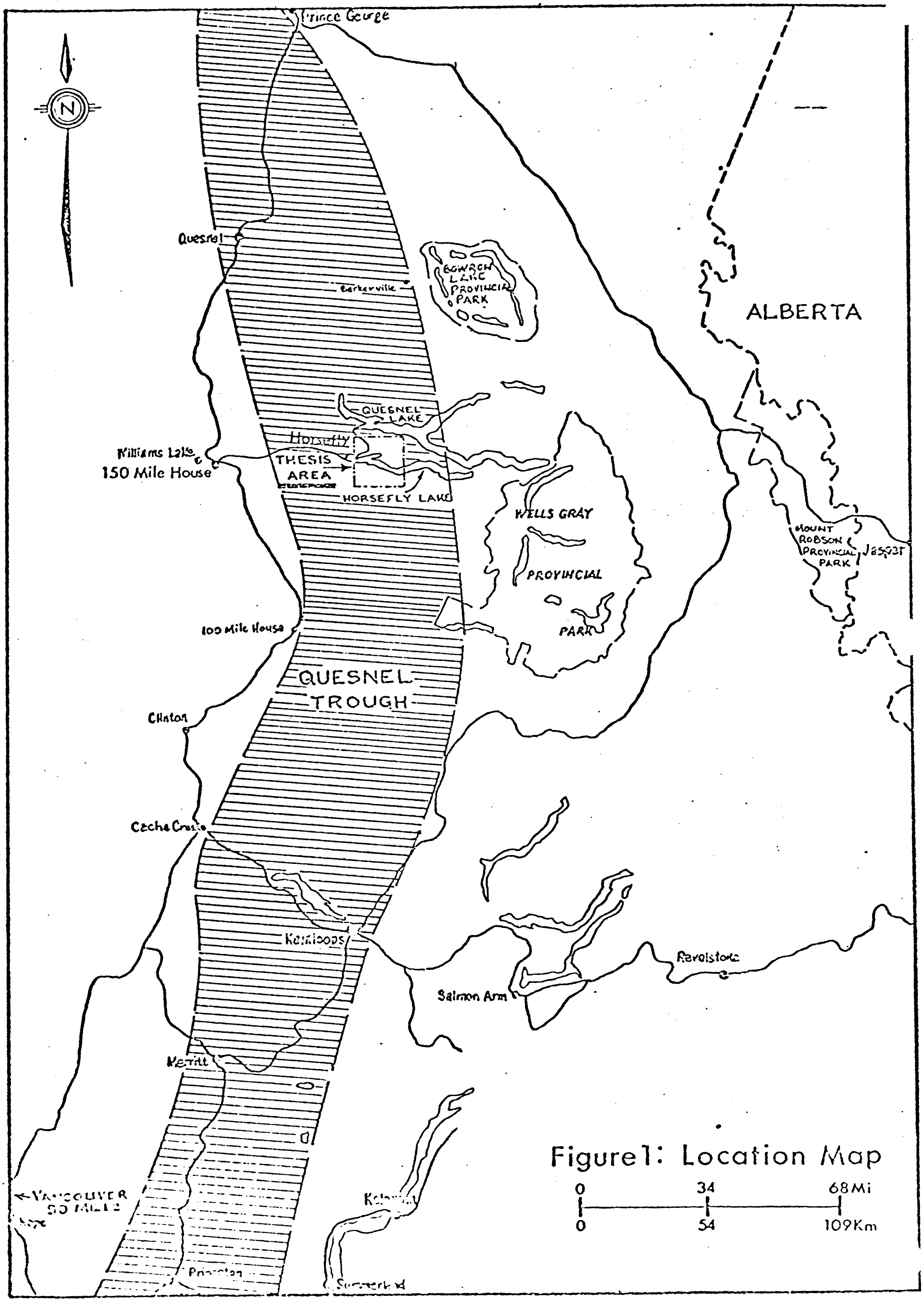


Figure 1: Location Map

A good system of secondary logging roads and game trails provides access to all parts of the area from Horsefly.

Topography is varied, consisting of broad areas of relatively level upland (2134 m in elevation) broken by isolated or clustered hills rising 152 to 762 m above this surface (Plate I). Horsefly Lake bisects the central portion of the area and the broad, deep valleys of the Horsefly River and Beaver Creek bound the region to the south and west, respectively (Figure 3).

Immediately north and east of the area, terrain changes abruptly to steep and mountainous in the Cariboo Range, with summit elevations increasing to over 2134 m.

Previous Work

Available literature on the thesis area is sparse. The geology was first examined by Amos Bowman in 1885-86, and he published a map in 1887. In 1938 Douglas Lay examined and mapped the placer gold deposits of the Horsefly River.

Campbell (1961, 1963) mapped the Quesnel Lake area, which includes the northern and eastern portions of the thesis area, on a scale of 4 miles to the inch. He subdivided volcanic units on the bases of color and dominant phenocryst type but did not mention analcite or nepheline bearing rocks, nor the alkalic nature of the volcanic sequences. However, by collecting numerous fossils from interlayered sedimentary rocks, he did place age restrictions on most of the volcanic and pyroclastic members. His fossil localities are listed on G.S.C. map 3-1961.

Coates (1960) described four outcrops of analcite-bearing volcanic rocks northeast of Beaver Creek but mentioned neither the widespread occurrence of these rocks nor the alkalic nature of the volcanic succession.

Schink (1974) carried out a petrographic study of the Shiko Lake stock which indicated its alkalic nature and the association of minor quantities of nepheline within the syenite phase. He also dated biotites from both the stock and associated skarn zone.

Since 1970 various mining companies have been actively exploring the area but no detailed geological or chemical studies have been published.

Methods of Study

Field Methods

The present study is based on eight months field work in 1973 and 1974 during which time the writer mapped 480 square km around Horsefly Lake. Mapping was done on one-half and one-quarter mile to the inch aerial photographs, then transferred to a half-mile to the inch topographic base map. Areas selected for detailed study were mapped at a scale of 48 m to the cm along cut and flagged east-west lines. These data were compiled on the base map.

Laboratory Methods

Approximately 225 thin sections of selected rock specimens were studied by standard petrographic methods. Universal stage techniques were used for optic angle measurements and the determination of plagioclase compositions.

Modal analyses were performed by means of a point-count microscope stage and tabulator; 500 to 1,000 points were counted per slide. Sodium cobaltinitrate stain for the identification of potassium feldspar (Chayes, 1952) was used in the study of forty thin sections and sixty rock slab specimens. Feldspathoid minerals were identified by x-ray diffraction.

Fifty-one rock samples were chemically analyzed for eleven major and ten trace elements plus water and carbon dioxide. Samples were selected on the bases of freshness and areal coverage consistent with exposure and lithology. Rocks were analyzed for the writer at the Science Laboratories, Durham University, England and Vancouver Geochemical Laboratory, Vancouver, B.C.

II: General Geology

Quesnel Trough

The thesis area lies within the Quesnel Trough (Figure 2 in pocket), a linear belt of Upper Triassic to Middle Jurassic volcanic and volcaniclastic rocks. The Quesnel Trough extends from the 49th Parallel as far north as latitude 57°N, varying from 48-100 km in width, with a total known length of 1,120 km.

Roddick *et al* (1967) applied the name Quesnel Trough to an area of volcanic rocks that lies between Proterozoic and Paleozoic strata of the Omineca Geanticline to the east and Upper Paleozoic rocks of the Pinchi Geanticline to the west (Figure 2).

The Quesnel Trough is not a simple depositional feature but is a fault-bounded structure along most of its length (Campbell *et al*, 1970). Major defined faults of the Pinchi and Fraser Systems bound it to the west, whereas those of the Cariboo and Okanagan Systems terminate it to the east (Figure 2).

The oldest rocks within the Quesnel Trough are Upper Triassic phyllites, slates, and their higher grade metamorphic equivalents. These rocks rest unconformably on strata of the Omineca Geanticline (Campbell *et al*, 1970). Mafic volcanic flow and pyroclastic rocks, with coeval epiclastic rocks were deposited within the Trough until the end of the Triassic. They are weakly altered or metamorphosed and either unconformably overlie or are in fault contact with the older slates and phyllites (Hegge, 1974).

Local uplift and the emplacement of granitic batholiths marked the end of the Triassic Period within the Quesnel Trough. The plutons occupy a broad, northwesterly trending zone slightly oblique to the general trend of the Trough (Figure 2). These intrusions, dated at approximately 200m.y. (Chrismas, 1969; Northcote, 1969; Wanless et al, 1968), vary from quartz monzonite to hornblende quartz diorite or granodiorite; the Guichon, Thuya, and Takomkane Batholiths are examples.

A second period of volcanic activity is represented by Lower to Middle (?) Jurassic mafic and salic volcanic flow and pyroclastic rocks, synvolcanic stocks, dykes, and sills, and related volcaniclastic rocks. The time between Late Triassic and Early Jurassic volcanism appears to have been short, marked only by local uplift and erosion. On a regional scale volcanism appears to have been continuous (Hegge, 1974).

Upper Triassic volcanic and volcaniclastic rocks, with 200m.y. old intrusions, are dominant in the southern portion of the Trough, whereas Lower to Middle (?) Jurassic volcanic rocks and small intrusions are more prominent in the central and northern portions. However both can and do occur together (Procyshyn, personal communication, 1975). Generally, Jurassic volcanic flow and pyroclastic rocks are well-preserved and much less altered than similar Upper Triassic rocks.

A major intrusive event occurred during Early to Mid-Cretaceous time (80-140m.y.) in which calc-alkalic batholiths and stocks were emplaced along the outer margins of the volcanic rocks (Figure 2). These igneous rocks are typically biotite granites, granodiorites, and diorites, distinct from the 200m.y. old group by being less mafic, more potassic, and porphyritic (Hegge, 1974). The Raft and Okanagan Batholiths are examples.

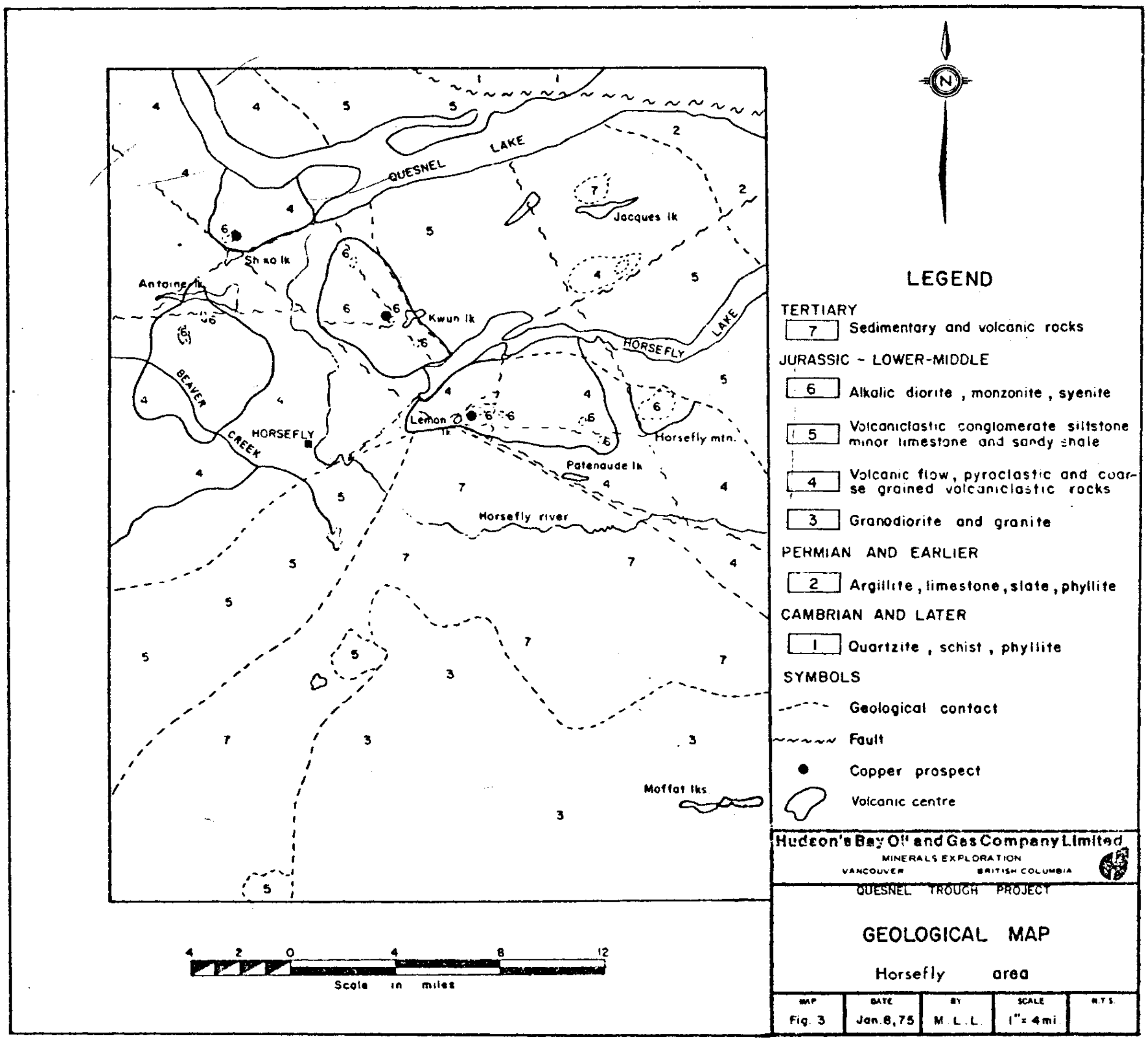
Tertiary deposits cover a large portion of the Quesnel Trough (Figure 2) and can be divided into two units; Eocene sedimentary and volcanic rocks, which vary in composition from rhyolite to basalt, and Miocene to Pliocene plateau basalts. The earlier unit is faulted or gently tilted whereas the later plateau-type flows are usually flat-laying.

Horsefly Area

Introduction

Lower Mesozoic rocks underlie 480 square km of the thesis area. These are the oldest exposed rocks, forming a central belt of volcanic flow, pyroclastic and coarse volcaniclastic rocks that extend from Horsefly Mountain westward through Lemon Lake then northwest to Shiko Lake (Figure 3). To the east and northwest, flanking the central volcanic belt, are fine-grained volcaniclastic rocks intercalated with arenites and argillites. To the west, outside of the thesis area, volcanic rocks are either covered by Tertiary lavas or faulted against rocks of the Cache Creek Group in the Pinchi Geanticline.

Hornblende diorite and granodiorite porphyry dykes cut the Mesozoic volcanic rocks. They are common throughout the Horsefly area, and are tentatively classified as Cretaceous in age.


QUESNEL LAKE
HORSEFLY LAKE
Jacques lk
Antoine lk
Kwun lk
BEAVER CREEK
HORSEFLY
Lemon lk
Horsefly mtn.
Patenaude lk
Horsefly river
Moffat lks
LEGEND
TERTIARY
7 Sedimentary and volcanic rocks
JURASSIC - LOWER-MIDDLE
6 Alkalic diorite, monzonite, syenite
5 Volcaniclastic conglomerate siltstone minor limestone and sandy shale
4 Volcanic flow, pyroclastic and coarse grained volcaniclastic rocks
3 Granodiorite and granite
PERMIAN AND EARLIER
2 Argillite, limestone, slate, phyllite
CAMBRIAN AND LATER
1 Quartzite, schist, phyllite
SYMBOLS
Geological contact
Fault
Copper prospect
Volcanic centre
Hudson's Bay Oil and Gas Company Limited
MINERALS EXPLORATION
VANCOUVER BRITISH COLUMBIA
QUESNEL TROUGH PROJECT
GEOLOGICAL MAP
Horsefly area
MAP Fig. 3
DATE Jan. 8, 75
BY M. L. L.
SCALE 1" = 4 mi.
N.T.S.
4 2 0 4 8 12
Scale in miles

Tertiary flow and sedimentary rocks form prominent exposures south of the Horsefly River and north of Jacques Lake (Figure 3); they also occur as erosional remnants on hilltops and as steeply dipping wedges along valley sides. These rocks rest unconformably on the Mesozoic rocks and contain fragments of older rock types.

Rocks of the Cambrian Cariboo Group in the Omineca Geanticline, form a prominent mountain range north and east of the thesis area; Permian to Pennsylvanian Cache Creek rocks crop out east and west of the area.

Much of the map-area is overlain by Pleistocene and Recent deposits which include glacial tills and lacustrine or fluviatile material. Up to 150 meters of glacial lake silts and glacial-fluvial deposits are found in the valleys of Beaver Creek and Horsefly River.

Lithology

Cariboo Group (Cambrian and Later)

Rocks of the Cariboo Group are complexly folded and metamorphosed and are in fault contact with Mesozoic rocks north of Quesnel Lake and with folded Cache Creek rocks east of Horsefly Mountain (Figure 3). These rocks have been described in detail by Holland (1954) and Sutherland Brown (1957).

Cache Creek Group (Permian and Earlier)

Rocks assigned to the Cache Creek Group are situated west of the Horsefly area (Campbell, 1961, 63). These rocks are steeply dipping and consist of assemblages of calcareous argillite, slate, phyllite, limestone, greywacke, chert, and mafic volcanics.

The volcanic rocks are mainly massive greenstones, "originally andesitic and basaltic lavas, pyroclastics and volcanic arenite" (Douglas et al, p. 416, 1970). Gabbro, pyroxenite, and serpentinite bodies are found in the volcanics along well-defined structural breaks.

Fossils occur most commonly in the limestones; fusulinids are the most common types and are diagnostic of the Late Pennsylvanian and most stages of the Permian (Danner, 1964).

Monger (1974) has interpreted that the complex Cache Creek Group consists of metamorphosed and folded island arc and ocean floor successions.

Geological mapping by the writer, east of the thesis area, has outlined a narrow belt of calcareous argillite, phyllite, chert and mafic volcanic rocks with minor limestone that extends south from Quesnel Lake (Figure 3). Exposures of ultramafic rocks were not observed although a few boulders of serpentinite were found.

These rocks are variably metamorphosed and folded, in places being intensely sheared and faulted. They are unconformably overlain by Lower Mesozoic volcanic siltstone and lithic wacke east of Horsefly Mountain, and are faulted against rocks of the Cariboo Group 13 km further east.

Lithology, observed contact relationships, folding and grade of metamorphism of these strata lead to their tentative classification as Cache Creek Group.

Takomkane Batholith (Granodiorite and Granite)

A large batholith composed of granodiorite, quartz diorite, and granite outcrops eight kilometers south of the thesis area (Figure 3). The granitic rocks are largely covered by Tertiary flow and sedimentary rocks, and Pleistocene deposits. Their exact age and relationship to the Mesozoic volcanics have not been definitely established although south of the Horsefly area, near Lake LaHache, the batholith appears to be intruded by a zoned stock composed of syenodiorite and mónzonite. This relationship coupled with similarity in composition and texture to rocks of the Guichon Batholith, dated at 200m.y., tentatively places its age as Late Triassic, slightly older than the Horsefly Group.

Lower and Middle Jurassic Rocks (Horsefly Group)

Mesozoic alkalic rocks form a central volcanic belt, which varies from 8 to 37 km in width (Figures 3 and 5) composed of a complex association of flow and pyroclastic rocks, intrusive and flow breccias, laharic deposits, stocks, dykes, sills, and coarse volcaniclastics.

Spatially and genetically-related volcanic and intrusive rocks have been grouped into volcanic complexes, intruded into and built upon thick successions of alkali basalt. On the basis of facies mapping, lithology, and chemical composition five separate centres have been outlined (Figure 3). These vary in size, depth of erosion, and types of associated rocks (Table I).

Flanking this central belt, to the east and northeast, are bedded volcaniclastic rocks with intercalations of arenite and sandy shale. Similar sedimentary rocks are found to the west where they are faulted against, or overlie Cache Creek Rocks.

Volcanic and intrusive rocks have been divided into three lithologically and mineralogically distinct groups, each believed to represent part of a continuous cycle of volcanism.

The oldest cycle ranges in composition from ankaramite to trachyte with accompanying intrusions that vary from olivine gabbro to syenite, and underlies an area that extends northwest from Horsefly Mountain through Lemon and Kwun Lakes to Shiko Lake. Age determinations (Schink, 1974), plus fossil assemblages (Campbell, 1961, 63) found in fine grained volcaniclastic rocks derived from this cycle, or shale-limestone interbeds, place its age as Early Jurassic.

Rocks of the middle cycle contain from 5 to 25% modal nepheline. They vary from tephrites to trachybasalts with phaneritic intrusions of syenodiorite and monzonite. Nepheline-bearing rocks are most abundant in the Lowry-Kwun Lake region with small intrusive bodies or fragmental deposits found at Shiko, Lemon, and Antoine Lakes.

Analcite-bearing flows, pyroclastics, and intrusive rocks form the youngest cycle, occurring at Antoine and Lowry Lakes, and immediately south of Shiko Lake. Fossil assemblages in nepheline-

Table I: Description of Igneous Complexes

Name of Complex	Maximum mappable size (km)[1]	% rocks of each volcanic cycle		
		Cycle I	Cycle II	Cycle III
Lemon Lake	11 x 9	95	5	-
Horsefly Mountain	3 x 11½	100	-	-
Antoine Lake	9½ x 6	15	10	75
Kwun-Hooker Lakes	10 x 10	35	25	40
Shiko Lake	6 x 6	50	15	35

1 implies lateral extent of known outcrop

and analcite-bearing wackes and interlayered limestone, south and east of Antoine Lake, place their age as Early or Middle (?) Jurassic.

Previous workers in the Horsefly area and areas to the north have applied the name Quesnel River Group (Coates, 1960, and Campbell, 1961, 63) to the Mesozoic volcanic and volcaniclastic rocks. Attempts to map and subdivide them have been based on color, nature of phenocrysts, and stratigraphic correlation over large areas. The alkalic and feldspathoidal nature of the group, and dominance of small, well-defined volcanic complexes have not been recognized in previous studies. The central nature of the group permits stratigraphic correlation within complexes only; lithology and chemical composition allow for correlation among complexes. Exceptions to this generalization are alkali basalts that are of regional extent and not related to defined igneous centres.

The definition of part of this group as a new alkalic rock province, its correlative bases, as well as the geographical implications of the name Quesnel River Group, have led the writer to rename the volcanic rocks found in the Horsefly area. Throughout this thesis, the three volcanic cycles will collectively be called the Horsefly Group.

Hornblende Diorite-Granodiorite Dykes (Cretaceous (?) Dykes)

Hornblende-bearing diorite, quartz diorite, and granodiorite dykes are ubiquitous in the area, and are mineralogically similar to small granodiorite and quartz diorite stocks, of

Cretaceous age, that occur to the south and east. These rocks cut all known Mesozoic rock types and are found as xenoliths or clasts in Tertiary flow and sedimentary rocks, respectively.

Dykes have widths from 0.3 to 3 m and strike east-west or northwest with dips of 40-85°N or NE. Strike directions are similar to those of dominant regional structures. The dykes contain volcanic rock fragments and show chilled, aphanitic margins. They have bleached or recrystallized their wall-rocks.

Phenocrysts of acicular, black hornblende and grey, tabular plagioclase are conspicuous in a fine grained to aphanitic grey or greyish-brown groundmass. Pyrite is always present as an accessory mineral and can compose up to 3% of the rock.

A hornblende-quartz diorite dyke that outcrops 1,500 m northeast of Lemon Lake (Figure 4, in pocket), was chemically analyzed (Sample RM-8, Appendix C). This was the only analyzed rock from the map-area showing normative quartz and tholeiitic or calc-alkaline characteristics.

These dyke rocks are chemically and mineralogically distinct from, and younger than the Mesozoic volcanic rocks. For these reasons and because of their similarity to known Cretaceous rocks they are classified as Cretaceous.

Tertiary Rocks

Tertiary volcanic rocks consist primarily of flat-laying, vesicular plateau basalts and basaltic tuffs. These rocks form prominent bluffs south of the Horsefly River and occur as erosional remnants throughout the area.

Sedimentary rocks classified as Tertiary (Campbell, 1961, 63) vary from conglomerate to lithic wacke and sandstone with shale lenses. Conglomerate and lithic wacke contain clasts of Mesozoic volcanic, pyroclastic, and intrusive rocks as well as gneiss, quartzite, and garnet schist derived from the Cariboo Group.

Sedimentary rocks unconformably underlie or are interbedded with flow rocks and, to a lesser extent, form small, isolated outcrops in low lying regions. Where interbedded with basalt they range in thickness from 5 cm to 9 m; frequently they are included as fragments at the base of basalt flows.

Olivine diabase or basalt dykes intrude Mesozoic volcanic rocks and cut a Tertiary conglomerate north of Jacques Lake. The dykes have widths of 0.3 to 2.5 m, show random orientation and are dark grey, aphanitic or fine grained and equigranular.

Basaltic flow rocks are dark grey to black, weather tan or buff, carry small phenocrysts of olivine and pyroxene, and are vesicular. Vesicles are elongate or irregular in shape, locally exhibit subparallel alignment, and compose 5 to 25% of the rock.

It is believed that there have been two periods of Tertiary volcanism separated by a period of sedimentation (Lay, 1938). Older volcanic flows and part of the sedimentary succession, not exposed in the Horsefly area, were gently folded before the extrusion of vesicular basalts and related tuffs. Fossils found in folded sedimentary rocks place the older succession in the Eocene. The flat-lying basalts are usually assigned to the Miocene (Lay, 1938).

General Structure

The main structural features of the Horsefly area are steeply-dipping northwest, northeast, and east-west faults which were active from Jurassic to Late Miocene time. The faults vary in extent from regional (20-60 km) to more local types that can be traced for only a few kilometers (1 to 5 km). Regional faults bound or terminate volcanic complexes, whereas local types are restricted to one complex and are typically curvilinear or radial in plan view.

The following criteria were used to define and outline the faults shown on Figure 4:

1) stratigraphic displacement
2) physiographic lineaments observed on aerial photographs (alignment of lakes and swamps, straight, narrow valleys, etc.)
3) ground and aerial magnetometer surveys
4) broken and sheared outcrop
5) slickensides on joint surfaces
6) rapid change in dip of bedding
7) fault gouge

Paucity of outcrop within fault zones and lack of stratigraphic marker horizons make statements on amount of displacement speculative. However, large amounts of displacement between adjacent complexes, and steep dips recorded for volcaniclastic units adjacent to fault zones indicate that the regional faults are block faults with vertical or near-vertical dip.

For example, the Horsefly Lake Fault (Figure 4) separates younger, feldspathoidal rocks of Cycles II and III from Cycle I rocks exposed in the Lemon Lake complex. Displacements along the fault must be large, with the Lemon Lake block moving up relative to the Kwun-Hooker block. South of Lemon Lake the Gibbons Creek Fault brings Tertiary sedimentary and volcanic rocks into contact with Mesozoic rocks of the first volcanic cycle. Here the fault plane is vertical and the Lemon Lake block moved up relative to the Tertiary rocks.

A similar pattern is observed if we compare the Shiko Lake block with the Kwun-Hooker Lakes block. Again Cycle I rocks are in fault contact with those of Cycles II and III. Figure 5 is a diagramatic representation of interpreted movement along regional faults across a northwest-southeast cross-section from Lemon to Shiko Lakes.

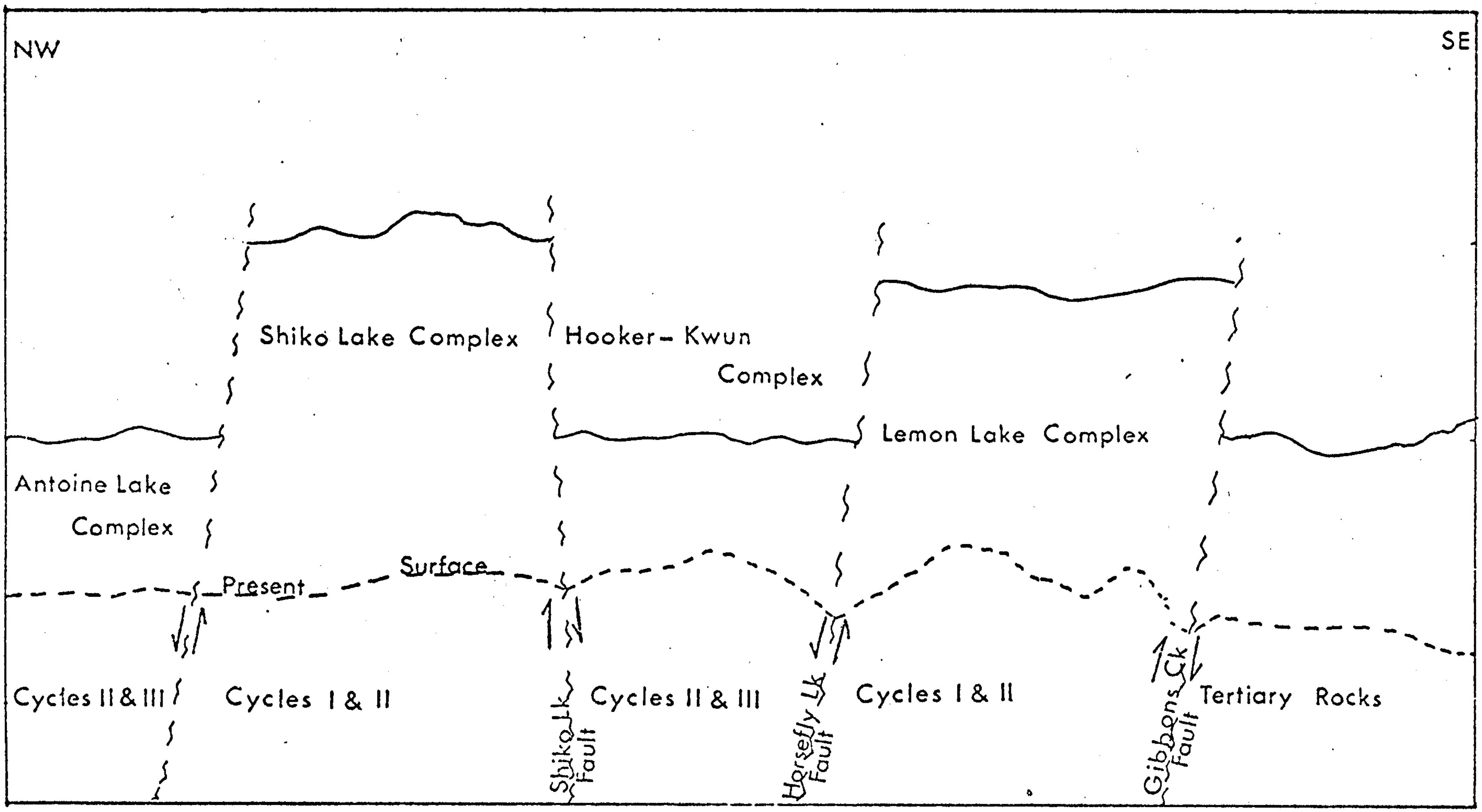


Figure 5: Diagrammatic interpetation of block. faults in the Horsefly area.

III: Stratigraphy and Petrology of the Horsefly Group

Introduction

A survey of literature on alkalic rocks gives the impression that the term 'alkalic rock' has been used differently by individual petrographers, sometimes in such a vague way that it is hard to know what is meant by the term. In the present thesis an alkalic rock is defined on these bases:

1) lack of modal quartz,
2) presence of nepheline and olivine in the normative mineralogy,
3) presence of modal, calcium rich and/or sodic pyroxene,
4) appropriate chemical variation as shown by variation plots and tetrahedral diagrams,
5) presence of modal nepheline and analcite.

The first four criteria apply to Cycle I rocks; all five are met in rocks of Cycles II and III.

Individual rock names are based on modal compositions and texture. The writer has used no new or locally derived names, preferring instead simple modifiers such as analcite monzonite or nepheline syenodiorite. This approach has the benefit of conveying the general composition of such rocks in common geological terminology with the prefix "analcite" or "nepheline" indicating the presence of these as primary modal minerals.

Tables II and III list essential volcanic and intrusive rock types and diagnostic petrographic criteria. Chemical analyses and normative mineralogy of representative rock types support this classification scheme (Appendix C).

Modal compositions of representative rocks composing the Horsefly Group are given in Appendix A, with sample localities shown in Figure 4. Average modal compositions are listed in Tables IV and VII to X.

Petrology and Stratigraphy

Alkali-Olivine Basalt (Unit 7, Figure 4)

Alkali-olivine basalt is the oldest member of the Horsefly Group, widely distributed in the form of pillow lavas, massive and amygdaloidal flows, and autoclastic breccias. Outcrops north of Patenaude Lake indicate a maximum total exposed thickness of 1,350 m with individual flows varying from 1 to 30 m thick. The lower boundary of the unit is not exposed; the upper boundary is marked by a change from porphyritic olivine-rich flows to flows that contain clinopyroxene and plagioclase phenocrysts, with olivine restricted to the groundmass (alkali-basalt).

Autoclastic breccias are increasingly abundant towards the top and consist of angular to round blocks or smaller fragments of olivine basalt cemented by a matrix of similar material. Thin interbeds of siltstone, mudstone, and calcareous arenite are found throughout.

Table II: Modal Classification for Volcanic and Intrusive Rocks of Cycle I (Modified after Streckeisen, 1967)

		no quartz <5% foids	no quartz <5% foids	no quartz <5% foids	no quartz no foids	no quartz no foids
feldspar ratio(%)		10 - 35 plagioclase	35 - 65 plagioclase	65 - 90 plagioclase	> 90 plagioclase	> 95 plagioclase
color index(vol.%)	dominant mafics	aegirine-augite biotite rare Na amp.	Ca. augite aegirine-augite rare biotite	Ca. augite rare olivine rare biotite	Ca. augite olivine	Ca. augite >10% olivine
0 - 35	stocks	syenite	monzonite	syenodiorite		
0 - 35	dykes + sills	syenite, trachyte	monzonite, latite	syenodiorite (rare)		
0 - 35	flows	trachyte (rare)		trachybasalt C.I. 25-30%		
35 - 65	stocks				alkali gabbro	
35 - 65	dykes + sills			trachybasalt (rare)	alkali basalt alkali gabbro	olivine gabbro
35 - 65	flows			trachybasalt C.I. 35-40%	alkali basalt	alkali-olivine basalt
> 65	cumulates xenoliths					ankaramite peridotite

Table III: Modal Classification for Volcanic and Intrusive Rocks of Cycles II and III (Table Modified after Streckeisen, 1967)

		Neph > 20% No Anal	10 - 20% Neph No Anal	5 - 15% No Anal	5 - 15% No Anal	> 25% Anal < 5% Neph	< 25% Anal < 5% Neph	< 25% Anal No Neph	< 30% Anal No Neph
Feldspar ratio(%)		0 - 30% Plag	30 - 60% Plag.	60 - 90% Plag	90% Plag (An% > 50)	0 - 10% Plag	10 - 40% Plag	40 - 90% Plag	95% Plag (An% > 50)
Color Index	Dominant Mafics	Aegirine, Aegirine-Augite	Ca-Augite Aegirine-Augite	Ca-Augite	Ca-Augite Olivine	Aegirine, Aegirine-Augite, Na-Amp	Aegirine-Augite Ca-Augite	Ca-Augite Olivine	Olivine Ca-Augite
0 - 35	Stocks		Monzonite	Syeno-diorite			Monzonite		
	Dykes Sills	Phonolite (As Fragments In Tuffs)	Monzonite	Syeno-diorite		Phonolite	Monzonite		
	Flows			Trachy-basalt CI 25%		Phonolite (Rare)			
35 - 65	Dykes Sills				Tephrite				Teschenite
	Flows			Trachy-basalt CI 35-45%	Basalt			Trachy-basalt	Basalt
65					Ankara-mite				

Individual flows are porphyritic, glomeroporphyritic (Plate II, A) or aphanitic, and massive, amygdaloidal, or brecciated. In general flow tops are amygdaloidal breccias, flow centres are massive, and bottoms are brecciated or massive. Rarely, a thin (5-10 cm) chilled amygdaloidal edge marks the bottom of a flow.

Pillowed olivine-basalt forms widely-distributed outcrops south of Horsefly Lake, north of Patenaude Lake, east of Shiko Lake, and east of Sucker Lake (Figure 4). Though most exposures are isolated outcrops and not parts of continuous sections, the pillow lavas are estimated to compose 15% of the succession.

Individual pillows vary from 15 cm to 1.5 m in diameter. They consist of an outer, aphanitic rim that grades into a porphyritic centre. Interstices between pillows are filled by secondary minerals or by fine grained wacke, siltstone, and mudstone. Radial jointing was observed in one vertical rock face with amygdules aligned parallel to joint surfaces.

In hand specimen alkali-olivine basalt is a pale green or greenish-black rock containing phenocrysts of olivine and clinpyroxene. Olivine phenocrysts have a dull or waxy green color caused by alteration and weathering.

In thin section porphyritic varieties show olivine, clinpyroxene, and, more rarely, labradorite and magnetite (Plate II, B) phenocrysts set in a fine brown to black crystalline matrix. Matrix material composes up to 70% of the rock and consists of granular olivine and clinopyroxene with laths of plagioclase. Accessory minerals are magnetite, apatite, and fine brown oxides. The mineralogy of fine grained, equigranular flows is similar to that of the groundmass in porphyries. Modes of ten olivine basalts are listed in Appendix A, the average is given in Table IV.

Olivine phenocrysts are subhedral prisms or aggregates of anhedra, 2-7 mm, weakly zoned with colourless cores and light green rims. Phenocrysts exhibit corroded borders rimmed by opaque oxides and many are filled with microfractures sealed by serpentine and chlorite. Typically only olivine cores are fresh, whereas edges are replaced by serpentine, chlorite, and carbonate.

Phenocrysts of clinopyroxene are 2-10 mm long and weakly zoned, with colourless or pale green cores and green or greenish-brown rims. Larger phenocrysts (4-10 mm) exhibit hourglass structure and contain numerous inclusions of groundmass olivine and magnetite; zone boundaries are frequently outlined by opaque inclusions. Smaller phenocrysts tend to be more homogeneous and have a pale purplish-brown tint. Phenocrysts are usually fresh though some have chlorite and epidote cores with rims of hematite charged with grains of magnetite.

Measurements of $2V_z$ and $Z\wedge c$ were made on zoned pyroxene phenocrysts. The most common type of zoning is that in which rims of pale green or brown pyroxene mantle clear or purplish-brown cores. Where zoning is pronounced optical measurements were made on different parts of the crystal. Recorded measurements are

Table IV: Average Modal Compositions of Cycle I Extrusive Rocks

Rock Type	Alkali-Olivine Basalt	Alkali Basalt	Trachy-basalt
Phenocrysts			
Diop Aug	15	9.8	10
Olivine	7.5	-	-
Plagioclase	2.8	14	22
Magnetite	1.0	1.0	-
Matrix			
Diop Aug	16	12.1	15
Olivine	9.2	7.5	2.8
Plagioclase	42.5	42	31
Potassic Feld	-	-	10.1
Magnetite	4.1	4.1	3.6
Apatite	0.4	0.8	1.2
Calcite	1.4	1.7	2.1
Analcite	-	-	1.9
Hematite	-	3.4	-
Other	1.1	4.1	-
N*	10	7	6
An% (Range)	58-75	44-65	42-65

*N Number of analyses (Appendix A)

listed in Table V. The composition suggested by optical data is diopsidic augite.

Phenocrysts of plagioclase are lath-shaped (0.5-2 mm) and normally zoned with cores of An_{70-75} and rims of An_{58-65}.

Small irregular bodies of ankaramite (2 x 5 m maximum size) outcrop near the base of the exposure of olivine basalts at Patenaude Lake and Hooker Lake (See Appendix A for modal composition, and Appendices C and D for major and trace element chemistry).

Peridotite xenoliths in olivine and alkali basalt flows at Patenaude Lake, Lemon Lake, and Horsefly Peninsula, vary from 0.5 to 4 cm in diameter, are subround to round, and conspicuous on weathered surfaces because of their pale brown or green color. They are medium grained rocks composed of chlorite, actinolite, serpentine, calcite, and epidote with small core areas of olivine, clino and orthopyroxene, magnetite, and spinel (?).

<u>Alkali Basalt (Unit 8, Figure 4)</u>

Alkali basalts are similar to alkali-olivine basalts but more abundant; differing megascopically by the absence of olivine phenocrysts. These rocks overlie or are interlayered with olivine basalts; contact relationships are normally obscured by overburden. However, at Horsefly Peninsula, the two flow types are separated by thin layers of pyroxene-rich wacke and siltstone, and north of Patenaude Lake blocks of olivine basalt are included in alkali basalt.

Alkali basalts occur as massive, porphyritic flows or as autoclastic and flow breccias, with interbeds of tuff breccia, north of Patenaude Lake and at Viewland Mountain and Horsefly Peninsula. Individual flow units vary from 2 to 20 m thick. The maximum exposed thickness of the unit is 450 m at the Horsefly Peninsula.

Alkali basalt consists of pyroxene (10-35%) and plagioclase (5-20%)
phenocrysts set in an aphanitic grey, green, or reddish-brown matrix. Pyroxene varies from 1 to 6 mm in length and is similar to those found in alkali-olivine basalt (Table V). Plagioclase is tabular or lath shaped (1-3 mm) with an anorthite content of 45-65%.

Olivine is restricted to the groundmass, which is subophitic to intergranular, 0.1 to 0.2 mm in grain size, and consists of plagioclase laths and granules of clinopyroxene and olivine. Accessory constituents are magnetite, rods of apatite, and patches of brown oxide containing grains of epidote, chlorite, and albite. Spherulites are abundant in amygdaloidal flows (Plate II, C) north of Patenaude Lake and are found only in rocks with an isotropic brown or yellowish-green matrix suggestive of devitrified glass. Towards the tops of flows matrix composition changes to fine grains of plagioclase and epidote enclosed by an opaque groundmass consisting dominantly of hematite.

Hematite, chlorite, epidote, and brown dust are the most abundant constituents of the matrix in tuff breccias. Fragments consist of angular crystals of clinopyroxene, olivine, and plagioclase. Lapilli are angular and commonly rimmed by hematite or magnetite.

Table V: Values of $2V_z$ and $Z \wedge c$ for Clinopyroxenes of Cycle I Extrusive Rocks.

Rock Type	Rock Number	Chemical Number	Average of at least three crystals	
			$2V_z$	$Z \wedge c$
Olivine Basalt	73-139	RM-30	54	43
Olivine Basalt	73-177	-	50	40
Olivine Basalt	73-314	RM-45	51-56	41-45
Olivine Basalt	73-158	RM-13	52	41
Alkali Basalt	73-163	-	50	39
Alkali Basalt	73-333	RM-33	51-59	39-48
Alkali Basalt	73-192	RM-36	50-57	40-47
Alkali Basalt	73-47	RM-44	53-58	42-46
Trachybasalt	73-178	RM-2	53-58	42-48
Trachybasalt	73-56	RM-23	52-59	41-47
Trachybasalt	73-46	-	53	43
Trachybasalt	73-261	-	52	42

Trachybasalt (Unit 9, Figure 4)

Trachybasalt forms relatively thick flows, 10-100 m, and thin dykes (2-6 m) flanking intrusive complexes. They are most abundant in the Lemon and Kwun-Hooker Lake areas (Figure 4). Laterally they are terminated by faults and plutons and are overlain by lapilli tuffs and coarse grained volcaniclastic rocks. At Lemon Lake trachybasalt flows are interlayered with lapilli tuffs, 1 to 8 m thick, composed dominantly of trachybasalt fragments.

Flows are primarily breccias with up to 50% angular to subround fragments of alkali basalt, gabbro, olivine basalt, lapilli tuff, and lithic wacke. Trachybasalt fragments are also common composing up to 15% of fragment types. Fragments are 3 mm to 1 m in diameter and increase in size toward the bottom of the flow. Flow contacts are aphanitic with amygdaloidal margins, 2 to 7 cm thick, which contain small fragments of underlying rock types.

Fluidal textures are common and consist of aligned phenocrysts and, more rarely, matrix material and amygdules which are swirled and molded around phenocrysts (Plate II, D). This texture is best defined in thin, massive flows.

At Lemon Lake trachybasalts show quaquaversal dips around the igneous complex (Figure 4). This feature is important for defining centres of volcanism and is indicative of central vent eruptions.

Trachybasalt flows are similar to alkali basalts in hand specimen but are distinguished by their fluidal textures and, in thin section, by the presence of alkali feldspar in the matrix or as rims around plagioclase phenocrysts.

In thin section they exhibit tabular or lath shaped plagioclase and prismatic clinopyroxene phenocrysts in an intergranular or trachytoid matrix of plagioclase, potassic feldspar, clinopyroxene, opaques, and minor analcite. Average modal composition is given in Table IV.

Plagioclase phenocrysts are 1 to 5 mm long, homogeneous to complexly zoned, and twinned, with albite-carlsbad laws most common. Plagioclase typically is seriate and varies from labradorite to andesine (An_{42-65}) laths showing a strong parallel alignment. Potassic feldspar forms partial to complete mantles around plagioclase crystals and narrow (0.01-0.05 mm) lenses along albite twin planes. It has a $2V_z$ of 52-69° with extinction angles $X \wedge 001$ of 2 to 8° and therefore belongs to the low temperature orthoclase-microperthite group (Mackenzie and Smith, 1956).

Clinopyroxene is much the same as that found in alkali and olivine basalts (Table V). It exhibits hourglass structure, is concentrically zoned and twinned on (110). It is typically colourless, though pale green zones and purple cores do occur.

Matrix alkali feldspar is found as interstitial anhedral grains in flows and dykes. It also occurs as irregular patches, 0.1-1 mm) composing up to 6% of the groundmass in flows. Analcite is in irregular, isotropic patches , 0.1-0.3 mm, throughout the groundmass or as a late alteration product of andesine.

Olivine Gabbro (Unit 2, Figure 4)

Olivine gabbro forms sill-like bodies situated along major structural breaks. Intrusions vary from 30 to 200 m wide and 220 to 2,500 m in length exposed in small, widely spaced outcrops southeast of Lemon Lake and north of Patenaude Lake (Figure 4). Outcrops are fractured and sheared, in places consisting wholly of fault gouge. Contact relationships with other units are obscured by overburden.

In hand specimen olivine gabbro is greenish-grey, dark green or black and weathers a rusty or orange brown. It is an equigranular, medium grained (2-5 mm) rock with a color index of 45-60%. Pyroxene forms stubby, black crystals with pale green rims. Other mafic constituents are waxy-green olivine, and plates of magnetite and chromite. Plagioclase is dark grey, tabular and frequently enclosed by pyroxene crystals.

Thin sections shew olivine to be subhedral to subround, equidimensional grains mantled by magnetite and hematite. It is replaced by iddingsite, chlorite, epidote, and serpentine, sometimes to such a degree that only crystal outlines remain (Plate II, E). The mineral is crossed by curving microfractures containing magnetite, iddingsite, and serpentine.

Pyroxene is diopsidic augite (Table VI) with $2V_z$ of 48-55°. It is pale green, prismatic and slightly larger (3-5 mm) than other constituents, with narrow oxide plates along cleavages or zone boundaries and inclusions of plagioclase and olivine. The augite is partly replaced, along cleavage traces and crystal edges,

Plate II

Plate II

A) Photomicrograph of glomeroporphyritic clinopyroxene with magnetite in alkali-olivine basalt. Plane-polarized light.

B) Photomicrograph of magnetite, clinopyroxene, and subround olivine phenocrysts in an alkali-olivine basalt flow breccia. Plane-polarized light.

C) Photomicrograph of spherulites in amygdaloidal alkali basalt. Matrix is composed of devitrified glass (palagonite) and plagioclase and clinopyroxene phenocrysts. Amygdules are zoned from potassic feldspar cores to epidote, chlorite, hematite rims. Plane-polarized light.

D) Photomicrograph of trachybasalt showing subparallel alignment of plagioclase and elongation of amygdules. Cross-polarized light.

E) Photomicrograph of olivine partly altered to serpentine, calcite, and magnetite in olivine gabbro. Cross-polarized light.

F) Photomicrograph of 'islands' and irregular patches of clinopyroxene enclosed by hornblende in alkali gabbro. Cross-polarized light.

Scales of photomicrographs are the same except where noted.

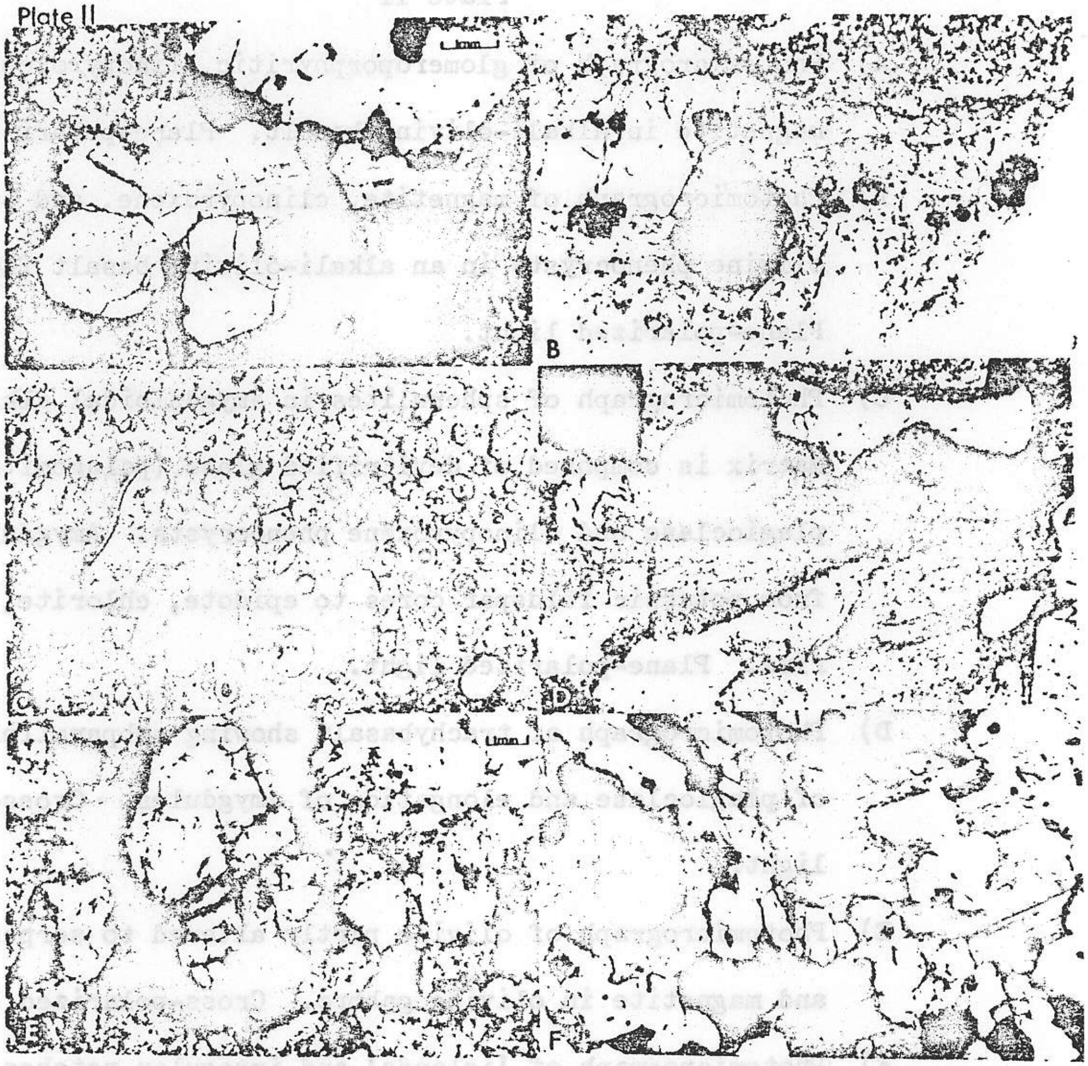


Plate II
1mm
B
D
1mm
F

by epidote, chlorite, biotite, and, more rarely, green hornblende.

Plagioclase is weakly zoned labradorite (An_{60-70}) that is well twinned according to albite and Carlsbad laws. Interstitial accessory minerals are magnetite, chromite, and prisms of apatite. In intensely sheared rocks hematite, chlorite, calcite, and serpentine are common constituents.

Alkali Gabbro (Unit 3, Figure 4)

There are two plutons of alkali gabbro in the Horsefly area; a sill-like body east of Lemon Lake and an elliptical stock south of Lowry Lake (Figure 4). At Lemon Lake the intrusion is 2,500 by 220-700 m, bordered by olivine gabbro on the south, and intruded by a syenodiorite - syenite complex to the north.

Southern exposures of the gabbro are porphyritic with irregular aggregates of pyroxene in a fine grained, equigranular groundmass. The porphyry contains angular fragments of olivine gabbro, exhibits a sub-parallel alignment of mafic constituents, and contains schlieren composed of alkali feldspar, plagioclase, and zeolites. Porphyritic alkali gabbro grades into medium grained, equigranular gabbro over a distance of 60 to 130 m.

To the north alkali gabbro grades into hornblende diorite (Figures 4 and 6), the change reflected by a gradational increase in hornblende and a corresponding decrease in pyroxene. The diorite forms a zone 70-260 m wide that parallels the gabbro along its entire length.

Thin sections of diorite, collected near gabbro contacts, show hornblende as rims around, or lenticular blebs throughout pyroxene grains. At distances of 130 to 270 m from the contact hornblende forms large (5-11 mm), irregular grains that coalesce and enclose all other minerals (Plate II, F). Pyroxene is reduced to small anhedral grains (0.2-0.9 mm) scattered throughout hornblende crystals. Here plagioclase consists of untwinned andesine or oligoclase, whereas adjacent to the gabbro it is twinned labradorite with andesine rims.

Lithology, contact relationships, and thin section studies suggest that hornblende diorite is a contact phase of the alkali gabbro, having formed as a result of reaction between alkali gabbro and water rich sediments.

The second stock of alkali gabbro is situated 850 m south-east of Lowry Lake (Figure 4) and is 400 by 500 m in area. Only four outcrops were observed and from these the gabbro appears identical to the medium-grained gabbro exposed at Lemon Lake.

Dykes of alkali gabbro are rare. Only two occurrences were noted, one east of Lemon Lake, which cuts olivine gabbro, and one at Horsefly Peninsula that intrudes alkali basalt. These dykes are 0.2 to 2 m wide, vary from fine grained, equigranular to porphyritic and are aphanitic along exposed contacts. They are mineralogically similar to the intrusions, strike north-south, and dip steeply to the east.

In hand specimen alkali gabbro is a dark grey rock that weathers a tan-grey or brown. Grey plagioclase and black pyroxene are dominant minerals with alkali feldspar a common constituent.

Thin sections of porphyritic alkali gabbro show clinopyroxene aggregates, consisting of three or more individual grains with embayed edges, varying from 4 to 8 mm in diameter. Individual grains are concentrically zoned with pale green cores and darker green rims. They exhibit hourglass structure, and are diopsidic augite with aegirine-augite rims (Table VI). Matrix pyroxene is similar to phenocrysts though it lacks hourglass structure and may be a pale purplish-green colo

Plagioclase varies from labradorite to andesine and is equant or subhedral, ranging from 0.5 to 4 mm in diameter. Alkali feldspar is present in all sections studied, including those of dyke rocks. It occurs as anhedral or subhedral grains or tablets 0.1-1.5 mm, interstitial to pyroxene and plagioclase. Accessory minerals are magnetite, apatite, and sphene.

Syenodiorite Intrusive Breccia (Unit 4, Figure 4)

Five circular syenodiorite stocks are found within the thesis area. The largest is 500 by 400 m and forms the upper and southern portions of Viewland Mountain. Four smaller stocks outcrop between Lemon Lake and Black Mountain. These vary from 200 by 300 to 160 by 700 m and have medium grained, equigranular cores, and porphyritic, fine grained margins.

All five intrusions are breccias; fragments compose 40 to 75% of the syenodiorite near contacts and 10 to 20% in more massive cores. Fragments are angular to subround, vary from 1 mm to 10 cm in diameter, and show no size sorting. They are commonly broken into two or more non-rotated pieces cemented by syenodiorite.

Fragments are cognate (accessory) and vary from alkali or alkali olivine basalt to trachybasalt and from pyroxene-rich lapilli tuff to lithic wacke with trachybasalt most abundant. In places the outer margins of stocks consist of brecciated trachybasalt or lapilli tuff in a matrix of porphyritic syenodiorite.

In hand specimen syenodiorite is a mottled grey and black rock that is typically fine grained and equigranular. Porphyritic varieties are found adjacent to intruded rocks and contain prismatic or broken pyroxene, irregular flakes of biotite, and tabular or angular plagioclase phenocrysts aligned parallel to the contacts. Equigranular varieties are composed of the above minerals plus alkali feldspar.

In thin section plagioclase exhibits concentric and oscillatory zoning (Plate III, A) with cores of andesine (An_{38-48}) and rims of oligoclase (An_{21-28}). It forms equant, subhedral grains that average 1 mm in diameter and are well twinned. In porphyritic varieties phenocrysts are subhedral or subangular, average 2.5 mm and are weakly zoned andesine (An_{42-47}).

Clinopyroxene forms prismatic or subhedral grains that are colourless or pale green in colour showing a purplish-brown tint

Table VI: Values of $2V_z$ and Z c for Clinopyroxene in Cycle I Intrusive Rocks.

Rock Type	Rock Number	Chemical Number	Average of at least three crystals	
			$2V_z$	$Z\wedge c$
Olivine Gabbro	73-36	RM-28	48-52	37-41
Olivine Gabbro	73-340	-	50-55	39-46
Alkali Gabbro	73-6	RM-38	53-61	42-52
Alkali Gabbro	73-296	-	51-57	40-45
Syenodiorite	73-109	RM-14	58	45
Syenodiorite	73-160	RM-26	55-63	43-52
Syenodiorite	73-158	-	54-59	42-46
Monzonite	73-304	RM-50	53-62	41-52
Monzonite	73-343	RM-34	55	44
Monzonite	73-246	-	56-62	45-52
Syenite	73-44	RM-18	56-66	44-54
Syenite	73-313	RM-31	62	50
Syenite	73-79	-	57-69	44-56

in the Z vibration direction. They vary from 0.3 to 3 mm in size, are weakly zoned with $2V_z$ of 54 to 63° (Table VI), and contain inclusions of magnetite and apatite.

Alkali feldspar is tabular and subhedral, 0.4-2 mm across, shows Carlsbad twins, and occurs between plagioclase and pyroxene grains. It has a $2V_z$ of 57-68° and extinction angles on (010) of 8-13° and belongs to the low temperature orthoclase-microperthite series (Mackenzie and Smith, 1956). Rectangular crystals of microperthite, averaging 1 mm, are also present and consist of irregular streaks of albitic feldspar with higher birefringence than the host orthoclase. Microperthite composes less than 5% of the syenodiorite and is found only in centres of stocks. Accessory minerals are biotite, magnetite, apatite, and monazite.

Monzonite (Unit 5, Figure 4)

Pyroxene monzonite is the most abundant rock type within igneous complexes, forming stocks, intrusive breccias, sills, dykes, and the cores of zoned plutons. Stocks are roughly circular in plan and vary from 160 by 230 to 700 by 1,000 m (Figure 4). The stocks are intrusive into alkali and alkali-olivine basalt, trachybasalt, volcaniclastic rocks, and lapilli tuffs, and are commonly bounded by major faults. Trachybasalts and salic lapilli tuff or tuff breccia flank and partly overlie monzonite intrusions.

Observed contacts are steeply dipping, and the stocks have brecciated or deformed and hornfelsed adjacent sedimentary and flow rocks. Monzonite exhibits aphanitic borders that grade into fine grained, equigranular or porphyritic rocks over distances of 10 cm to 6 m.

The monzonite stock south of Hooker Lake is exposed in only one outcrop, its size and shape having been determined by percussion drill cuttings. The stock conforms in plan to a circular feature observed on aerial photographs, and is overlain by nepheline- and analcite-bearing tuffaceous wackes. The stock west of Kwun Lake contains large roof pendants of trachybasalt and lapilli tuff and has a narrow, outer zone composed of syenodiorite. The monzonite plug east of Lemon Lake has been intruded and intensely brecciated by a nepheline-bearing syenodiorite pluton.

Stocks vary texturally from porphyries with numerous vugs (Lemon and Hooker Lake) to medium grained equigranular types (Kwun and Shiko Lake). Their mineralogy is similar throughout the area; modal compositions are listed in Appendix A and Table II.

In hand specimen monzonites exhibit phenocrysts of plagioclase and/or alkali feldspar set in a fine grained to aphanitic pink or pinkish-grey groundmass. In equigranular types cream-coloured plagioclase and pink feldspar are equant and form a granular matrix around pyroxene prisms or anhedra. Apatite is a visible accessory mineral occurring as clear, vitreous grains between pyroxene and alkali feldspar.

Under the microscope plagioclase is seen to be normally zoned andesine and oligoclase. It is frequently surrounded by anhedral grains of potassic feldspar (0.2-0.6 mm); where these are present plagioclase exhibits irregular or curved boundaries suggesting resorption.

Table VII: Average Modal Composition of Cycle I Intrusive Rocks (Excluding Analyses from Zoned Stocks)

Rock Type	Olivine Gabbro	Alkali Gabbro	Syenodiorite	Monzonite	Syenite	Trachyte	Latite
Diop·Aug Aeg-Augite	26	31	21.7	17.7	12.8	11.2	19.6
Olivine	15.3	5.6	1.0	0.7	-	-	-
Plagioclase	50.6	51.8	49	39	26	20	44
Alkali Feld	-	5.5	19	34.1	51	55	29
Biotite	2.6	1.5	4	3.2	6	2.2	3.2
Hnde	0.7	1.2	1.4	-	1.2	7	-
Magnetite	4.6	4.0	3.0	2.2	0.7	0.3	2.5
Analcite	-	-	-	0.2	0.3	1.1	-
Nepheline	-	-	-	0.7	0.9	-	-
Apatite	0.1	0.4	1.5	0.9	1.7	2.1	1.0
Sphene	-	0.1	0.2	-	-	-	-
Sulphides	-	-	0.1	-	-	-	0.2
N*	3	5	7	7	7	4	2
An% (Range)	60-70	65-45	21-48	42-21	6-22	4-14	26-39

*N Number of analyses (Appendix A)

Potassic feldspar forms subhedral grains 0.4-2 mm or an interlocking mosaic of anhedral grains interstitial to plagioclase and pyroxene. Larger crystals are poikilitic, enclosing pyroxene, plagioclase and apatite. Potassic feldspar is typically homogeneous but at Kwun Lake strings or patches of sodic feldspar occur in the cores of potassic feldspar crystals. Optically potassic feldspar is variable with a 2Vx $\perp$ to (010) of 56-67° and extinction angles of 7-11°; these are consistent with the orthoclase-microperthite (Mackenzie and Smith, 1956).

Pale green to purplish-brown diopsidic augite (Table VI) is the major ferromagnesium mineral. Diopsidic augite varies from 0.3 to 3 mm in diameter, is concentrically zoned, has hourglass patterns, and contains numerous inclusions of magnetite and apatite. Aegirine-augite forms partial rims around diopsidic augite or occurs as slender needles 0.2-1 mm long throughout the rock. Aegirine-augite is pleochroic from green to brownish-green with extinction angles X$\wedge$c of 11-15°.

Biotite forms irregular flakes enclosing clinopyroxene, plagioclase, and potassic feldspar. Its habit, replacement of pyroxene, and irregular distribution, lead to the conclusion that it is of deuteric origin.

Olivine is an accessory mineral in the stock east of Shiko Lake, occurring as subround grains (0.3-1.1 mm) which cluster around pyroxene crystals. Square pseudomorphs 0.3-1.5 mm across, composed of zeolites, potassic feldspar, and calcite are disseminated throughout the stocks at Lemon and Kwun Lakes. These compose up to

2% of the rock and are interpreted to be altered nepheline. Other accessory minerals are magnetite, apatite, sphene, and chalcopyrite. Chalcopyrite is found as disseminated grains interstitial to pyroxene and potassic feldspar.

Monzonite porphyries are mineralogically similar to equigranular rocks with potassic feldspar and zoned andesine-oligoclase forming tabular phenocrysts that vary from 1.5 to 4 mm in length. Olivine is more abundant, aegirine-augite is rare, and perthitic feldspar more common.

Monzonite breccias occur north of Horsefly Mountain, west of Black Mountain, and north of Antoine Lake (Figure 4). They are mineralogically similar to previously described stocks and have arcuate forms with steeply dipping or vertical contacts.

Fragments compose 20-65% of the rock and range from less than 1 mm up to 12 cm across. They are angular to subrounded, unsorted, and are evenly distributed throughout the monzonite. They consist of alkali and alkali-olivine basalt, trachybasalt, syenodiorite, monzonite, and lapilli tuff, with trachybasalt and intrusive rock fragments most abundant.

The matrix is fine grained, equigranular monzonite in which crystals are frequently angular and broken. Plagioclase has distorted twin lamellae and pyroxene shows granulated crystal edges.

Monzonite dykes and dyke swarms are peripheral to, and intrude compositionally similar stocks. Dykes vary from less than 3 cm to 3.5 m in width, have random trends, but dip steeply toward nearby stocks. They cut all rock types of the first cycle except syenite and orthoclase-bearing lapilli tuff (Unit 12) in which they occur as fragments.

Texturally and mineralogically they are similar to larger intrusions but contain more biotite and carry minor quantities of hornblende.

Sills are compositionally similar to dykes and are most common along flow contacts or bedding planes in sedimentary rocks. They vary from 0.5 to 5 m thick and from 5 to 100 m in length.

Composite Stocks (Units 4,5,6, Figure 4)

Two composite stocks, composed of syenodiorite, monzonite, and syenite are found in the Horsefly area.

The Shiko Lake stock is situated 1,200 m north of Shiko Lake and has the shape of a "thick, asymmetric horseshoe about a mile across and open to the northeast" (Schink, p. 9, 1974). The stock is intrusive into alkali-olivine basalt, lapilli tuff, and tuff breccia, and fine grained volcaniclastics. It is faulted against analcite basalt-trachybasalt to the north, and is flanked by lapilli tuff and tuff breccia to the north and east (Figure 4).

The Lemon Lake stock is situated 2.6 km south of Horsefly Lake and is 2.2 by 1.0 km in size. To the south and west the stock is intrusive into hornblende diorite, alkali gabbro and alkali-trachybasalt. To the north it is faulted against alkali-trachybasalt, whereas to the east it is intruded by a syenite pluton (Figure 6).

The stock exhibits both lateral and vertical zonation (Figures 6, 7, and 8). Porphyritic, fine grained syenodiorite forms the upper and outer zone. This zone is 300 to 1,800 m long and 500 to 1,000 m wide (Figure 6) and is cut by monzonite and syenite dykes. Where altered the syenodiorite takes on a spotted appearance with light grey plagioclase enclosed by a fine grained, black matrix.

Monzonite forms an intermediate zone 1,200 by 500-650 m, that grades laterally into syenodiorite and vertically into syenite. Syenite is exposed in two outcrops and composes numerous frost-heaved boulders; its presence at depth has been confirmed by drill samples.

The Shiko and Lemon Lake stocks are texturally and mineralogically similar and the following petrographic descriptions apply to both, except where noted. Average modal compositions are listed in Table VIII.

Fine to medium grained syenodiorite (0.5-3 mm) forms the outer zone of both stocks. At Shiko Lake it is gradational into monzonite over an outcrop distance of 80 to 260 m, whereas contact relationships are poorly defined at Lemon Lake.

In hand specimen syenodiorite varies from fine grained and porphyritic to medium grained, equigranular. It is mottled black and grey, or pinkish-grey and weathers brownish-grey. Plagioclase is the only mineral to form phenocrysts and these show a parallel alignment adjacent to contacts.

In thin section plagioclase phenocrysts are tabular, 1.5-4 mm and normally zoned with labradorite cores (An_{54-61}) and andesine rims (An_{38-45}). Potassic feldspar is subhedral to anhedral, 0.4-2.2 mm in diameter, and twinned according to the Carlsbad law. Its relative proportions are variable with amount increasing toward the

Table VIII: Average Modal Composition of Composite Stocks

Rock Type	Syenodiorite	Monzonite	Syenite
Diop Aug Aeg-Augite	22.6	21.5	14.1
Olivine	0.6	0.1	-
Plagioclase	48	35	23
Potassic Feld	17	33.4	55
Biotite	60	3.4	3.8
Hnde	0.7	1.0	0.5
Magnetite	2.7	2.7	1.1
Analcite	0.1	0.1	0.1
Nepheline	0.2	1.2	0.7
Apatite	1.1	1.9	1.8
Sphene	0.1	-	-
Sulphides	-	0.1	0.2
N*	5	6	6
An% (Range)	38-61	24-47	7-25

*N Number of analyses (Appendix A)

monzonite zone. As the percentage of potassic feldspar increases its habit changes from small grains, interstitial to plagioclase and pyroxene, to subhedral laths that poikilitically enclose the above constituents. It has 2V ⊥ 010 of 53-64° with extinction angles on (010) of 7-11° indicating an Or content of 70-90% (Tuttle, 1952). Close to the monzonite zone small quantities of microperthite are associated with potassic feldspar.

Clinopyroxene is concentrically zoned with pale green or brownish-green cores and pale to dark green rims. $2V_z$ varies from 54 to 63° (core to rim) with extinction angles Z∧c of 41 to 52°. Its appearance and optical properties are similar to those of diopsidic augite found within previously-described flow and intrusive rocks.

Biotite is found as primary plates that are pleochroic from dark brown to reddish-brown. These vary from 0.5 to 1.5 mm long and contain inclusions of magnetite and apatite. Accessory minerals are magnetite, apatite, and sphene. Olivine is a rare constituent, being found as subround grains adjacent to pyroxene.

Monzonite composes the intermediate zone of both stocks and is mineralogically similar to the monzonite of intrusive breccias and individual plutons. It is light grey to pinkish-grey, medium grained, equiangular, and composed of potassic feldspar, plagioclase, clinopyroxene, biotite, and magnetite.

Under the microscope plagioclase shows tabular or lath shaped crystals 1.8-4 mm in diameter with broken or distorted albite twin lamellae. Plagioclase is normally zoned with cores of andesine (An_{43-47}) and rims of oligoclase (An_{24-28}).

Microperthite forms laths 2-5 mm or anhedral grains 1.5-4 mm poikilitically enclosing plagioclase, magnetite, and pyroxene. It shows a well-defined parallel alignment in sections from Shiko Lake but is randomly oriented in those from Lemon Lake. The exsolved sodium feldspar is much more prominent than in syenodiorite, composing 15 to 40% of individual crystals.

Clinopyroxene is subhedral and prismatic, 2-4 mm, with colourless or pale green cores and rims of green, pleochroic aegirine-augite. Optical measurements indicate a similar range of $2V_z$ and extinction angles as in the syenodiorite (Table VI).

Small amounts of clear, anhedral or prismatic nepheline are scattered throughout the monzonite. These are partly replaced by potassic feldspar, analcite, and carbonate. Monzonite grades into syenodiorite. The change in composition is reflected by an increase in potassic feldspar, whereas the percentage of mafic minerals remains relatively constant (Table VIII).

Syenite forms the inner zone of both stocks and is gradational from monzonite by an increase in potassic feldspar and a decrease in mafic constituents (Table VIII). It is a pink, medium to coarse grained (4-8 mm) rock composed of potassic feldspar, plagioclase, acicular pyroxene, and biotite. At Shiko Lake it is well foliated with the foliation paralleling the major axis of the syenite zone (Schink, 1974).

In thin section microperthite forms interlocking, subhedral to anhedral grains, 4-7 mm, that form mosaics enclosing plagioclase laths and biotite flakes. Plagioclase forms irregular or subhedral grains, 3-5 mm, and is weakly zoned with cores of oligoclase (An_{15-25}) and rims of albite (An_{7-11}).

Clinopyroxene is found as weakly zoned, embayed or ragged crystals with pale green cores and dark green, pleochroic rims of aegirine-augite (Table VI). Aegirine-augite also forms acicular crystals (1.5-4 mm in length) throughout the rock and these are enclosed by microperthite.

Pseudomorphs, 1-3 mm, with prismatic shape, composed of analcite, potassic feldspar, and zeolites are found throughout the syenite. These are thought to represent replacement of nepheline. Common accessory minerals are apatite, biotite and magnetite.

North of the Shiko Lake stock a linear skarn zone has been developed between syenodiorite and tuff breccia. The skarn is composed of diopside (55%), andesine (22%), biotite (15%), magnetite (3%), and garnet (3%), with minor pyrite (1.5%), and chalcopyrite (0.5%) (Schink, 1974). Fragments of altered volcanic flow and sedimentary rocks are found within the skarn suggesting that it might represent metamorphosed and altered tuff breccia.

Biotites from the Shiko Lake stock, and associated skarn zone, have been dated by K-Ar methods (Schink, 1974). They yield an apparent age of 187-192 m.y., which compares favourably with corresponding fossil ages for Cycle I sedimentary rocks.

Syenite (Unit 6, Figure 4)

Syenite composes two small stocks, numerous dykes, and sills throughout the thesis area. Stocks intrude or are peripheral to monzonite plutons or zoned intrusions and are circular in outline, varying from 90-330 by 160-500 m. They are porphyritic, with phenocrysts of plagioclase and potassic feldspar enclosed in a fine grained, equigranular matrix. Potassic feldspar exhibits a subparallel alignment adjacent to contacts where vugs 0.2-1.8 mm across, lined with zeolite, carbonate, aegirine, and alkali feldspar are common.

Stocks contain up to 35% fragments of monzonite, syenodiorite, latite, and various flow and pyroclastic rocks. Fragments are angular, 2 mm to 8 cm in diameter, and increase in abundance towards contacts.

In thin section the petrography of the stocks is seen to be similar to that of the syenite found in zoned intrusions (Tables VII and VIII; Appendix A). Stocks consist of zoned oligoclase-albite, perthitic feldspar, aegirine-augite, and nepheline (Plate III, B). Accessory minerals are apatite and magnetite.

Syenite dykes are intrusive into all other rock types of the first volcanic cycle except trachytes and orthoclase-bearing lapilli tuff. Dykes are 0.3 to 3.3 m wide with random strikes and steep dips. They are most abundant within or adjacent to intrusive centres.

Sills are 1 - 7m thick and have aphanitic margins; adjacent rocks are bleached and partly recrystallized.

Latite and Trachyte Dykes (Unit 10, Figure 4)

Latite forms narrow dykes at Shiko Lake and occurs as fragments in pyroxene- and orthoclase-bearing lapilli tuffs. Dykes vary from 0.5 to 2 m in width, show narrow chilled margins, and are most common along fault zones adjacent to the Shiko Lake stock. They cut syenodiorite of the stock as well as adjacent tuff breccia and olivine basalt.

In hand specimen they are grey or pinkish-grey rocks weathering buff or brownish-grey. Latites are porphyritic with potassic feldspar and plagioclase phenocrysts comprising up to 20% of the rock.

In thin section plagioclase shows weak zoning with cores of An_{35} and rims of An_{23}. Potassic feldspar forms tabular to anhedral phenocrysts, 2-4 mm, with granulated and embayed crystal edges.

Clinopyroxene forms small (1-2 mm), prismatic, pale green crystals that contain inclusions of magnetite, apatite, and chalcopyrite. Biotite, when present, forms irregular, brown flakes (1-2 mm) that enclose pyroxene crystals and magnetite grains.

Groundmass material is equigranular and fine grained (0.1-0.6 mm) composed of an interlocking aggregate of potassic feldspar, plagioclase, and aegirine-augite. Accessory minerals are magnetite, apatite, pyrite and chalcopyrite.

Trachyte dykes are found within and adjacent to Lemon and Kwun-Hooker Lakes igneous complexes. They intrude all rock units of the first cycle and are found as fragments in orthoclase-bearing lapilli tuff and clasts in perthite-bearing wacke.

Dykes vary from 0.3 to 2 m in width, form sharp contacts with adjacent rock units and show a parallel alignment of phenocrysts which follow wallrock contacts. Dykes have random orientations and steep dips with several showing curved outcrop patterns (Figure 4) similar to ring dykes.

Trachytes are porphyritic with phenocrysts of potassic feldspar, plagioclase, and pyroxene or hornblende in an aphanitic buff or light grey matrix. Phenocrysts average 2 mm, are lath shaped and surrounded by acicular crystals of pyroxene and hornblende.

In thin section trachytes have a microcrystalline groundmass that is usually aligned parallel to orientated feldspar phenocrysts.

Plagioclase phenocrysts vary from oligoclase to albite (An_{4-17}), and are twinned according to the albite law; they are embayed and exhibit broken crystal edges. Sanidine forms clear, tabular phenocrysts (2 mm in diameter) which show a distinct basal cleavage. Sanidine has a $2V_x$ of 10-15° and shows parallel extinction on (001) faces. Crystals have irregular, curved edges and contain inclusions of pyroxene and apatite.

Aegirine-augite occurs as acicular needles or short, prismatic crystals that are smaller than either plagioclase or sanidine. Pyroxene exhibits distinct prismatic cleavage and is pleochroic from green to yellowish-green.

Plate III

Plate III

A) Photomicrograph of a zoned and partly resorped plagioclase phenocryst in syenodiorite porphyry from Viewland Mountain. Cross-polarized light.

B) Photomicrograph of the Lemon Lake syenite showing perthite, aegirine, albite, and sphene. Cross-polarized light.

C) Photomicrograph of the matrix of a mafic lapilli tuff. Crystal fragments are composed of clinopyroxene, plagioclase, and crystallized shards. Plane-polarized light.

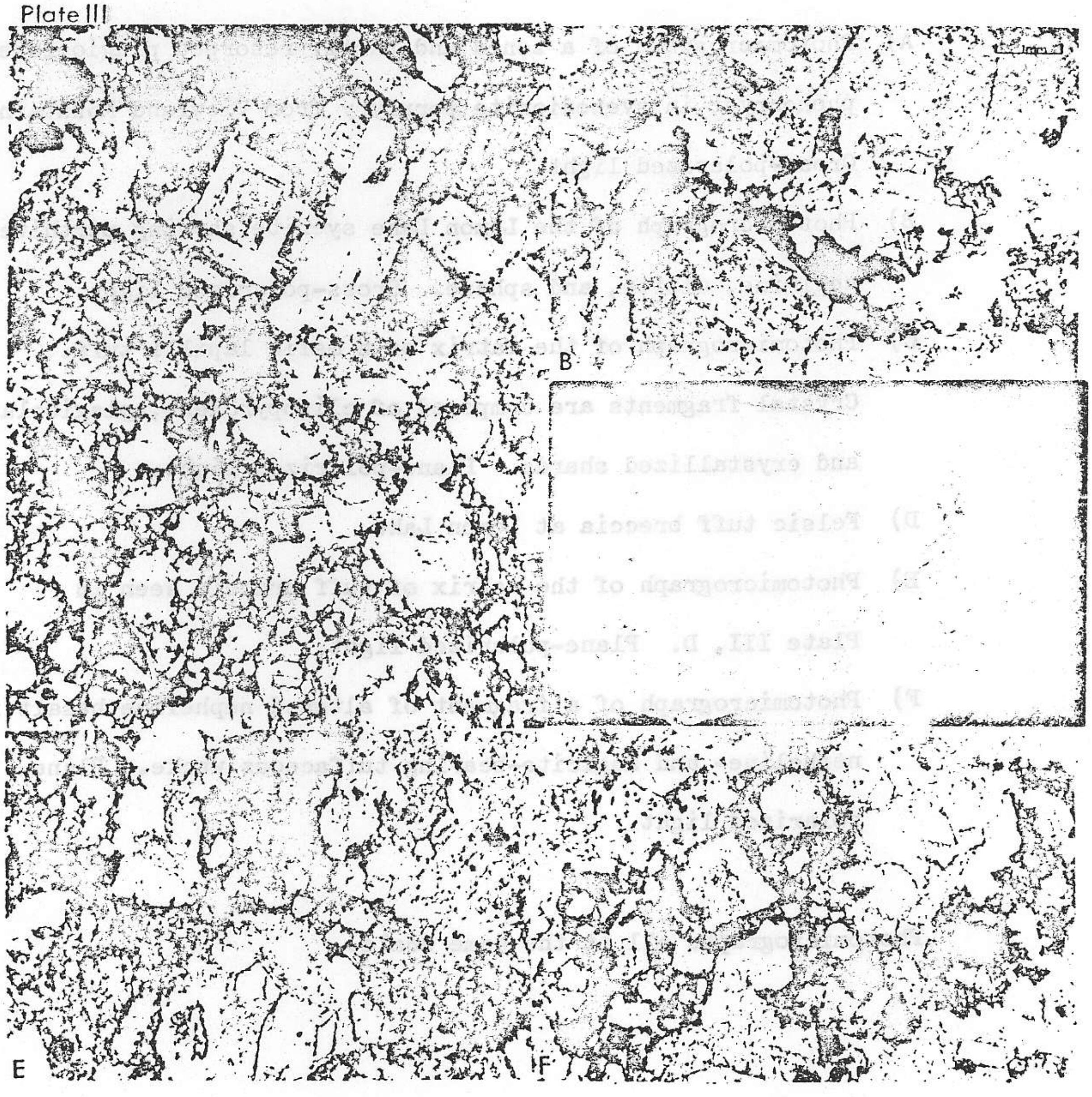
D) Felsic tuff breccia at Lemon Lake.

E) Photomicrograph of the matrix of tuff breccia seen in Plate III, D. Plane-polarized light.

F) Photomicrograph of a fragment of altered nepheline basalt in nepheline- and analcite-bearing tuffaceous wacke. Plane-polarized light.

Photomicrographs all at the same scale.

Plate III



Amphibole, when present, form acicular crystals (0.6-1 mm long) that are pleochroic from pale brown to green. It has a $2V_z$ of 59-63°, and extinction angles that average 18°; it is considered to be hornblende. Hornblende may be mantled by a pleochroic yellow to reddish-brown amphibole considered to be kaersutite. Where amphibole is abundant aegirine-augite is restricted to the groundmass or reduced to small blebs within hornblende crystals.

The groundmass is predominantly feldspathic with lath-shaped albite and potassic feldspar arranged in a parallel, fluidal texture. In addition to feldspar, aegirine and/or aegirine-augite occurs throughout with accessory magnetite, biotite, and apatite. Irregular patches, 0.05-0.7 mm, of analcite, zeolites and carbonate are common throughout the groundmass.

Clinopyroxene-bearing Lapilli Tuff and Tuff Breccia (Unit 11, Figure 4)

Deposits of pyroxene-bearing lapilli tuff and tuff breccia have been subdivided into two units for purposes of description. The division is based on dominant fragment types, abundance of potassic feldspar, and anorthite content of matrix plagioclase. For the purposes of geological mapping they are considered as one unit.

An older, more mafic succession is recognized that consists predominantly of gabbro and alkali or alkali-olivine basalt fragments. This sequence forms elongate or irregular lobe-shaped deposits that are interlayered with, or gradational into, lithic wackes. The tuff deposits are unconformably overlain by epiclastic rocks that contain felsic clasts, or by younger, more felsic, tuff sequences.

Mafic lapilli tuff and tuff breccia deposits are found primarily within Lemon and Kwun-Hooker Lake igneous complexes where a greater proportion of mafic rocks are exposed. The deposits consist of 35-80% angular to subround fragments that are dominantly accessory[1] in nature. Essential fragments (MacDonald, 1972) comprise 5% of the tuffs and are recognized by their bomb-like shapes and 'bread-crust texture' (MacDonald, 1972). Accidental fragments are rare and consist of slate and/or phyllite.

Within successions composed primarily of tuff breccia there is no size sorting, either along strike or in inferred dip directions. Larger blocks (0.3 m) are randomly distributed throughout, with smaller blocks and lapilli separating larger fragments. Successions of lapilli tuff grade upwards into crystal tuff or tuffaceous wacke and, rarely, laterally into these rock types. Crystal tuffs have a matrix similar to lapilli tuff but are bedded and, in places, beds are slumped or distorted around large blocks. Individual beds vary from 4 cm to 5 m and contain up to 15% lapilli sized fragments.

At Lemon Lake tuff beds have divergent trends around the complex indicating derivation from vents that were situated above intrusive bodies.

Fragments vary from 1 mm to 2 m with an average size of 10 cm, in tuff breccias, and 2.5 cm in lapilli tuffs. More than 85%

1 Accessory is the term applied to fragments of older rocks formed during the same volcanic cycle, generally such fragments are formed by or derived from the same volcano.

of the fragments consist of either gabbro or alkali and alkali-olivine basalt. The remainder are composed of conglomerate, lithic wacke, siltstone, limestone or accidental and essential fragments.

Exposures of lapilli tuff and tuff breccia are distinctive on weathered surfaces as fragments stand out against a brown or greyish-green matrix.

Matrix material consists of angular or curved crystals of clinopyroxene and plagioclase set in a fine, oxide-rich groundmass (Plate III, C). Epidote, chlorite, albite, and carbonate have, to a large extent, replaced original groundmass constituents.

A younger, more salic lapilli tuff and tuff breccia succession has been defined which is more abundant than the mafic tuffs. This younger succession is exposed at Shiko, Hooker-Kwun, and Lemon Lakes forming curvilinear or lobe shaped deposits that vary from 3 to 45 m in thickness. The deposits are intruded by, flank, and partly overlie syenodiorite to syenite stocks and intrusive breccias.

At Lemon Lake the tuffs are exposed over an area 6 by 4 km, whereas at Shiko Lake they underlie an area 6 by 1.5 km. Exposures are limited at Hooker-Kwun Lakes because of extensive overburden.

Salic lapilli tuff and tuff breccia are composed dominantly of syenodiorite to syenite fragments enclosed by a matrix of clinopyroxene, plagioclase, and potassic feldspar (Plate III, D). They overlie older, mafic lapilli tuff and lithic wacke sequences and are interlayered with lithic wackes that contain a large proportion of monzonite and syenodiorite clasts.

The pyroclastic rocks consist of 20-75% angular to sub-angular fragments that are primarily accessory in nature. Essential fragments are rare, and when present are recognized by their spindle or ribbon shapes. Exceptions to this are lapilli tuffs interlayered with volcaniclastics north and northeast of Usses and Niquidet Lakes (Figure 4). Here essential fragments compose up to 30% of fragment types. They consist of curved or spindle shaped areas of chlorite that contain round to elongate, or shard-like bodies composed of epidote, chlorite, and zeolites.

Fragment size varies from less than 1 mm to 3 m with an average of 13 cm, in tuff breccia, and 2 cm in lapilli tuffs.

There is a distinct lateral gradation of fragment size at Lemon Lake. Tuff breccia, adjacent to a nepheline-bearing syenodiorite intrusive breccia (Figure 4), contains fragments that range in size from 10 cm to 2 m. Fragments decrease in size northerly, toward Horsefly Lake, with a minimum average of 1.5 cm at the furthest recognized exposures. The pattern does not repeat itself east and south of the intrusion where alternating sequences of lapilli tuff, tuff breccia, and crystal tuff are exposed.

Composition of fragments varies with syenodiorite and monzonite typically comprising more than 35%. Other types include syenite, latite, mafic lapilli tuff and tuff breccia, olivine basalt to trachybasalt, and epiclastic rocks.

Matrix material consists of angular and curved crystals, or pieces of crystals, set in a mixture of epidote, chlorite, albite, prehnite, and magnetite or hematite (Plate III,E).

Crystals consist of pale green, colourless, or dark green clinopyroxene (5-20%), zoned plagioclase (An_{12-47}), and potassic feldspar (5-30%). Small quantities of microperthite are present (2-10% and at Lowry Lake biotite is a minor constituent along with apatite.

Orthoclase-bearing Lapilli Tuff and Tuff Breccia (Unit 12, Figure 4)

Orthoclase-bearing lapilli tuffs and tuff breccias are the youngest exposed rocks of the first volcanic cycle. They contain fragments of all previously described units and are intruded by nepheline and analcite monzonite dykes, and overlain by feldspathoidal tuffaceous and epiclastic rocks. They underlie an area 4.5 by 2.4 km west of Black Mountain and form extensive deposits north and south of Antoine Lake.

Fragments compose 40-80% of the unit, are extremely angular, and vary from less than 2 mm to 4 m (rare) with lapilli most abundant. Fragments are 90-95% accessory in nature, the remainder composed of essential fragments. Syenite, monzonite, and trachyte, or their breccia equivalents make up 50-80% of the fragments; the remainder are composed of latite, trachybasalt, and various pyroclastic and volcaniclastic rocks.

In hand specimen orthoclase-bearing tuffs are distinguished from salic to mafic pyroxene-bearing tuffs by the abundance of potassic feldspar, and the pink or reddish-brown color of the matrix.

In thin section matrix material consists of angular or broken crystals of potassic feldspar, microperthite, plagioclase (albite to andesine), clinopyroxene, and biotite with minor hornblende and nepheline. These constituents are set in a fine, ash-size, hematite-rich groundmass.

Volcaniclastic Rocks (Unit 13, Figure 4)

Coarse to fine grained volcaniclastic rocks form extensive deposits in and around centres of intrusive and pyroclastic activity. These sedimentary rocks consist of interbedded conglomerate, lithic wacke, and siltstone. Within a given section this succession is likely to be repeated several times, coarse grained, poorly sorted material being most abundant. Total estimated thickness for this unit is 200 to 250 m.

Individual beds vary from 5 mm to 4 m in thickness with cross and graded bedding common. Contacts vary from gradational to irregular and sharp with local unconformities present. Sharp contacts occur where there is a rapid change in sediment size.

Conglomerates with large clasts (3-25 cm) are found within or adjacent to volcanic complexes, and are gradational into medium grained, lithic wackes. Here angularity of clasts, mixture of large and small clasts, and size of matrix material indicate poor sorting and short distances of transport.

Clasts within these rocks are 95% volcanic in origin with the remainder composed of mudstone, limestone, or phyllite. Clasts are angular to rounded, vary in size from 1 mm to 1 m and comprise 35-60% of conglomerates, and 10-40% of lithic wackes. Typically large and small clasts are found together but in sections exhibiting graded bedding or in thicker, more continuous successions there is a gradational change from large to small clasts. This gradation takes place up dip.

Northeast and southwest of the volcanic belt volcaniclastic rocks are the dominant facies. They are exposed over distances of 13 to 16 km (Figure 4), and rock types become finer grained as distance from the volcanic belt increases. Correlated with this is a decrease in abundance of volcanic clasts and an increase in roundness of grains and degree of sorting. Adjacent to Quesnel Lake sedimentary rocks are pyrite-rich, calcareous argillites and shales that are isoclinally folded. Lack of exposure makes it difficult to correlate these rocks with relatively undeformed volcaniclastics further south and east.

Volcaniclastic rocks are subdivided into two successions on the bases of clast type and relative abundance of clinopyroxene and potassic feldspar. This division corresponds to the two-fold classification of clinopyroxene-bearing lapilli tuff and tuff breccia (Unit 11).

An older succession, containing angular to rounded clasts of alkali and alkali-olivine basalt, gabbro, and pyroxene-rich crystal and lapilli tuff, forms the lower portion of the sedimentary section at Lemon Lake and in areas to the northeast. It also forms small, discontinuous outcrops west of Antoine and south of Hooker Lake.

Matrix material consists of subangular to rounded grains of clinopyroxene (20-35%), plagioclase (10-25%), and magnetite (1-5%). Potassic feldspar is not present and the anorthite content of plagioclase ranges from 40-75%. Grains and clasts are cemented by calcite, chlorite, epidote, and albite which give the rock a green or grey appearance.

The younger sedimentary succession unconformably overlies older sediments at Lemon Lake and forms extensive deposits southwest of the central volcanic belt.

It contains rounded to angular clasts (1 mm - 30 cm) of syenodiorite, monzonite, syenite, trachybasalt, and latite with smaller quantities of volcaniclastic and pyroclastic rock types. Rare, rounded clasts (3 mm to 3 cm) composed of chalcopyrite-pyrite, and albite, or sphalerite-chalcopyrite and albite have been found east of Lemon and Usses Lakes, respectively.

Matrix material consists of angular to rounded grains of potassic feldspar (5-20%), clinopyroxene (5-15%), and plagioclase (10-35%) with small amounts of apatite and magnetite. Anorthite content of plagioclase varies from 12 to 45% and magnetite is much less abundant than in the older succession.

Grains and clasts are lithified by chlorite, epidote, calcite, and clay minerals. Close to igneous complexes the matrix is largely replaced by albite, epidote, and zeolites, or by analcite, sodalite, and zeolites.

Fossil assemblages are rare in these successions with sedimentary structures, local unconformities, and change.in sediment size over short distances indicating rapid deposition under high energy conditions. Current marks and standing wave features have been found in lithic wacke and siltstone beds east of Usses and

Niqundet Lakes. Ripple marks are asymetrical and give current directions from the southwest and west, the general direction of the volcanic pile.

An ammonite was found east of Usses Lake and Campbell (1961) has collected fossil assemblages from shale or limestone interbeds southwest and west of Antoine and north of Lea Lakes. These place both volcaniclastic successions as Early Jurassic.

Perthite-bearing Conglomerate and Lithic Wacke (Unit 14, Figure 4)

Perthite-bearing pebble conglomerate and lithic wacke form a narrow, tongue-shaped deposit situated east of Kwun and Usses Lakes. It overlies conglomerate to siltstone of older volcaniclastic successions and is, in turn, overlain by, or interbedded with feldspathoidal tuffaceous wackes and conglomerates. Contacts between feldspathoidal sediments and perthite beds are irregular and local unconformities are common.

Perthite-bearing sedimentary rocks outcrop over an area 6.5 by 2.5 km and are conspicuous in hand specimen because of the presence of pinkish-grey or bone white perthite (1 to 6 mm) that composes 10-35% of the rock. Angular to rounded clasts (1 mm to 8 cm) of monzonite, syenite, trachybasalt, orthoclase-bearing lapilli tuff, and pyroxene-bearing lithic wacke to siltstone comprise 5-35% of the unit. Intrusive and pyroclastic clasts are most abundant, decreasing in size away from the Kwun-Hooker Lakes area.

Beds within the succession strike 30-40°NW and dip 20-35°NE, and vary from 1 cm to 2 m thick; total estimated thickness is 30 m.

Outcrop pattern, general trend, nature of matrix and clasts, and contact relationships indicate the source of the perthitic sediments to be monzonite and syenite stocks, intrusive breccias, and pyroclastic rocks situated between Kwun and Hooker Lakes. Their relationship with feldspathoidal sediments indicates a short span of time between the first and second cycles of volcanism.

Laharic Breccia (Unit 15, Figure 4)

An elongate, irregular deposit of laharic breccia (3 to 20 m thick) is exposed northeast of Lemon Lake, underlying an area 3.3 by 0.6-1 km. Towards Horsefly Lake the lahar is gradational into finely bedded, lithic wacke; to the west and east it overlies lapilli tuff, pyroxene conglomerate to wacke, and olivine to trachybasalt flows. To the south it is intruded by a nepheline-bearing syenodiorite pluton.

The lahar shows a complete lack of sorting with blocks being nested between lapilli and ash-size material. Fragments are angular to subrounded,vary greatly in size, and exhibit granulated or milled edges. Fragment type is variable, and lapilli tuff, trachybasalt, syenodiorite, and monzonite are represented.

There is a high ratio of matrix to fragments with fragments comprising 15-40% of the rock. The matrix consists of finely granulated rock debris and broken crystals of pyroxene, plagioclase, and potassic feldspar. Epidote, chlorite, albite, and clay minerals cement crystals and fragments giving the rock a distinct green color. In places matrix material is absent and fragments are in contact along granulated edges. In other parts of the deposit the cement seals fractures that transect both fragments and crystals.

Fine grained, poorly bedded lithic wacke appears to represent lateral extension of the lahar, and can be traced in outcrop to the edge of Horsefly Lake. Clasts and grains in the wacke are similar to those found within the lahar, though smaller and more round. Lithic wacke strikes east-west and dips 20-30°N.

The lahar overlies volcaniclastic rocks and pillow lavas. Its distinct green, rather than reddish-brown color indicates in part, a subaqueous origin. The lahar probably formed on the upper slopes of a water saturated-volcanic cone situated to the south. Movement down the flanks onto or along the sea floor would explain most of its contact and textural features.

Rocks of Cycle II

Tephrite (Unit 18, Figure 4)

Narrow tephrite dykes are exposed between Lemon Lake and Black Mountain, and south of Lowry Lake. They also occur as fragments in nepheline and analcite-bearing pyroclastic rocks. They vary from 10 cm to 4 m in width, have sharp contacts with adjacent rock types, and are porphyritic with fine grained or aphanitic borders.

Phenocrysts compose 20-35% of the rock and consist of plagioclase and clinopyroxene with lesser amounts of nepheline. Close to contacts phenocrysts exhibit a subparallel alignment becoming randomly distributed toward dyke centres. The groundmass is fine grained or aphanitic and dark grey.

Plagioclase consists of tabular or lath shaped phenocrysts that average 2.5 mm in diameter. These are twinned and weakly zoned varying in composition from An_{69} to An_{57}. Albite forms partial rims around labradorite phenocrysts and lenses along twin lamellae.

Prismatic nepheline phenocrysts vary from 1.3 to 2.3 mm in diameter, and are poikilitic enclosing small grains of plagioclase, pyroxene, and magnetite.

Phenocrysts of clinopyroxene are prismatic and average 2.0 mm in size. They are concentrically zoned with pale brown or colourless cores and green or pleochroic green to greenish-yellow rims. From core to rim, $2V_z$ ranges from 47° to 61°.

Groundmass material is microcrystalline, 0.05 to 0.5 mm in diameter, and is composed of plagioclase laths, olivine and clinopyroxene granules, and flakes of reddish-brown biotite with interstitial nepheline, magnetite, and apatite.

Nepheline Trachybasalt and Basalt (Unit 19, Figure 4)

Nepheline trachybasalt and basalt are found in a series of small, isolated outcrops between Horsefly Lake and Black Mountain, and south of Antoine Lake. In most exposures it is difficult to determine whether these represent flow or dyke rocks though outcrops south of Antoine Lake are of a rubbly, brecciated nature containing small amygdules indicative of a flow.

These units are up to 4 m wide and contain angular fragments of adjacent rocks. At Antoine Lake trachybasalt overlies orthoclase-

Table IX: Average Modal Composition of Nepheline Extrusive and Intrusive Rocks (Cycle II)

Rock Type	Tephrite	Trachybasalt	Syenodiorite	Monzonite
Phenocrysts				
Diop Aug	16	13	2	-
Olivine	0.6	-	-	-
Plagioclase	10	14.5	27	-
Nepheline	7.3	6.5	4.6	1
Potassic Feld	-	-	-	7
Matrix				
Diop Aug Aeg-Aug	15	12	15.5	16
Olivine	8.6	-	-	-
Nepheline	4.9	3.9	2.6	11.5
Plagioclase	27	33.5	25	34.6
Potassic Feld	-	7.6	16	21.6
Biotite	1.8	1.0	1.2	1.7
Anal Zeol	3.6	2.8	0.9	1.6
Apatite	0.5	0.9	1.1	1.2
Magnetite	4.1	3.0	3.0	2.3
Calcite	2.3	1.0	-	-
N*	3	2	3	3
An% (Range)	57-69	44-59	28-53	9-23

*N Number of analyses (Appendix A)

bearing lapilli tuff and contains subangular fragments of syenite and monzonite.

In hand specimen trachybasalt is a greenish-grey or grey rock that weathers a brownish-grey. It is porphyritic with phenocrysts comprising a maximum of 35%. These are composed of plagioclase, clinopyroxene, and minor nepheline. Groundmass material is aphanitic or fine grained, equigranular.

In thin section plagioclase is seen as subhedral laths (2.2-3 mm) that are normally zoned from An_{59} to An_{44}. Plagioclase inclusions in pyroxene phenocrysts are partly altered to analcite and carbonate.

Nepheline phenocrysts are subhedral or irregular, 1.2 to 2 mm, and contain inclusions of apatite, magnetite, and pyroxene. They are partly replaced by zeolites, carbonate and analcite (Plates III, F and IV, C).

Clinopyroxene varies from pale green to purplish-brown and exhibits pronounced hourglass patterns. It is prismatic, 0.8-2.1 mm long; $2V_z$ varies from 50° to 59°.

Groundmass material is equigranular, 0.06 to 0.7 mm, and is composed of nepheline and potassic feldspar interstitial to, or forming irregular patches between, clinopyroxene and plagioclase.

Groundmass nepheline is anhedral (0.08-0.3 mm) with square, cross-sections and was identified by X-ray techniques. Potassic feldspar was identified by staining techniques and is anhedral with a dusty appearance due to numerous brown inclusions.

Nepheline-bearing Syenodiorite (Unit 16, Figure 4)

Two plutons composed of nepheline-bearing syenodiorite occur within the thesis area. The largest, 3.2 km east of Lemon Lake, is 2,600 by 1,300 m, and has vertical contacts with adjacent rocks.

A smaller body, exposed 1,300 m north of Shiko Lake, is 1,000 by 220 m. It has hornfelsed adjacent volcaniclastic rocks but his gradational contact with tuff breccias to the north and west.

Both intrusions are breccias with fragments composing 20 to 70% of the rock. These are angular to subangular though many exhibit rounded or abraded corners. Fragments vary from 1 mm to 9 m and appear to be randomly distributed. Fragment type is variable with tephrite, alkali basalt, syenite, monzonite, syenodiorite, lapilli tuff, and lithic wacke represented.

At Shiko Lake intrusive and pyroclastic fragments are equally abundant with flow and volcaniclastic types of minor importance. Monzonite is most abundant at Lemon Lake and is the only type to occur as large blocks (greater than 2 m), in places composing up to 95% of fragment types. Abundance and occurrence of monzonite suggest that it represents a small stock which has been intruded and brecciated by nepheline syenodiorite.

At Lemon Lake hematite, epidote, albite, prehnite, and pyrite with traces of chalcopyrite occupy distinct, linear zones within nepheline syenodiorite. These are continuous over the vertical length of the intrusion and vary from 1 cm to 1 m in width. They are extremely irregular and cross or coalesce around both fragments and matrix. The zones are gradational into syenodiorite over widths of 2 to 10 cm though sharp boundaries do occur. It is believed that these zones represent channelways for hydrothermal solutions moving toward the surface.

In hand specimen nepheline syenodiorite is a "crowded porphyry" with plagioclase, clinopyroxene, and nepheline phenocrysts composing up to 50% of the rock. Groundmass material is fine grained and equigranular.

Phenocrysts are seriate, with the groundmass ranging from fine grained, equigranular to mosaics of grains found between irregular patches of hematite, epidote, and albite. Average modal composition is listed in Table IX.

Plagioclase is tabular to lath-like, ranges from 0.6 to 2.7 mm and is continuously zoned. Zonation is complex with normal and oscillatory types; typically cores are An_{45-53} and rims An_{28-38}. The plagioclase is mantled by optically discontinuous potassic feldspar.

Nepheline phenocrysts are subhedral or rectangular (Plate IV, A), vary from 0.5 to 1.8 mm, and have a cloudy appearance. They are partly altered to albite and potassic feldspar along cleavage traces or crystal edges.

Clinopyroxene is prismatic to subhedral, varies from 0.9 to 3 mm and is concentrically zoned with brown cores and green rims. Phenocrysts are typically poikilitic, enclosing grains of plagioclase, apatite, and magnetite.

Groundmass material varies from 0.7 to 0.1 mm and consists of anhedral potassic feldspar and nepheline scattered between laths of plagioclase and larger granules of clinopyroxene. Magnetite, biotite, and apatite are common accessory minerals.

In the upper levels of the intrusion the groundmass consists of irregular patches of albite, epidote, and calcite, found between hematite- and magnetite-rich areas. Typical constituents of the groundmass have an angular or broken appearance and are scattered throughout opaques.

Nepheline Monzonite (Unit 17, Figure 4)

Narrow nepheline monzonite dykes are exposed in four outcrops south of Antoine Lake and two outcrops south of Lowry Lake. They are pale pink, weather a pinkish grey and with conspicuous, tabular phenocrysts of potassic feldspar in a fine grained trachyte matrix.

The dykes consist of potassic feldspar and nepheline phenocrysts set in an equigranular (0.3-0.8 mm) matrix of nepheline, potassic feldspar, plagioclase, and aegirine-augite, with accessory biotite, magnetite, apatite, and sphene (Plate IV,B).

Phenocrysts of potassic feldspar vary from 1.5 to 5 mm and are mantled by albite. Nepheline phenocrysts are subhedral and partly altered to analcite. Groundmass nepheline is anhedral and interstitial to potassic feldspar and plagioclase. Plagioclase is lath shaped, exhibits fine albite twins, and ranges in composition from albite to oligoclase.

Rocks of Cycle III

Teschenite (Unit 20, Figure 4)

Teschenite forms narrow dykes and sills north of Lowry and south of Antoine Lakes. These intrusions are irregular bodies ranging from 1 to 9 m in width or thickness. Dykes strike east-west or northwest, dip steeply to the south or northeast and have fine grained borders with coarser grained, porphyritic centres.

Teschenites are conspicuous rocks in hand specimen with large 2-5 mm, pale pink and cream coloured euhedral analcite phenocrysts which are concentrically zoned. Zonation typically consists of cream cores with pale pink rims. Analcite together with plagioclase and pyroxene phenocrysts is set in a fine grained or aphanitic grey to dark grey matrix.

In thin section matrix material is seen to consist of analcite, plagioclase, aegirine-augite, and olivine with accessory magnetite, apatite, and biotite (Plate IV, D).

Phenocrysts of analcite are well-formed trapezohedras with round or embayed edges, or glomeroporphyritic clusters of subround crystals. They are colourless or pale pink and weakly birefringent and twinned. Zone boundaries are outlined by rows of opaque inclusions; the cause of the color zonation is not known.

Some phenocrysts have broken or angular crystal boundaries and are cut by microfractures sealed with albite, sodalite, zeolites, and isotropic analcite. In a sill north of Lowry Lake analcite has seriate texture (Plate IV, E), the larger crystals having a corroded and broken appearance.

Matrix analcite is subhedral to anhedral, weakly birefringent, and partly replaced by albite and carbonate.

Plagioclase is weakly zoned labradorite (An_{51-64}) laths or tabular crystals, 0.3-4 mm in diameter, rimmed by albite and partly altered to analcite and carbonate.

Clinopyroxene varies from pale green to purplish-brown. Phenocrysts are 2-5 mm in diameter, exhibit hourglass patterns; $2V_z$ varies from 47-56°. Prismatic or subhedral, stubby crystals throughout the groundmass are pleochroic from pale green to green with $2V_z$ of 63 to 71° and extinction angles of 3 to 11°. The two types are considered to be diopsidic augite and aegirine respectively.

Olivine may compose up to 18% of the groundmass though rarely is it more abundant than 8%. It is subround to euhedral and partly replaced by biotite, chlorite, and carbonate.

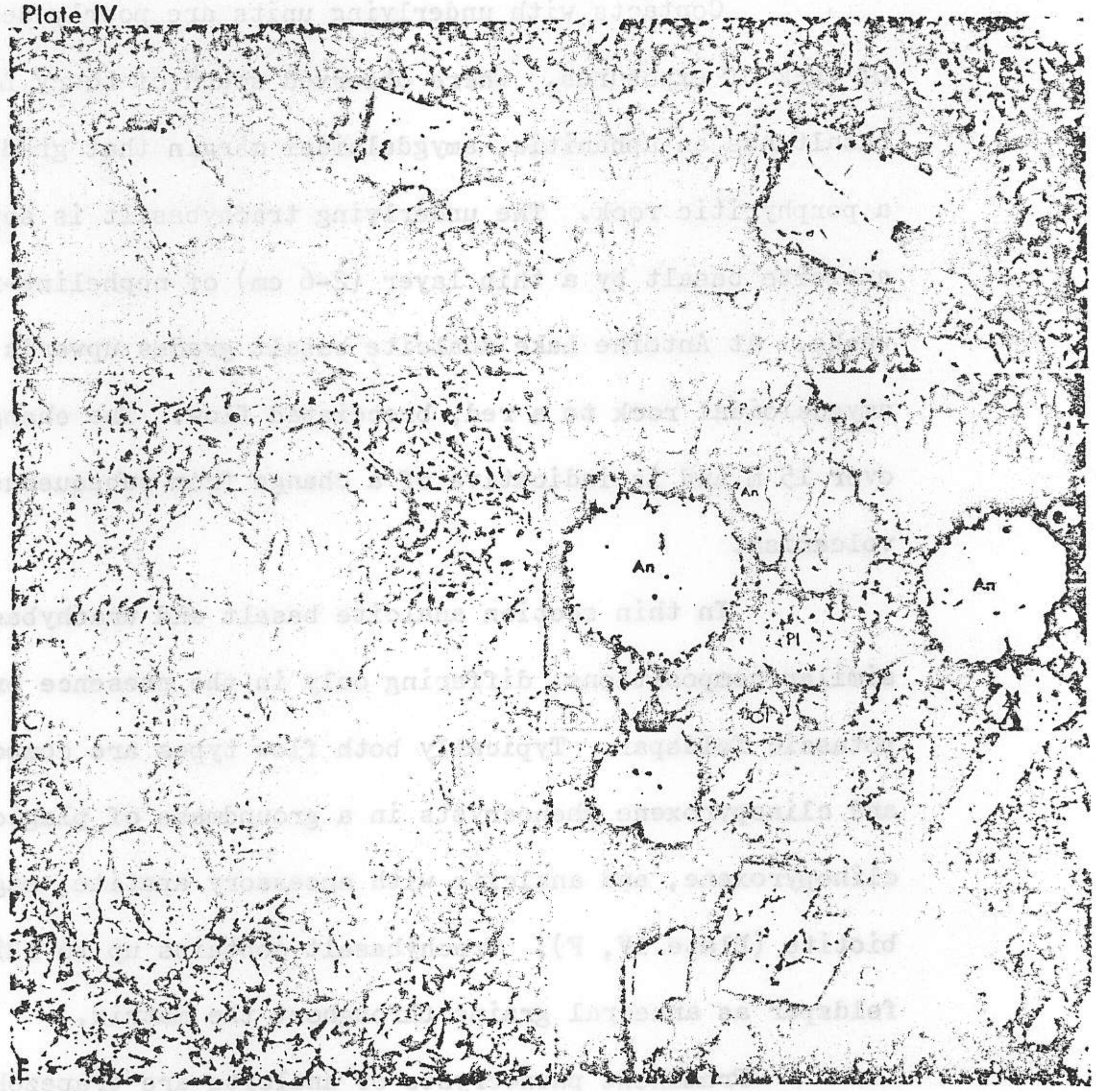
<u>Analcite Basalt and Trachybasalt (Unit 22, Figure 4)</u>

Analcite basalt and trachybasalt are exposed south of Antoine and Lowry Lakes and north of Shiko Lake. They are distinctive rocks with pink trapezohedras or subround crystals of analcite set in an aphanitic reddish-brown or grey matrix.

These basaltic rocks are thin flows 2-11 m having amygdaloidal and/or brecciated tops and massive centres. Breccias are autoclastic with fragments 3 cm to 1 m of analcite basalt lithified by mineralogically-similar material. Rarely, fragments of alkali basalt, orthoclase tuff, and various intrusive rocks occur throughout the flows. In places matrix material is deformed around fragments and here analcite phenocrysts are broken and subangular.

Plate IV

Plate IV



Contacts with underlying units are poorly defined because of lack of exposures. Where observed south of Lowry Lake analcite basalt has an aphanitic, amygdaloidal margin that grades upwards into a porphyritic rock. The underlying trachybasalt is separated from analcite basalt by a thin layer (2-6 cm) of nepheline-rich, tuffaceous wacke. At Antoine Lake analcite basalt grades upwards from a green, amygdaloidal rock to a red, brecciated flow. The change takes place over 15 m and is indicative of a change from subaqueous to subaerial volcanism.

In thin section analcite basalt and trachybasalt show similar compositions, differing only in the presence or absence of potassic feldspar. Typically both flow types are composed of analcite and clinopyroxene phenocrysts in a groundmass of plagioclase, clinopyroxene, and analcite with accessory apatite, magnetite, and biotite (Plate IV, F). Trachybasalt contains up to 13% potassic feldspar as anhedral grains throughout the matrix.

Prominent phenocrysts of analcite are trapezohedra or subround crystals 2-5 mm, colourless to pale pink and crowded with inclusions of magnetite and apatite. Analcite is weakly birefringent, shows lamellae twinning, and in places has embayed edges. It contains irregular patches of very fine crystalline material thought to represent a decomposition product (Pearce, 1970).

The dominant mafic constituent is diopsidic augite, as prismatic phenocrysts or small granules in the matrix. It is pale green, non-pleochroic with $2V_z$ of 48-53°. Zoning is common, crystals consist of colourless or pale green cores surrounded by darker green rims.

Aegirine-augite is found as grains or acicular crystals throughout the matrix and, more rarely, as pleochroic rims around diopsidic augite. Aegirine-augite is pleochroic from grass green to brownish-green with extinction angles of 12-16°.

Sparsely distributed, tabular plagioclase phenocrysts, or, more commonly, laths in the groundmass are normally zoned with cores as high as An_{71} and rims as low as An_{46}.

Relict phenocrysts of olivine were observed in several flows south of Antoine Lake. They consist of subround areas 1-2.1 mm composed of magnetite, chlorite, and serpentine with granules of olivine scattered throughout, comprising up to 10% of the flow.

Analcite Monzonite (Unit 21, Figure 4)

Five small stocks and several dyke-like bodies of analcite monzonite are exposed south of Antoine Lake. Stocks are circular or elongate in a northwesterly direction, and vary from 1,350 x 300 to 270 x 250 m. Dykes trend northeast or northwest, have steep dips, and range from 1 to 10 m in width. Contact relationships with adjacent rock units are not known because of extensive overburden.

The rocks are greyish-pink, weather a light grey, and are porphyritic with phenocrysts of potassic feldspar set in a fine to medium grained equigranular groundmass. Abundant secondary analcite fills small vugs. The groundmass consists of analcite, clinopyroxene, plagioclase, and potassic feldspar with accessory magnetite, pyrite, specular hematite, and apatite.

Table X: Average Modal Composition of Analcite Extrusive and Intrusive Rocks (Cycle III)

Rock Type	Teschenite	Basalt	Trachy-basalt	Monzonite	Phono-lite
Phenocrysts					
Analcite	8	13	3.5	1	11
Plagioclase	7	-	-	1.2	-
Diop Aug Aeg-Aug	6	12	10	-	-
Olivine	-	4	-	-	-
Potassic Feld	-	-	-	10	13
Matrix					
Analcite	15	10	13	12.5	14.5
Diop Aug Aeg-Aug	17	12.4	14	19	11.5
Olivine	10	5	1.5	-	-
Plagioclase	29	40	41	28	14.5
Potassic Feld	-	-	11	25	35
Magnetite	4.0	4.2	3.0	2.4	1.3
Apatite	0.7	0.5	0.6	1.1	2.0
Biotite	1.2	0.4	0.8	0.4	0.6
Amphibole	-	-	-	-	1.1
Cal Zeol	1.5	0.9	1.0	0.4	-
Sulphides	-	-	-	0.1	-
N*	4	3	2	4	2
An% (Range)	51-64	56-71	46-63	14-26	5-11

N* Number of analyses (Appendix A)

Analcite grains 0.5-2 mm are interstitial to potassic feldspar and plagioclase. They are pale pink, slightly birefringent, and contain small patches of microcrystalline material. Plagioclase and potassic feldspar are similar to those found in nepheline monzonite.

Analcite Phonolite (Unit 23, Figure 4)

Two dykes of analcite phonolite crop out south of Antoine Lake. They vary from 10 cm to 2.5 m in width and can be traced over distances of 10 to 30 m. They are porphyritic with phenocrysts of analcite and potassic feldspar in a pink to brown aphanitic matrix. Analcite phenocrysts are subround to subhedral, rarely occur as trapezohedra, and exhibit corroded edges rimmed by magnetite. Embayed edges are common, and here narrow fractures have reduced the phenocrysts to an aggregate of petal shaped grains. Analcite varies from 2-4 mm in diameter and is clear or pale pink in color, and weakly birefringent.

Potassic feldspar is lath shaped sanidine 2-6 mm, commonly rimmed by albite. It has a 2V of 9-13°.

Matrix material consists of feldspar laths 0.03-0.2 mm, aegirine or aegirine-augite, analcite, magnetite and/or hematite.

Analcite- and/or Nepheline-bearing Lapilli Tuff and Tuff Breccia (Unit 26, Figure 4)

Analcite- and/or nepheline-bearing lapilli tuffs and tuff breccias form extensive deposits north of Abbot Lake, along the Beaver Valley, south of Antoine Lake, and between Quesnel and Alah Lakes. Laterally they are gradational into bedded tuffaceous wackes of similar composition (Unit 25). The pyroclastic rocks appear to overlie all other rock types and are intruded by Cretaceous hornblende porphyry dykes.

Fragments compose 35-75% of the rock, are angular to subrounded, and dominantly accessory in nature. Essential fragments compose up to 10% and are recognized by their fluted or ribbon-like shapes (Plate V, C and D). Fragments vary from less than 1 mm to 2.5 m and show a distinct lateral size sorting north and south of Lowry Lake.

Greater than 75% of the fragments are composed of either analcite- or nepheline-bearing flow (Plate V, A) and intrusive rocks, the greater proportion of these being salic in composition. Other fragment types are augite monzonite or syenite, orthoclase tuffs, lithic wacke, and alkali to trachybasalt.

In hand specimen these pyroclastic rocks are distinctive by the abundance of pink or cream coloured analcite and the reddish-brown color of the matrix.

In thin section matrix material is composed of angular and/or curved crystals or crystal chips of analcite, nepheline, clinopyroxene, plagioclase and potassic feldspar (Plate V, B), which range in size from 0.2 to 6 mm. These are enclosed by a fine brown or yellowish-brown crystalline groundmass, largely of isotropic analcite and containing abundant hematite. The irregular brown patches, 0.1 to 1 mm, contain shard-shaped areas of chlorite, epidote, and zeolites. These are believed to be either essential fragments or devitrified glass.

Along the Beaver Valley the matrix has been replaced by fine grained felts or blebs of chlorite, aegirine, epidote, albite, and sodalite with specular hematite and pyrite.

Analcite crystals are subround or consist of parts of trapezohedra; they are far more abundant than nepheline which occurs as curved or irregular shaped crystals partly replaced by albite and carbonate.

Analcite- and/or Nepheline-bearing Tuffaceous Wacke (Unit 25, Figure 4)

Analcite- and/or nepheline-bearing tuffaceous wackes occur peripheral to feldspathoidal pyroclastic rocks in the Lowry - Alah Lakes region. Here the wackes exhibit quaquaversal dips around pyroclastic deposits suggesting an origin as reworked and water-deposited equivalents of the tuffs. Tuffaceous wacke also bounds pyroclastic rocks southwest and south of Antoine Lake.

Tuffaceous wackes are similar in composition to pyroclastic rocks they flank, differing structurally by their bedded nature and texturally by the rounded to subrounded character of the clasts and grains. Grains are cemented by chlorite, epidote, calcite, and albite giving the rock a pale green or grey-green color (Plate V,E).

Analcite- and/or Nepheline-bearing Volcaniclastic Rocks (Unit 24, Figure 4)

Feldspathoidal volcaniclastic rocks are exposed along the southern edge of Horsefly Lake and form extensive deposits overlying older, volcaniclastic rocks (Unit 13) northeast of Kwun and Usses Lakes. These sedimentary rocks are found north and east of

Plate V

Plate V

A) Photomicrograph of glomeroporphyritic analcite in a fragment of analcite basalt. Matrix is an analcite-bearing lapilli tuff. Plane-polarized light.

B) Photomicrograph of broken analcite and nepheline crystals in an analcite-nepheline-bearing lapilli tuff. Plane-polarized light.

C) Photomicrograph of angular analcite crystals and elongate, tailed, and chilled essential fragments in analcite-nepheline-bearing lapilli tuff. Plane-polarized light.

D) Photomicrograph of an essential fragment from lapilli tuff shown in Plate V, C. Note chilled rim and elongation of amygdules. Plane-polarized light.

E) Analcite-bearing tuffaceous wacke at Lowry Lake.

F) Interbedded analcite-nepheline-bearing siltstone and conglomerate.

Plate V

feldspathoidal pyroclastic flow and intrusive rocks; and strike northeast or northwest with dips of 25-50° NE or NW.

They form bedded successions of alternating siltstone, lithic wacke, and conglomerate (Plate V, F); total thickness is estimated to be 150-200 m. Size and abundance of clasts decreases to the north and east whereas roundness of clasts generally increases. Individual beds vary from 2 cm to 10 m thick with conglomerate forming thicker sequences. Contacts between beds vary from gradational to sharp and irregular with graded bedding, scour marks, and unconformaties common.

Clasts within these rocks are 97% volcanic in origin with the remainder composed of mudstone and limestone. Argillite clasts are found only in conglomerates or lithic wackes that rest unconformably on older, volcanic units.

Clasts vary from less than 1 mm to 10 cm, are subangular to rounded, and comprise 10-20% lithic wacke, 25-60% conglomerates, and less than 5% of sand-sized wackes. They vary widely in composition with analcite or nepheline pyroclastic and flow rocks most common.

The matrix consists of angular to rounded silt- or sand-sized grains of plagioclase, clinopyroxene, analcite, and, more rarely, nepheline. These are cemented by limonite, chlorite, and epidote with minor carbonate.

Stratigraphic Summary

Table XI is a summary of geological events in the Horsefly area during Jurassic time, and Tables XII and XIII are schematic diagrams of rock associations for each of the three volcanic cycles. The sequence of geological events is based on field and petrographic criteria, and the stages described are interpretations based on the general picture of evolving mafic to salic volcanic cycles.

Eruption of alkali-olivine and alkali basalt marked the beginning of the platform stage of Cycle I. These flow rocks have an aggregate thickness of 2,000 m and are estimated to compose 60% of the volcanic succession; individual flows are thin, and can be traced over large areas. Alkali-olivine and alkali basalts have a general northerly or northwesterly trend and are found far to the south and north of the Horsefly area. Their distribution appears to be controlled by northerly faults that can be identified over tens to hundreds of kilometers. Pillow lavas and interlayered sedimentary rocks indicate their marine nature, and thin siltstone or mudstone beds, separating flows, are indicative of the intermittent nature of volcanism.

Alkali and olivine gabbro dykes and sills are situated along east-west or northwesterly-striking faults, and are mineralogically similar to alkali-olivine and alkali basalt flows, suggesting they were feeder dykes for such flows. Mafic pyroclastic rocks and fine to coarse volcaniclastics are deposited in basins adjacent to or within the growing volcanic pile.

Table XI: Summary of Geological Events and Units in the Horsefly Area During Early and Middle(?) Jurassic Time

AGE DECREASING UPWARDS

VOLCANIC CYCLE II — Hydrothermal Stage	Secondary silicates	albite, zeolites, carbonate, chlorite epidote.
	Oxides and sulphides	Hematite, pyrite, trace chalcopyrite (association only with syenodiorite breccias)
VOLCANIC CYCLE II	Volcanic Centre Stage	Nepheline tephrite and nepheline monzonite dykes, Nepheline-bearing syenodiorite intrusive breccias, Nepheline basalt-trachybasalt, flows and dykes, Nepheline and analcite-bearing pyroclastic and volcaniclastic rocks, Erosion of dom stage of Cycle I (perthite wacke).
	Unconformity	~~~
	Late vein Stage (Hydrothermal of Dome Stage)	Zeolites, calcite, epidote Carbonate, chalcopyrite Perthite, aegirine, and pyrite
	Dome Building Stage	Trachyte dykes, Syenite stocks, dykes, and sills, Laharic breccias, Orthoclase-bearing pyroclastic rocks
VOLCANIC CYCLE I — Hydrothermal Stage	Secondary silicates	Orthoclase, albite, biotite, zoisite, epidote, aegirine, zeolites, carbonate, scapolite, apatite, chlorite, fluorite.
	Sulphides and Oxides	Chalcopyrite, bornite, tetrahedrite chalcocite, enargite Pyrite, magnetite, arsenopyrite
VOLCANIC CYCLE I	Volcanic Centre Stage (Central vent	Syenodiorite and monzonite stocks, intrusive breccias and dykes. Zoned syenodiorite-monzonite-syenite stocks. Salic pyroclastic and volcaniclastic rocks. Reefoidal limestones. Trachybasalts; flows and autoclastic breccias.

(continued on next page)

Platform Stage (Fissure eruptions)	Mafic pyroclastic and volcaniclastic rocks. Limestone lenses. Alkali-olivine and alkali basalts; flows, pillow lavas, autoclastic breccias. Olivine and alkali gabbro dykes and sills; feeders for flows(?)

VOLCANIC CYCLE III

Burial Stage	Zeolite facies metamorphism
Erosional Stage	Nepheline and analcite volcaniclastic rocks.
Hydrothermal Stage: Secondary silicates	Analcite, sodalite, aegirine, zeolites, carbonate, albite, chlorite, epidote.
Hydrothermal Stage: Oxides and Sulphides	Hematite, specular hematite, pyrite (associated with analcite monzonite).
Volcanic Centre Stage	Teschenite dykes Analcite basalt-trachybasalt flows Analcite monzonite stocks, intrusive breccias, and dykes. Analcite phonolite dykes. Analcite-nepheline-bearing pyroclastic and tuffaceous sedimentary rocks.

Table XI: (continued from previous page)

Eruptions of trachybasalts marked a change from regional fissure eruptions to central vents and the initiation of the volcanic centre stage (Table XI). Trachybasalts are found within or adjacent to igneous complexes, form relatively thick flows of limited extent, and are estimated to compose 15% of the volcanic succession. In the Lemon Lake area trachybasalts exhibit quaquaversal dips around the igneous complex. This is additional evidence for their origin as central vent eruptives.

Trachybasalts are predominantly flow breccias with fragment types and mineralogy similar to syenodiorite intrusive breccias. These circular or elliptical stocks within intrusive complexes thus could be the source of trachybasalt flows.

Monzonite stocks, sills, and dyke swarms are the most abundant rock units within igneous complexes and are of several, slightly different ages as evidenced by their cross-cutting relationships. Latites are mineralogically similar to monzonites and most likely represent feeders for flows of equivalent composition.

During the volcanic centre stage pyroclastic activity was prominent, as is evidenced by the abundance of salic lapilli tuffs and tuff breccias. Material eroded from pyroclastic deposits and near-surface intrusions was deposited in narrow basins adjacent to the volcanic centres.

During intrusion of monzonite stocks and syenodiorite-syenite composite plutons, a hydrothermal phase formed and separated from the cooling monzonite-syenite magma. This fluid precipitated sulphides and gave rise to the widespread alteration assemblages found within and around volcanic centres, leading to the formation of porphyry and copper skarn deposits within intrusions or along their contacts (Chapter IV).

A late intrusive event is marked by syenite stocks and syenite-trachyte dykes and sills which are estimated to compose 2-3% of the volcanic succession. These are associated with orthoclase-bearing pyroclastic rocks which are the youngest deposits of Cycle I. Hydrothermal activity is also associated with these syenite intrusions (Chapter IV) though alteration assemblages formed at this time are of only local extent and no copper sulphides were precipitated.

The length of time separating volcanic cycles is not known though it must have been relatively short. Syenite stocks formed during Cycle I were being eroded and deposited as sedimentary debris (perthite-bearing wacke) at the same time that nepheline-bearing pyroclastics and tuffaceous wackes were deposited.

Nepheline-bearing rocks are the least abundant members of the Horsefly Group. These vary from mafic (tephrite and basalt) to salic (monzonite and syenodiorite), are primarily small intrusions or extrusions and pyroclastic deposits within Cycle I centres, or are associated with analcite-bearing rocks that are abundant to the west of rocks of the first cycle.

The third volcanic cycle is composed of rocks that contain analcite as a primary, magmatic mineral. Its primary nature is interpreted from:

1) The zoned nature of analcite phenocrysts, and their weak birefringence and twinning (Pearce, 1970),
2) Euhedral and subhedral crystal form, embayed nature of crystals and seriate texture,
3) Occurrence as fragments in pyroclastic deposits, broken crystals in flow breccias,
4) Occurrence of analcite with unaltered plagioclase in teschenites, and with sanidine in phonolites,
5) Presence of fresh nepheline in analcite-bearing rocks,
6) Lack of evidence of replacement by analcite of any pre-existing mineral,
7) Decomposition products within analcite crystals (Pearce, 1970),
8) Presence of secondary analcite that is isotropic, untwinned, and coats microfractures that transect analcite phenocrysts.

In general, nepheline-bearing rocks are older than analcite rich volcanics, though the emplacement of the two types must overlap in time as they occur together in pyroclastic and epiclastic rocks. Analcitic stocks and dykes cut nepheline-bearing rocks but the opposite case has not been observed.

Volcanism during Cycle III was both subaerial and subaqueous as suggested by the red to green color of flows, and the lateral variation of pyroclastics into bedded tuffaceous wackes. The quaquaversal dips of tuffaceous wackes suggest that the aerial volcanism was confined to small, emergent islands. Burial of the volcanic rocks (Late Jurassic (?)) resulted in the formation of low grade metamorphic minerals (prehnite, carbonate, chlorite) (Monger, et al, 1972). These are only locally developed, most abundant along fault zones or in volcaniclastic rocks close to Quesnel Lake, and difficult to distinguish from the hydrothermal, propylitic assemblage. They typically occur as fine grains or clusters of grains which have replaced plagioclase and pyroxene.

Five volcanic centres have been outlined in the Horsefly area (Figure 3, Table I). Criteria for classifying the areas around Lemon Lake, Shiko Lake, Kwun-Hooker Lakes, and Antoine Lake as centres are the presence of:

1) Numerous associated intrusive rock types of various compositions that differ in form from small elliptical or elongate stocks to composite plutons and dyke swarms;
2) intrusive breccias having circular outlines;
3) abundant pyroclastic deposits that vary from crystal tuffs to tuff breccias, and which flank or overlie intrusions;
4) elongate or wedge-shaped deposits of coarse volcaniclastic rocks;
5) tuffaceous wackes, crystal tuffs, and trachybasalts dipping radially away from igneous complexes;
6) Laharic breccias.

Centres are either fault-bounded or flanked by alkali-olivine and alkali basalt, or by extensive deposits of fine to coarse-grained volcaniclastics that are mineralogically similar to rocks composing central complexes.

One area, interpreted as a deeply eroded centre, occurs at Horsefly Mountain (Figure 4). Here hornblende-pyroxene gabbro and diorite are the dominant rock type, accompanied by small, elliptical plutons of monzonite intrusive into the more mafic types. At Horsefly Mountain there is a complete absence of pyroclastic deposits, coarse volcaniclastics, flow rocks, as well as dyke swarms and feldspathoidal rocks, suggesting a deeply eroded volcanic complex.

Table XII: Rock Associations and Magmatic Trends of Cycle I, Letters denote source material for pyroclastic and volcaniclastic rocks.

	(A)	(B)	(C)	(D)	(E)	(F)	(G)
Extrusive Rocks & Cumulates	Ankaramite	?	Alkali-Olivine Basalt	Alkali Basalt	Trachy-basalt	?	Trachyte (Rare)
Intrusive Rocks	?	Olivine Gabbro	Olivine Gabbro?	Alkali Gabbro	Syeno-diorite	Monzonite	Syenite & Trachyte Dykes
	(H)				(I)		(J)
Pyro-clastic Rocks	Mafic Lapilli Tuff - Tuff Breccia; Derived from B to D, minor K				Salic Lapilli Tuff-Tuff Bx; From E to F Minor G;H,K, & L		Ortho-clase Lapilli Tuff F+G
	(K)				(L)		
Volcani-clastic Rocks	Mafic Conglomerate - Wacke, Derived from B to D, & H				Salic Conglomerate - Wacke Derived from E to G, & I		
	(M)			(N)			
Late Erosional Products	Perthite-Bearing Conglomerate-Wacke, Derived from F to G, & J			Laharic Breccia; Derived from G to G, & I to J, & L			

Table XIII: Rock Associations and Magmatic Trends for Cycles II and III. Letters denote source material for pyroclastic and volcaniclastic rocks

		(A)	(B)	(C)	(D)	(E)
NEPHELINE-BEARING ROCKS	Extrusive Rocks & Cumulates	Ankaramite	Basalt	Trachy-basalt	?	?
	Intrusive Rocks	?	Tephrite (Dykes & Sills)	Syenodiorite	Monzonite	?
		(F)	(G)	(H)	(I)	(J)
ANALCITE-BEARING ROCKS	Extrusive Rocks	?	Basalt	Trachy-basalt	?	Phonolite (Rare)
	Intrusive Rocks	Olivine Teschenite (Dykes)	Teschenite (Dykes & Sills)	?	Monzonite	Phonolite Dykes
		(H)			(I)	
COMBINED NEPHELINE & ANALCITE-ROCKS	Pyroclastic Rocks	Nepheline and/or Analcite Lapilli Tuff-Tuff Bx; Derived from B to J			Tuffaceous Wacke, Derived from B to J	
	Volcaniclastic Rocks	Nepheline- and/or Analcite-bearing Conglomerate and Wacke, Derived from B to L, and H to I				

IV: Economic Geology

Introduction

Copper-gold prospects in the Horsefly area, have been divided into four general classes, based on rock associations and mineralogy. The four classes are porphyry, pyrometasomatic, volcaniclastic, and metamorphic.

Porphyry and pyrometasomatic prospects are the most abundant, as well as the most important with respect to size and complexity. Found only within igneous complexes they are spatially associated with volcanic and intrusive rocks of the first volcanic cycle. They are dominantly fracture-controlled, consisting of stockwork systems, vein networks, shear zones, and disseminations.

Porphyry and pyrometasomatic prospects contain similar sulphide assemblages which can be grouped into four distinct types:

1) Bornite + chalcocite ± enargite ± tetrahedrite + magnetite
2) Bornite + chalcopyrite ± tetrahedrite + pyrite + magnetite
3) Chalcopyrite + pyrite ± arsenopyrite ± magnetite
4) Pyrite >> chalcopyrite ± arsenopyrite

Minor amounts of gold are associated with all four assemblages, whereas silver occurs in trace amounts or is absent.

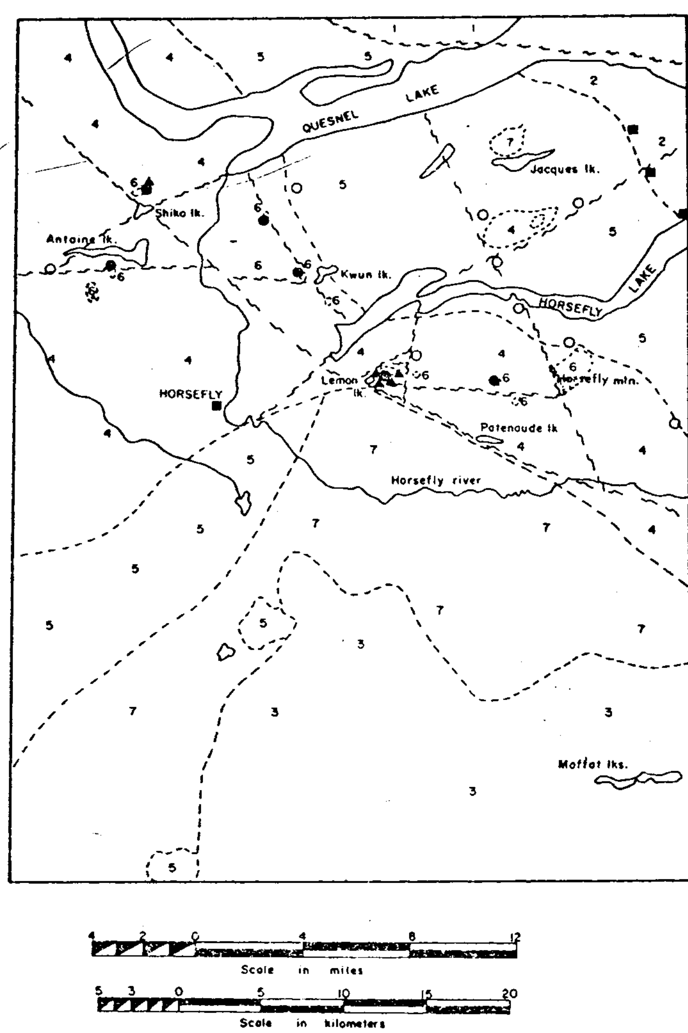
Porphyry prospects are associated with zoned syenodiorite, monzonite, and syenite intrusions at Lemon and Shiko Lakes (Figure 4, 6, and 10, in pocket), with small monzonite stocks at Kwun and

Hooker Lakes, and with monzonite intrusive breccias at Antoine and Lemon Lakes (Figure 4 and 10).

Porphyry deposits can be subdivided into complex and simple types. Complex deposits consist of stockwork systems and disseminations with concentrically zoned sulphide and alteration assemblages. Sulphides occur both in intrusions and in adjacent volcanic and pyroclastic rocks. Examples of this type are the Lemon and Shiko Lake prospects. Simple types are confined to monzonite stocks or intrusive breccias and consist predominantly of vein networks. Sulphide and alteration assemblages are not zoned and consist dominantly of chalcopyrite and pyrite with traces of bornite and enargite. Examples are the Antoine and Hooker Lake prospects.

Pyrometasomatic deposits are developed peripheral to porphyry occurrences with host rocks ranging from alkali and trachybasalt (Lemon Lake) to salic pyroclastics (Shiko Lake) and mafic intrusions (Lemon Lake). This class of deposit occurs as vein networks, disseminations, and shear zones in which sulphide assemblages commonly exhibit cross-cutting patterns that establish age relationships. The locations of known pyrometasomatic showings are given in Figure 10.

Volcaniclastic deposits consist of chalcopyrite, arsenopyrite, and pyrite with minor amounts of sphalerite, galena, pyrargyrite, and gold. They are found as single veins or fracture networks within calcareous argillites and tuffaceous wackes that were



N

LEGEND

TERTIARY

- 7 — Sedimentary and volcanic rocks

JURASSIC - LOWER-MIDDLE

- 6 — Alkalic diorite, monzonite, syenite
- 5 — Volcaniclastic conglomerate siltstone minor limestone and sandy shale
- 4 — Volcanic flow, pyroclastic and coarse grained volcaniclastic rocks
- 3 — Granodiorite and granite

PERMIAN AND EARLIER

- 2 — Argillite, limestone, slate, phyllite

CAMBRIAN AND LATER

- 1 — Quartzite, schist, phyllite

SYMBOLS

- Geological contact
- Fault
- ● Porphyry deposits
- ▲ Pyrometasomatic deposits
- ○ Volcaniclastic deposits
- ■ Metamorphic deposits

FIGURE 10

GEOLOGICAL MAP SHOWING LOCATIONS OF KNOWN MINERAL DEPOSITS deposited in basins adjacent to central volcanic complexes. Host rocks belong to the first volcanic cycle and Figure 10 shows locations of known occurrences.

Metamorphic deposits are found within Cache Creek Group rocks east of the main volcanic belt. Sulphides occur as single or multiple veins and as massive pods or lenses within folded argillites, phyllites, limestones and their higher grademetamorphic equivalents. Metals present are commonly lead, zinc, copper and associated precious metals. Showings are small and not considered to be economically important.

Volcanic and intrusive rocks of Cycles II and III lack copper sulphides, although analcite monzonites and nepheline syenodiorites contain minor amounts of pyrite and specular hematite.

Copper sulphides within the Horsefly Group are thus associated only with rocks of the first volcanic cycle. Except for small showings in volcaniclastic rocks, copper is restricted to alkalic complexes of monzonitic composition.

Lithology and Mineralogy of Mineral Deposits

Porphyry Class:

The Lemon Lake copper prospect is typical of complex porphyry deposits. Sulphides are associated with a zoned syenodiorite-monzonite-syenite stock situated 700 m northeast of Lemon Lake (Figure 6, in pocket).

Within the intrusion and adjacent volcanic and pyroclastic rocks sulphide and alteration minerals are laterally and vertically zoned (Figures 6, 7, and 9, in pocket).

Pyrite associated with a propylitic alteration assemblage (Table XIV), is widespread forming a zone 5 by 4 km that is centered on the defined copper-bearing zone (Figure 9). The pyrite zone has been outlined by surface mapping and induced polarization surveys. It is truncated to the east by a north-south fault and to the north by the Horsefly Lake Fault. The zone continues west of Lemon Lake where lenses of massive pyrite (up to 5 m thick) occur along trachyte-alkali basalt or trachybasalt-lapilli tuff contacts. In places a thin layer of iron-rich carbonate overlies sulphide lenses.

Pyrite and associated alteration minerals are found as coatings on fractures, amygdaloidal fillings, massive lenses, fine disseminations or coarse aggregates. It varies by volume from 0.1 to 15% averaging 3%, excluding the massive lenses which contain 40-80% pyrite. Small amounts of chalcopyrite (up to 0.3%) and arsenopyrite (up to 0.2%) are associated with the pyrite. Chalcopyrite occurs as granules between, or partly replacing pyrite grains, as irregular blebs within mafic constituents, and as aggregates in amygdules. Arsenopyrite is invariably associated with pyrite and forms subhedral crystals or irregular blebs.

Pyrite and chalcopyrite with biotite, magnetite, albite, and minor epidote and orthoclase (Table XIV) form a crescent-shaped zone that is parallel to the outer margin of the syenodiorite

Table XIV: The Relationship of Sulphide and Alteration Assemblages in Different Types of Deposits (see Table XV for list of abbreviations).

Zone	Porphyry Deposits in Composite Stocks	Porphyry Deposits in Monzonite Stocks and Intrusive Breccias	Pyrometasomatic Deposits
Inner Zone	--------------	--------------	(1) Bn+Tet± Enar± Cc Orth, Ep, Aeg, Biot Mt, Ap, Scap, Fl
	(1) Bn + Cp + Tet ± Enar ± Py Orth, Ep, Aeg, Biot Mt, Ap, Scap, Fl	---------------	(2) Bn + Cp + Tet + Py Orth, Ep, Biot, Mt, Alb, Ep
Outer Zone	(2) Cp+ Py ± Tet Biot, Mt, Alb, Ep, Orth, Zois	(1) Cp + Py ± Bn Orth, Ep, Biot Mt, Ap	(3) Cp + Py + Arsn Biot, Mt, Ep, Chl Cb, Alb
	(3) Py ± Cp ± Arsn Alb, Chl, Cb, Zeol Ep, Zois	(2) Py ± Cp Alb, Ep, Cb, Chl, Mt, Zeol	(4) Py + Arsn Cb, Chl, Alb, Ep, Zeol

Table XV: List of abbreviations used throughout the thesis

Act -	Actinolite	Hm	Hematite
Aeg -	Aegirine	Mt	Magnetite
Alb -	Albite	Neph	Nepheline
Anal -	Analcite	Orth	Orthoclase
Ap -	Apatite	Per	Perthite
Arsn -	Arsenopyrite	Py	Pyrite
Biot -	Biotite	Pre	Prehnite
Bn -	Bornite	Scap	Scapolite
Cb -	Carbonate	Sod	Sodalite
Cc -	Chalcocite	Sul	Sulphide
Chl -	Chlorite	Tet	Tetrahedrite
Diop. Aug. -	Diopsidic Augite	Zeol	Zeolite
Enar -	Enargite	Zois	Zoisite
Ep -	Epidote	Dom	Dominant
Fl -	Fluorite	Min	Minor
Hnde -	Hornblende		

(Figures 6, 7, 8, and 9, in pocket). The zone is defined by the development of secondary biotite and the presence of secondary potassic feldspar (Appendix B). It is 2.4 km by 1,350 m in plan and terminated to both the east and north by major faults (Figures 6 and 9). The distribution of the zone west of Lemon Lake is not known due to lack of exposure.

Sulphides are found predominantly as coatings on closely spaced fractures, varying from 0.1 mm to 1 cm in width, and in concentration from 3 to 20 per 10 square decimetres. In areas of intense fracturing sulphide and alteration assemblages form stockworks as well as fine disseminations throughout the syenodiorite. Pyrite:chalcopyrite ratios vary from 1:2 to 12:1 and gold values range from 0.01 to 0.08 ounces per ton.

An inner zone, centered on monzonite (Figures 7, 8, and 9) consists of chalcopyrite and bornite with minor tetrahedrite, enargite, and pyrite. Gold values vary from 0.01 to 0.10 ounces per ton. Associated alteration minerals are orthoclase, epidote, aegirine, and biotite with minor magnetite, apatite, scapolite, and fluorite.

Sulphide and alteration minerals are found as stockworks and disseminations with chalcopyrite and bornite, varying from 0.25 to 3.50% by volume. Chalcopyrite:pyrite ratios vary from 3:1 to 20:1; tetrahedrite and enargite are present as minor constituents. This inner zone is defined by the abundance of orthoclase and epidote, lack of pyrite, and appearance of bornite and aegirine. The width of this zone has not been defined though it appears to be bounded by northwest and northeast faults that transect the stock (Figure 9).

Percussion drill cuttings (H.B.O.G., 1974) indicate a vertical zonation of sulphide and alteration minerals that corresponds to the lateral pattern (Figures 7 and 8). For lack of detailed drilling, the extent of the various zones at depth is not known.

The Shiko Lake copper prospect is another example of the complex porphyry deposit. It is similar to the Lemon Lake copper prospect though alteration assemblages and sulphides are not as widespread.

Sulphide and alteration minerals are associated with a zoned syenodiorite-monzonite-syenite stock located 2,000 m south of Quesnel Lake (Figures 4 and 10). A pyrite zone, some 300 by 450 m, is developed around the northern and eastern portions of the stock. Pyrite, and traces of chalcopyrite and arsenopyrite, are found along fractures 0.02 mm to 1.2 cm wide in hornfelsed volcanic and pyroclastic rocks. Pyrite also replaces mafic fragments and fine matrix material in the pyroclastics, and occurs as amygdaloidal fillings in olivine basalts. Chlorite, zeolites, zoisite, calcite, and albite are associated with the sulphides. Pyrite varies from 0.01 to 10% by volume, averaging 1.5%. The pyrite zone is terminated to the south by a northeast fault that has brought analcite basalt and trachybasalt into contact with Cycle I volcanic and pyroclastic rocks (Figure 4).

Within the intrusion, sulphide and alteration assemblages exhibit a pattern of zonation similar to those at Lemon Lake. The syenodiorite appears to be an extension of the pyrite zone as pyrite, with traces of chalcopyrite and arsenopyrite, occurs with chlorite, epidote, albite, and carbonate. Sulphides are found along narrow fractures and joint planes, and occur as disseminations in areas of more intense alteration. The pyrite:chalcopyrite ratio varies from 2:1 to 20:1 with chalcopyrite found as granules between pyrite grains or as a replacement of plagioclase and mafic constituents.

Chalcopyrite and pyrite with minor tetrahedrite form an intermediate zone that is centered on the monzonite portion of the stock. The zone is defined by the development of secondary biotite and potassic feldspar. Sulphide and alteration minerals are found as coatings on widely spaced fractures, as stockworks, and as disseminations. Disseminated material is most common between closely spaced fractures and the pyrite to chalcopyrite ratio varies from 2:1 to 1:10.

An inner bornite and chalcopyrite zone is associated with the monzonite-syenite core of the stock. The zone is 150 by 300 m and is defined by the presence of bornite and aegirine (Table XIV).

Enargite and tetrahedrite occur in minor amounts with pyrite either absent or present in trace quantities. Associated alteration minerals are orthoclase, epidote, biotite, magnetite, apatite, and fluorite. Sulphide and alteration assemblages occur along fractures and joints and, more rarely, as disseminations. In places chalcopyrite and pyrite are reduced to a limonite rich boxwork.

Copper prospects at Kwun and Hooker Lakes are examples of simple porphyry type occurrences associated with small, monzonite stocks.

The Kwun Lake stock is located 500 m west of Kwun Lake between Lowry and Alah Lakes (Figure 4). It is composed of a narrow, outer zone of syenodiorite which grades into fresh, pyroxene monzonite over distances of 1 to 10 m. The stock is situated along a prominent northeasterly fault and is extremely fractured and sheared.

Chalcopyrite and pyrite, with traces of bornite, are found as fracture coatings within syenodiorite and along syenodiorite-country rock or syenodiorite-monzonite contacts. In areas of more intense fracturing sulphides are disseminated throughout the rock, occurring primarily as a replacement of mafic constituents, or as granules adjacent to secondary biotite, orthoclase, and epidote. Other alteration minerals are magnetite, albite, and chlorite.

Xenoliths or roof pendants of volcanic flow and pyroclastic rocks are found throughout the stock. These vary from 3 cm to 3 m in width and have been extensively altered. Here chalcopyrite, bornite, and pyrite occur as fine disseminations or large blebs.

The property is currently being explored by Fox Geological Consultants and Newconex.

A circular monzonite stock is situated 300 m south of Hooker Lake (Figure 4). The stock is not exposed at surface but was outlined by magnetometer and induced polarization surveys and percussion drill cuttings. It is covered by 7 to 35 m of analcite-nepheline tuffaceous wacke and conglomerate.

The stock is approximately 300 by 400 m in size, composed of pyroxene monzonite, and situated between two prominent north-south faults.

Pyrite with minor quantities of chalcopyrite coat fractures along with epidote, biotite, albite, chlorite, and carbonate. Pyrite varies from 0.2 to 7% by volume, with pyrite to chalcopyrite ratios of 3:1 to 30:1.

The stock is intrusive into fine grained volcaniclastic rocks and alkali-olivine basalt, though contact relationships are not well established. Intruded rocks are moderately fractured, hornfelsed, and contain zoisite, chlorite, prehnite, carbonate and pyrite. Overlying analcite-nepheline-bearing rocks are fresh.

Sulphide occurrences in intrusive breccias are similar to those in small monzonite stocks. Mineralized breccias vary from circular to elliptical and from 1,000 by 300 to 200 by 300 m in size (Figure 4).

Sulphides are either disseminated throughout the monzonite, concentrated around or within mafic fragments, or occur as thin coatings on narrow fractures (0.01 to 0.5 mm in width). Pyrite is the most abundant sulphide (0.3-4%) with minor amounts of chalcopyrite (trace to 0.5%), and bornite (trace to 0.1%). Associated alteration minerals are albite, biotite, epidote, chlorite, and carbonate with minor magnetite, and potassic feldspar (Table XIV). Showings are small, ranging from 15 by 30 to 100 by 200 m with sulphide and alteration assemblages primarily found in the outer portions of the intrusions.

Pyrometasomatic Class

All known prospects of this class are found along the syenodiorite phase of zoned intrusions, along or adjacent to faults. Five pyrometasomatic showings have been outlined at Lemon Lake with one occurrence known at Shiko Lake (Figure 10).

At Lemon Lake pyrometasomatic occurrences vary in size from 30 by 60 to 300 by 260 m (Figure 6) and are extremely irregular in form. Host rocks are hornfelsed alkali basalt, trachybasalt, alkali gabbro, and hornblende diorite. Hornfelsed volcanic and intrusive rocks are composed of diopside and, more rarely, hornblende porphyroblasts in a fine or medium grained equigranular matrix of plagioclase, diopside, garnet, biotite, and magnetite.

The largest pyrometasomatic prospect is situated 250 m south of Chain Lake (Figure 6) along the contact between syenodiorite and a succession of trachybasalt flows. The trachybasalts are cut by numerous syenodiorite and monzonite stringers that range from 1 mm to 3 cm in width.

Both trachybasalts and the stringers are cut and offset by a series of closely spaced, mineralized northwest, east-west, and northeast fractures that increase in abundance toward the syenodiorite contact. Fractures vary from 0.01 mm to 1.8 cm in width and from 2 to greater than 20 per 10 square decimetres.

Sulphide and alteration minerals within fractures show a distinct age relationship based on cross-cutting features and changes in mineralogy (Table XIV). Pyrite in assemblage 3 is partly replaced by chalcopyrite, whereas chalcocite rims bornite, and bornite plus chalcocite replace chalcopyrite in assemblage 2. Assemblage 1 consistently occurs in northwest trending fractures, whereas the other assemblages have east-west, northeast, or northwest orientations. Types three and four are most abundant and widespread.

Within the prospect copper grade is highly variable with adjacent ten foot sections assaying trace, 3%, 0.1%, 1.5%, 0.3%, and trace copper. Chalcopyrite to pyrite ratios vary from 3:1 to 1:15 and metal to sulphur ratios from low to high. Copper-rich areas within the trachybasalt grade north and south into pyrite rich flow rocks containing only traces of chalcopyrite.

Other pyrometasomatic deposits within the Lemon Lake complex have similar mineralogies though are much smaller and less well defined (Figure 6).

The pyrometasomatic deposit at Shiko Lake is situated along the northwest contact of the stock and is 15 by 100 m in size. There chalcopyrite, pyrite, and traces of bornite are associated with biotite, diopside, garnet and epidote that have reacted from and replaced both matrix and fragments of a tuff breccia or lapilli tuff. Temporal relationship of the sulphide minerals is not well established though pyrite and chalcopyrite appear to be older than bornite. Bornite is associated with orthoclase, aegirine, and magnetite, whereas chalcopyrite occurs with biotite, diopside, magnetite, albite and epidote.

Porphyry and pyrometasomatic deposits are closely related, both in time and space. Pyrometasomatic prospects are peripheral to defined porphyry deposits and are developed only along syenodiorite-country rock contacts. Mineralogy and zonation of sulphide-alteration assemblages are similar and inferred age relationships of sulphides in pyrometasomatic deposits correspond to the lateral zonation associated with porphyry prospects.

Sulphide and alteration minerals in both classes of deposit are believed to have formed over the same time interval from solutions having the same source. The pyrometasomatic prospects represent the precipitation of a hydrothermal solution within skarn zones formed by the intrusion of zoned stocks into slightly older volcanic assemblages.

Volcaniclastic Class

Prospects associated with this class are found in argillites and tuffaceous wackes with interlayered basalt flows common. Prospects typically contain silver, or lead and zinc with minor copper, arsenic, and gold. Sulphides are characteristically arsenopyrite, pyrrhotite, chalcopyrite, pyrite, sphalerite, galena, and pyrargyrite. Bornite and chalcocite are rare. Associated gangue minerals are calcite, ankerite, albite, and chlorite.

Most prospects occur as single veins, varying from 1 cm to 6 cm; or as fracture systems that range in size from 1 mm to 1 cm and from 2 to 10 per square foot. Showings are small and widely scattered throughout basins adjacent to volcanic complexes.

Wallrocks show little alteration except for bleaching of argillite and the development of narrow envelopes of chlorite, albite, and epidote adjacent to some veins.

Metamorphic Class

This class of deposit is the least abundant, occurring as pods or narrow fracture zones within calcareous argillite or grey, recrystallized limestone of the Cache Creek Group. Sulphide zones vary from 2 by 5 m to 5 by 10 m and consist of arsenopyrite, pyrite, pyrrhotite, and quartz with or without chalcopyrite and sphalerite.

Conclusions

The formation of porphyry and pyrometasomatic deposits is undoubtably complex, though there can be little doubt that the mineralizing processes are directly associated with the cooling and crystallization of alkalic intrusions of monzonitic composition. With the exception of small volcaniclastic deposits, all copper-gold occurrences in the Horsefly area are found adjacent to or within monzonite stocks, intrusive breccias, and zoned plutons. Younger trachyte-syenite intrusions and older gabbro-syenodiorite stocks and sills contain no associated sulphides.

The location of monzonite stocks in the cores of old volcanic complexes, their similarity to many of the pyroclastic deposits in the area, and their textures lead to the conclusion that they were sub-volcanic and the sulphide associations we now see occur in the lower portion of hydrothermal systems which led to the surface where they may have emerged as solfataras and hot springs.

Field, petrographic, and chemical evidence support the conclusion that copper, and to a lesser extent gold, was concentrated in differentiating alkalic magmas until a monzonitic composition was reached. At this point a hydrothermal sulphide-bearing phase separated, leaving later syenitic magmas depleted in copper.

This relationship is illustrated by Figure 11, where copper, in ppm, has been plotted against Thornton and Tuttle's (1960) differentiation index for extrusive and intrusive rocks of Cycle I. All of the analyzed rocks were first examined under the binocular microscope and in thin section to assure they contained no visible sulphides.

It can be seen that copper content increases from olivine gabbro through alkali gabbro to syenodiorite, reaching a maximum average of 170ppm in monzonite. This value is extremely high for rocks of this composition as they are reported to average only 20-30ppm (Vinogradov, 1962). Younger syenite and trachyte stocks and dykes, and the cores of zoned intrusions contain fifteen times less copper, averaging 12ppm.

Extrusive rocks show a completely different trend with copper content decreasing as differentiation occurs. This implies that either less copper was available to the eruptive magmas, or copper was lost from them due to escape of volatiles. Copper was thus concentrated in the more fluid-volatile and alkali rich phases which were collecting in quiescent portions of a sub-volcanic environment.

Taking the Lemon Lake prospect as a typical example the porphyry and pyrometasomatic deposits are envisioned as forming in the following manner.

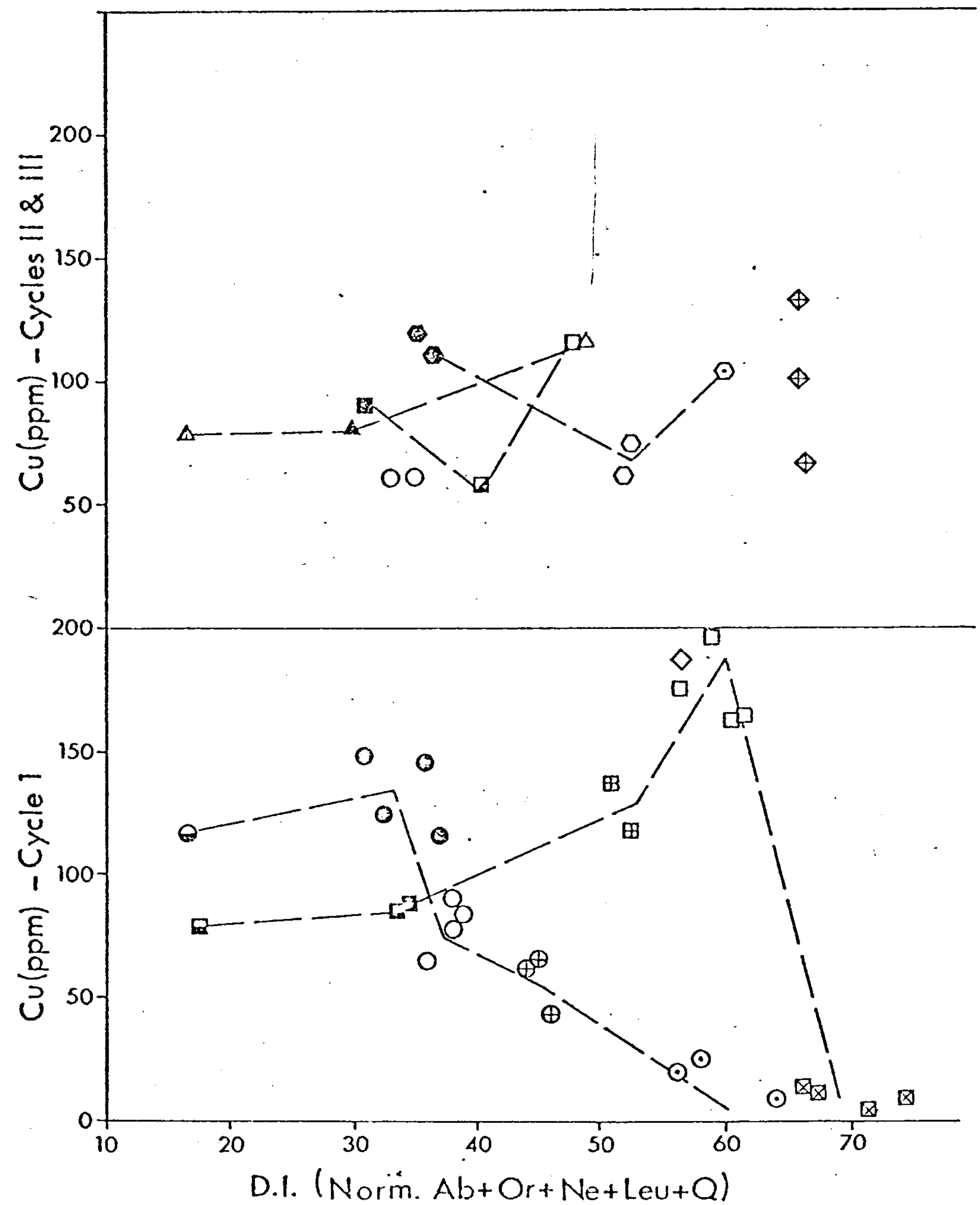


Figure 11: Variation of copper in extrusive and intrusive rocks of the Horsefly Group. See Table XVI for explanation of symbols.

Table XVI: Key to symbols used on variation diagrams

Cycle I

Extrusive	Intrusive
Ankaramite	Olivine Gabbro
Alkali-Olivine Basalt	Alkali Gabbro
Alkali Basalt	Syenodiorite
Trachybasalt	Monzonite
Trachyte	Matrix of Monzonite Intrusive Breccia
	Syenite

Cycle II

Extrusive	Intrusive
Nepheline Ankaramite	Tephrite
Nepheline Basalt	Nepheline-bearing Syenodiorite
Nepheline Trachybasalt	Nepheline Monzonite

Cycle III

Extrusive	Intrusive
Analcite Basalt and Trachybasalt	Analcite Monzonite and Phonolite
Phonolite	Olivine Teschenite
	Teschenite
	Alkali Teschenite

Volcanic and pyroclastic rocks and basic intrusions were extensively sheared, fractured and hornfelsed by the intrusion of a crystallizing body of intermediate magma. The roof and marginal parts of the Lemon Lake stock crystallized to form syenodiorite. At the same time syenodiorite was laterally injected into the country rocks sealing fractures and forming irregular dyke-like bodies.

As the residual magma changed in composition (enrichment of alkalis, settling out of pyroxene and olivine) less mafic rocks formed. The increased volatile content and possibly a reduced cooling rate resulted in a coarser grain size for the monzonite of the intermediate zone. Convective movements within the monzonite zone caused the syenodiorite shell to fracture and monzonitic magma filled these lower pressure zones.

As crystallization of the monzonite neared completion it, along with syenodiorite and adjacent basic volcanic and intrusive rocks were faulted, sheared, and fractured in northwest, north-south, and northeasterly directions. The cause of these extensive movements is not known though they could be due to further movement of magma within adjacent parts of the volcanic complex.

The volatiles and alkalis collecting in the monzonite were released and permeated crystalline monzonite, syenodiorite, and adjacent Horsefly Group rocks. The sulphide-bearing solution(s) moved laterally and vertically along fault zones and fractures crystallizing under changing temperature, pressure and possible pH conditions (Garrels and Christ, 1965).

Changes in composition of the solution(s) is reflected in the lateral zonation and variation in vein mineralogy. Considerable disequilibrium between country rocks and solutions, as evidenced by extensive alteration envelopes, and rapid movement along fault zones explains the rapid precipitation within and cross-cutting nature of veins in the skarn zones.

Sulphide assemblages within the monzonite have high Cu/Fe and metal/S ratios, and associated silicates have high K/Na and K + Na/Ca ratios. Within the syenodiorite zone (Alteration type two, Tables XIV and XV) metal/S and Cu/Fe ratios have decreased, and alteration minerals exhibit a corresponding decrease in K/Na and K + Na/Ca ratios. Solutions would have also become increasingly oxidized as magnetite is now a dominant phase. The pyrite zone contains only minor quantities of copper, abundant pyrite, and alteration assemblages are dominantly calcium- and sodium-rich. Figure 7.25 in Garrels and Christ (1965) illustrates an identical change in sulphide and oxide assemblages with decreasing pH and increasing Eh at 25°C. Pyrometasomatic deposits exhibit all of the above features though these are often superimposed on one another and confined to skarn zones adjacent to major faults.

Solutions are thus envisioned as being basic with base exchange and solution and precipitation type metasomatism predominating.

The alteration assemblages differ from those of calc-alkalic porphyry copper deposits by the absence of quartz, sericite, and abundant clay minerals, and the presence of aegirine and, possibly scapolite. This would indicate a relatively basic solution with high K + Na/H ratios, such that the stability fields of sericite and kaolinite-montmorillonite are not reached. Solutions remain within the stability fields of orthoclase and albite with base cation fixation resulting (Myer and Hemley, 1967). The alteration assemblages thus reflect the alkalic and undersaturated nature of the rocks from which they were derived.

It is also of interest to note that massive lenses of pyrite with traces of chalcopyrite, flank the porphyry and pyrometasomatic deposits. The lenses are found along mafic-salic flow contacts or mafic flow-salic pyroclastic contacts and stratigraphically occur above and lateral to other types of deposits. This, coupled with the presence of thin, iron-rich carbonate layers above them, give them the appearance of small, massive sulphide type deposits.

The lenses form part of the general pyrite zone and appear to represent the surface expression of undiluted solutions which formed, at depth, the porphyry and pyrometasomatic deposits. One can thus envision a whole series of different deposit types forming from the separation of one (or more) hydrothermal sulphide-bearing phase. Porphyry and pyrometasomatic deposits at depth, massive sulphide types at the surface or lateral to the volcanic complex, and epithermal veins which flank the complex (volcaniclastic types?).

Alteration Assemblages

Field mapping and petrographic studies have led to the recognition of four separate and distinct alteration events.

Alteration assemblages are associated with monzonite, syenite, nepheline syenodiorite, and analcite monzonite at Lemon, Shiko, Hooker-Kwun, and Antoine Lakes, respectively. Table XVII summarizes alteration-sulphide assemblages and gives associated intrusive rock type; Appendix B lists individual alteration minerals and their principal mode of occurrence within each assemblage. Where a distinct, lateral zonation can be defined inner to outer zones are labeled as such.

Table XVII: Alteration Assemblages, Sulphides and Associated Rock Types for Various Alteration Events, (see Table XV for list of abbreviations).

Source of Solutions		Inner Zone (1)	(2)	Outer Zone (3)
Cycle I Monzonite	Dom.	Orth, Ep, Aeg	Biot, Mt, Orth, Ep	Alb, Chl, Cb
	Min.	Biot, Mt, Scap, Ap, Fl	Alb, Zois	Ep, Zeol, Zois
	Sul.	Bn, Cp, Tet, Py Enar	Cp, Py, Tet	Py, Cp, Arsn
Cycle I Syenite	Dom.	Per, Aeg	Chl, Zeol, Cb	Cb
	Min.	Ep	Ep, Per	---
	Sul.	---	Py	Cp
Cycle II Nepheline Syenodiorite	Dom.	Alb, Chl, Hm, Ep	---	---
	Min.	Zeol, Cb, Pre	---	---
	Sul.	Py, Cp	---	---
Cycle III Analcite Monzonite	Dom.	Anal, Sod, Aeg	Anal, Cb, Chl, Alb	Cb, Chl, Hm, Zeol
	Min.	Cb, Zeol, Alb	Hm, Sod, Act	Ep, Alb, Anal, Act
	Sul.	Py	---	Py

V: Chemistry of the Horsefly Group

Introduction

A representative suite of rocks from the Horsefly Group was analyzed for major and trace elements. Abundances of major elements were determined by X-ray fluorescence,and trace elements by emission spectrography. Forty-eight samples were analyzed at the Science Laboratories, Durham University; five additional samples and four duplicates were analyzed at Vancouver Geochemical Laboratories. Results of duplicate analyses done at separate laboratories are listed in Table XVIII.

Whole rock analyses, with calculated normative mineralogies, are reported in Appendix C; trace element data are listed in Appendix D. Sample locations are shown on Figure 4.

Samples were first studied in thin section to ascertain their freshness; those showing effects of hydrothermal alteration or containing abundant calcite and/or zeolites were discarded. Samples showing oxidation of the iron-titantium oxides were also excluded from the analyzed suite.

Exceptions to the above generalizations are two samples of monzonite (RM-3, RM-4) and two of syenite (RM-17, RM-18), each showing partial alteration of magnetite and sphene to hematite and leucoxene, respectively. These four samples were otherwise fresh and because they were collected from copper-bearing intrusions were included for analyses. These are the only analyzed samples from the Horsefly Group to contain normative hypersthene and lack normative nepheline.

Table XVIII: Duplicate analyses from independent laboratories for major and trace elements, (in weight per cent and ppm respectively).

	RM - 24		RM - 18		RM -13		RM - 2	
SiO_2	52.46[a]	53.26[b]	59.03[a]	59.71[b]	48.64[a]	48.78[b]	49.31[a]	50.24[b]
Al_2O_3	16.26	16.73	18.27	17.95	12.69	12.82	13.00	13.63
Fe_2O_3	2.11	2.18	1.22	1.29	3.25	3.31	2.08	2.25
FeO	6.02	5.78	3.43	3.30	9.17	9.37	6.19	6.28
MgO	3.05	3.12	2.01	1.94	6.99	7.22	4.26	4.41
CaO	7.61	7.72	3.24	3.10	10.49	10.12	13.30	12.85
Na_2O	5.69	5.98	4.33	4.15	2.78	2.66	3.78	3.72
K_2O	2.02	2.33	6.13	6.38	2.39	2.15	2.66	2.62
H_2O	1.65	1.32	1.3	1.13	2.14	2.02	2.49	2.23
CO_2	1.67	n.d.*	0.00	n.d.	0.06	n.d.	1.16	n.d.
TiO_2	0.75	0.94	0.52	0.55	0.90	1.08	0.98	1.01
P_2O_5	0.44	0.41	0.31	0.36	0.32	0.32	0.52	0.50
MnO	0.26	0.23	0.11	0.14	0.17	0.15	0.28	0.26
Ba	1287	1231	1690	1725	616	600	989	995
Sr	1572	1568	885	881	1084	1108	1410	1381
Rb	30	36	110	110	61	60	45	53
Nb	5	4	6	5	7	3	7	4
Zr	94	103	137	137	63	49	97	103
Y	22	26	29	20	20	20	27	24
Ni	6	4	0	1	80	91	6	8
Cr	12	8	11	10	326	323	17	13
Cu	105	96	13	9	146	133	43	38
Zn	108	106	48	54	101	110	69	42

a Durham University

b Vancouver Geochem Laboratory

* Not determined

Major Element Chemistry

Extrusive and intrusive rocks from each of the three volcanic cycles, are strongly undersaturated with respect to silica, and closely resemble analyzed volcanic rocks from islands along the Mid-Atlantic Ridge (Gough, Tristan da Cunha, Inspiration, and St. Helena). The amount of normative nepheline and olivine is characteristic of the entire Horsefly Group, although modal feld-spathoids are restricted to rocks of the second and third cycles.

The Ne' - Ol' - Qtz' triangle is shown in Figure 12. All rocks from the Horsefly Group plot to the left of the plane of critical silica under saturation (Poldervaart, 1964), including the four samples containing normative hypersthene. In the main, rocks from the second and third cycles plot closer to the olivine-nepheline side of the triangle than first cycle rocks because of their greater proportion of normative nepheline.

The standard alkali-silica diagram, used to differentiate alkalic from non-alkalic rocks, is shown in Figure 13. The diagram incorporates the boundary line between Hawaiian alkalic and tholeiitic suites (MacDonald, 1968); and the dividing lines between alkalic and non-alkalic rocks as proposed by Irvine and Baragar (1972) and Schwarger and Rogers (1974).

All rocks form the Horsefly Group plot well above the three established boundaries. Feldspathoidal rocks mainly have a higher alkali content and contain less SiO_2 than their Cycle I counterparts.

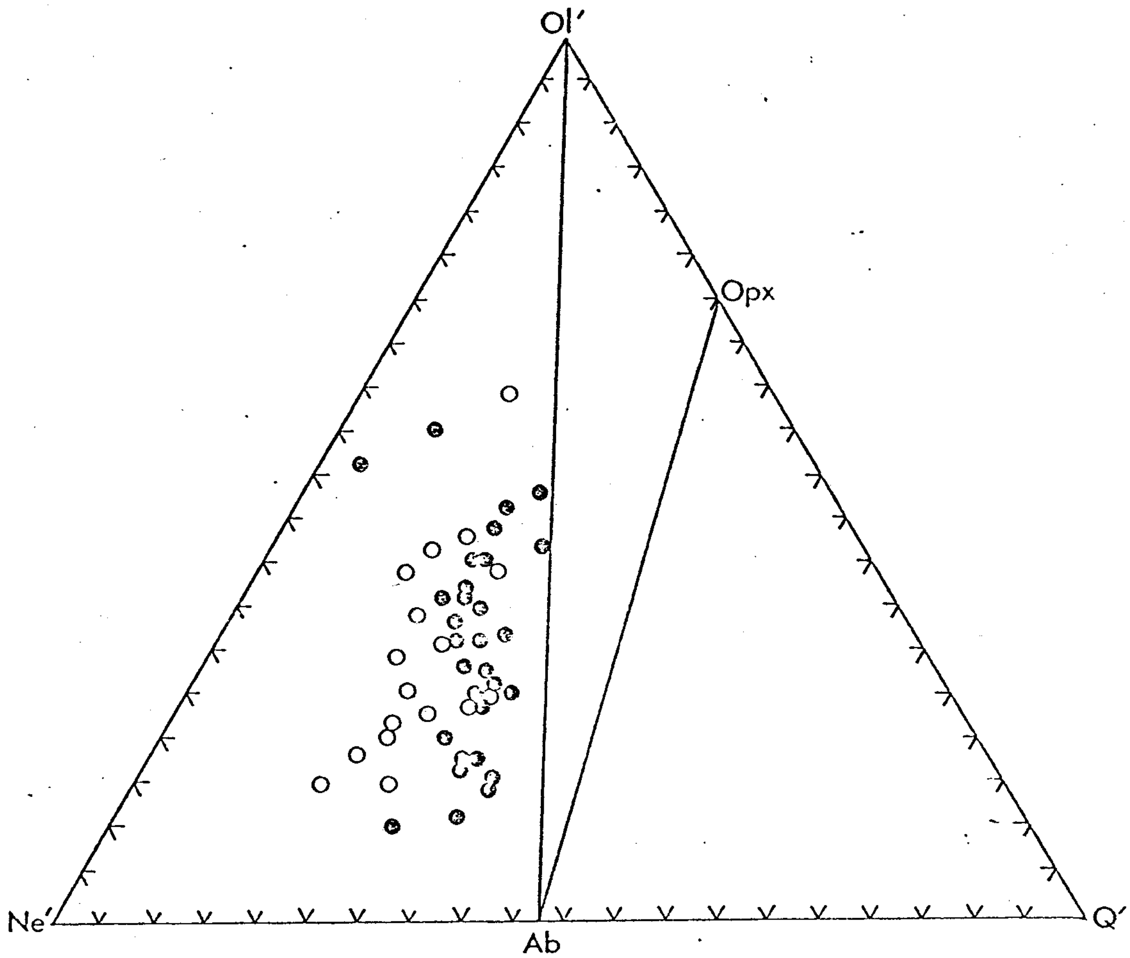


Figure 12: Normative Ne'-Ol'-Q' projection(after Poldervaart) of extrusive and intrusive rocks of the Horsefly Group. Heavy solid line(Ol'-Ab) separates alkalic from subalkalic rocks as defined by Poldervaart. Open circles represent feldspathoidal rocks of Cycles II and III, closed circles represent non-feldspathoidal rocks of Cycle I. Coordinates were determined in the following manner:

Ne' = Ne + 3/5Ab

Ol' = Ol + 3/4Opx

Q' = Q + 1/4Opx

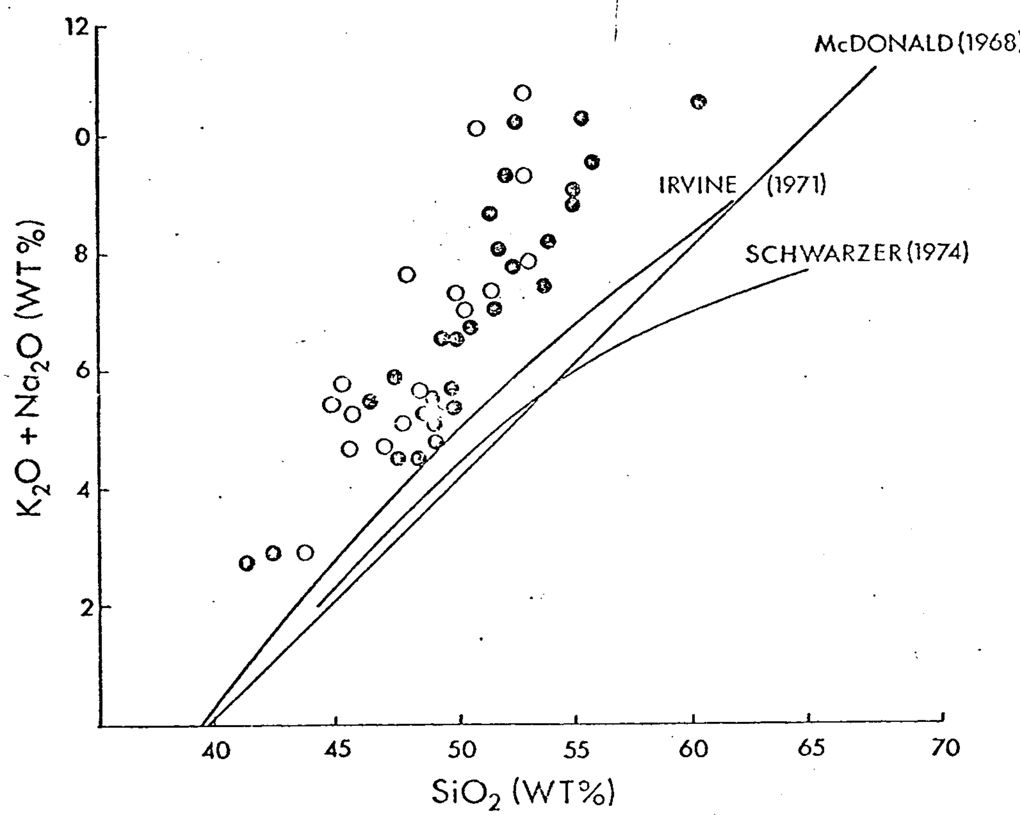


Figure 13: Alkali-Silica diagram for extrusive and intrusive rocks of the Horsefly Group. Open circles represent feldspathoidal rocks, closed circles represent non-feldspathoidal rocks.

Alkali content, for rocks of each cycle, increases rapidly over a narrow range of SiO_2 values from 45 to 55% (Figure 13). A similar trend, shown by volcanic rocks of the Mid-Atlantic Islands, leads directly to trachytes and syenites without excess silica (Baker, 1968).

Figure 14 is a variation plot of SiO_2 against a Differentiation Index (Thornton and Tuttle, 1960). All of the analyzed rocks plot on the undersaturated portion of the diagram, below the anorthite-orthoclase join. The diagram also shows that rocks from Cycles II and III tend to contain less silica than similar Cycle I rocks over the same range of the Differentiation Index.

A standard A-F-M diagram is shown in Figure 15. Lacking enrichment in iron, relative to alkalis, rocks of the Horsefly Group trend towards the alkali side of the triangle. This trend holds true for all three cycles and is quite different from trends shown by tholeiitic and calc-alkalic rock suites (Kuno, 1968).

MacDonald (1968), and Irvine and Baragar (1972), on the bases of normative albite, anorthite, and orthoclase, have divided alkalic rock suites into sodic, mildly potassic and potassic types. A triangular diagram, with the apices represented by these three components, is shown in Figure 16. The solid curve represents Irvine and Baragar's (1972) proposed dividing line for separating sodic from mildly potassic types. With three samples plotting on the sodic side of the curve, and none in the potassic corner of the triangle, it is clear that rocks of the Horsefly Group belong to the mildly potassic series.

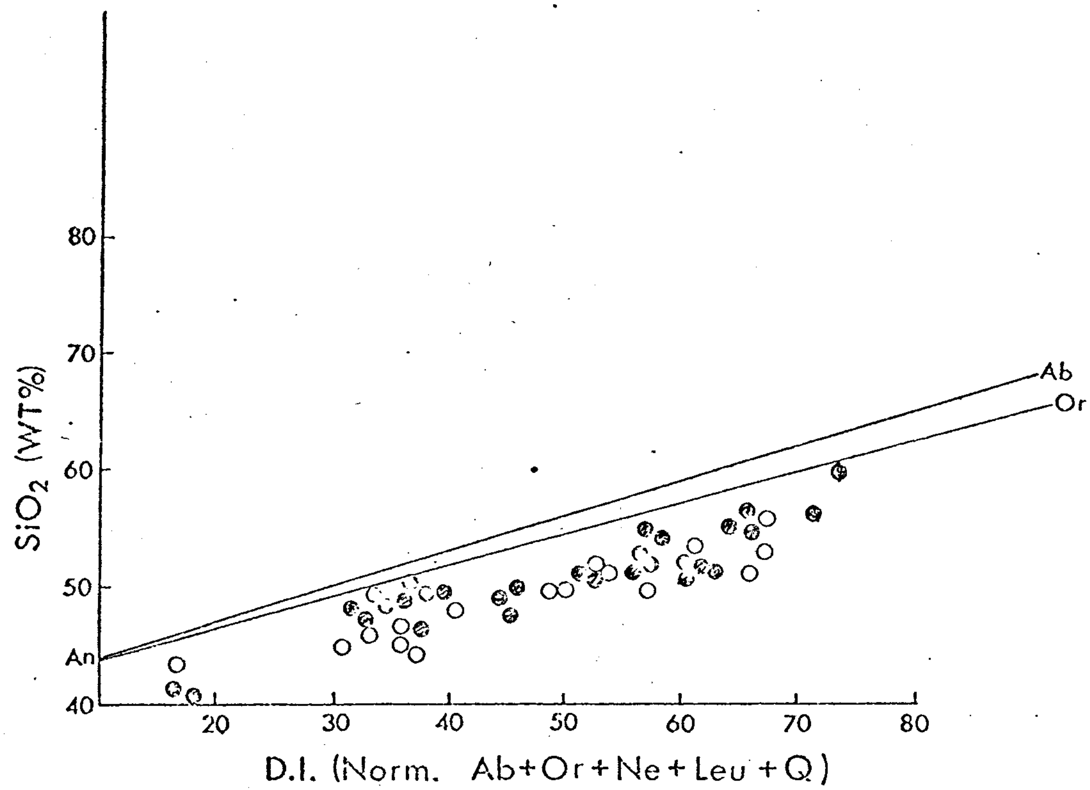


Figure 14: Weight percent SiO_2 plotted against Differentiation Index(Thornton and Tuttle, 1960) for extrusive and intrusive rocks of the Horsefly Group. Also shown is the Thornton and Tuttle saturation line An-Or which separates the field of undersaturated rocks(below) from that of saturated rocks(above), and the saturation line An-Ab which separates the fields of saturated and over saturated rocks. Open circles represent feldspathoidal rocks, closed circles represent non-feldspathoidal rocks.

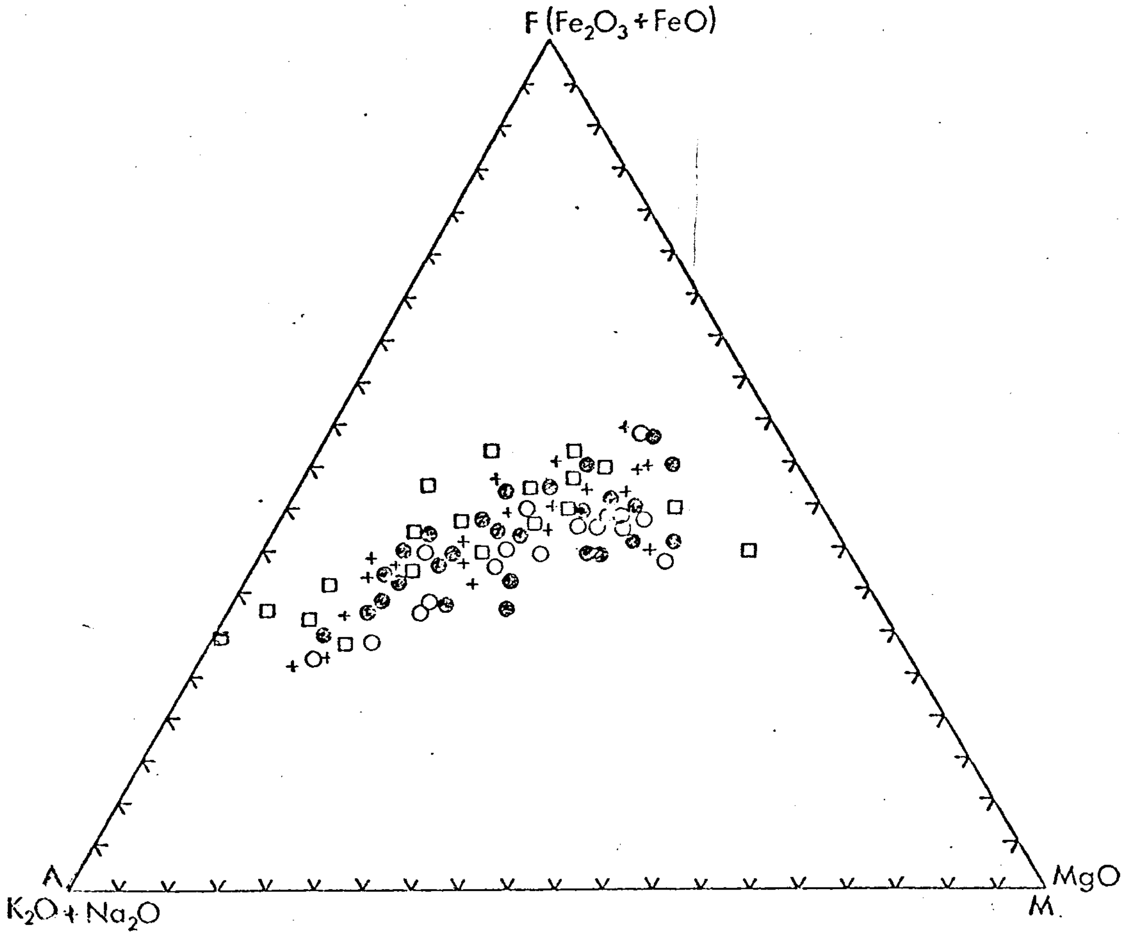


Figure 15: A-F-M diagram for extrusive and intrusive rocks of the Horsefly Group. Diagram also includes rocks from Gough Island(squares), and Tristan da Cunha(crosses). Open circles represent feldspathoidal rocks, closed circles represent non-feldspathoidal rocks.

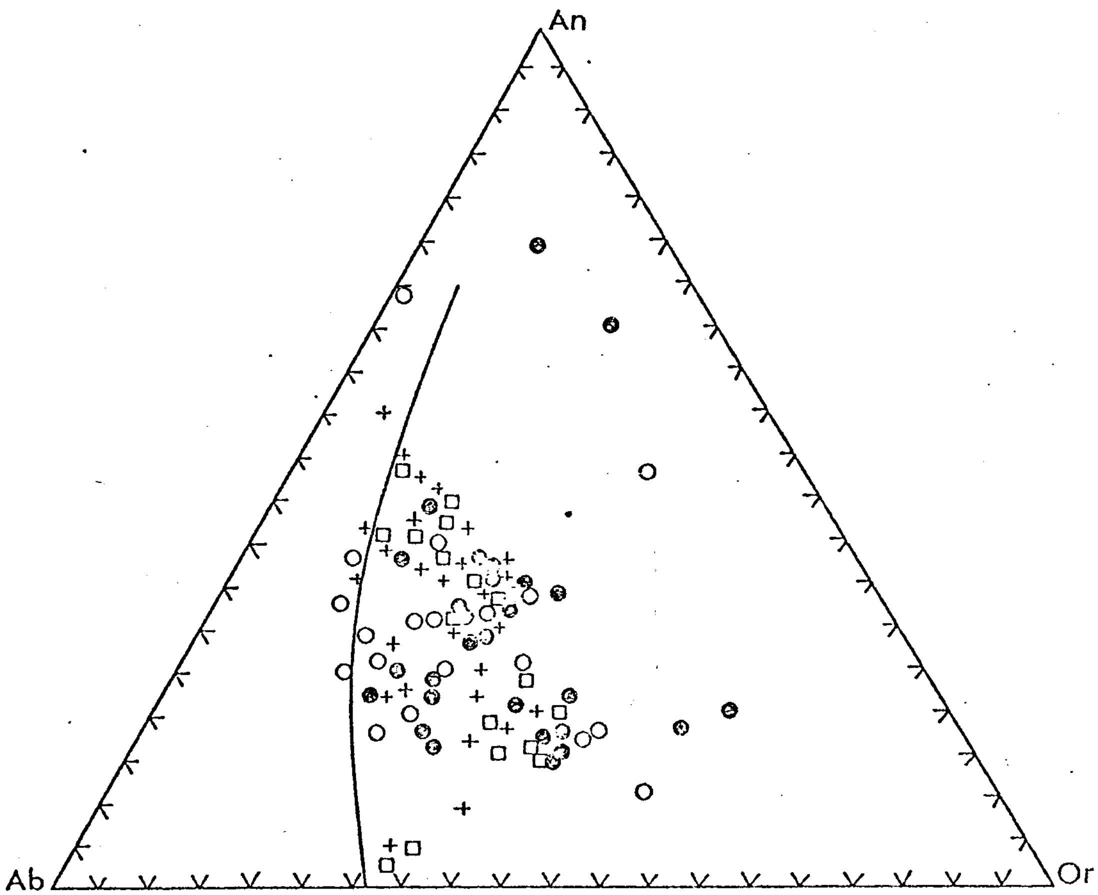


Figure 16: Normative An-Ab-Or projection of extrusive and intrusive rocks from the Horsefly Group. Solid curved line is Irvine and Baragar's proposed dividing line between sodic and mildly potassic suites of alkalic rocks. Also shown are analyzed samples from Gough Island(squares) and Tristan da Cunha(crosses). Open circles represent feldspathoidal rocks, closed circles represent non-feldspathoidal rocks.

4) Folding, metamorphism, and faulting, within the Cache Creek Group, occurred as a result of overriding or collision, and in response to E-W and NE stresses. High geothermal gradients (within zones of maximum stress?) caused partial melting of the Oceanic sequences. This resulted in Late Triassic calc-alkalic volcanism which culminated in the intrusion of 200m.y. plutons.

5) As the rate of overriding slowed and ceased (Late Triassic or Early Jurassic Time) structural readjustment of the Cache Creek rocks occurred (isostatic rebound, faulting). This resulted in rifting and uplift of Cache Creek and Upper Triassic volcanic rocks.

6) The uplift and rifting initiated a cycle of alkalic magmatism which occurred during Early Jurassic to Mid-Jurassic (?) time.

7) Once warping and crustal fracturing of the Cache Creek rocks was established the rift zone became, to some extent self-perpetuating (Baily, 1974); acting as a heat and volatile drain on the underlying mantle.

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APPENDIX A

Modal compositions of extrusive and intrusive rocks composing the Horsefly Group

TABLE 1: Modal Analyses of Extrusive and Intrusive Rocks of the Horsefly Group

	Ankar-amite	Alkali-Olivine Basalt								Alkali Basalt							Trachybasalt					
Sample #	351	189	298	158	73	177	88	314	139	192	47	82	106	333	48	163	98	56	178	352	261	46
Phenocrysts																						
Diop. Aug.	40	17	-	-	5	15	11	5	16	15	11	-	8	10	7	18	14	15	8	-	7	16
Olivine	14	7	11	-	13	7	4	6	9	-	-	-	-	-	-	-	-	-	-	-	-	-
Magnetite	2	-	2	-	-	3	2	-	1	2	-	-	1	2	-	2	-	-	-	-	-	-
Plagioclase	-	4	-	-	10	3	-	8	-	18	13	-	12	24	21	10	30	21	23	28	15	17
An %		74-63			69-58	71-68		66-59		65-57	63		59-48	62-53	57-43	65-59	57	63-49	56	54-45	56-42	61-58
Matrix																						
Diop. Aug.	12	10	21	23	19	11	17	15	12	14	8	21	7	13	11	11	13	13	10	23	19	11
Olivine	13	8	8	16	7	10	10	11	8	8	10	7	4	13	5	6	2	4	6	5	-	-
Plagioclase	14	46	47	52	48	43	52	44	52	35	47	59	37	32	40	47	25	28	29	29	31	45
Potassic Feld.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	11	6	13	9	15	6.5
Magnetite	5	4	3.2	4	5.1	3	4	5	2	3	3.9	4.1	5	3.7	5	4.2	3	3.2	3.4	4.8	3	4.3
Apatite	1	1	0.8	-	1.9	-	-	1	-	1	0.6	0.2	1	0.6	2	0.3	2	1.5	1.3	0.2	2.1	0.4
Calcite	-	-	3	1.3	2	3	-	2	-	1	2.5	-	4	0.7	4	0.2	-	3.3	3.5	2	3.9	0.2
Analcite	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5	2.8	-	4	-
Hematite	-	-	-	-	-	-	-	-	-	-	1	-	2.1	-	2	-	-	-	-	-	-	-
Fine Oxide	-	2	5	3.7	-	2	-	3	-	3	4	7.7	-	3	3	1.3	-	-	-	-	-	-
An % Average	69	64	59	57	54	56	64	66	52	52	49	54	-	54	43	56	50	48	51	47	46	55

Appendix A (cont.)

	Olivine Gabbro			Alkali Gabbro					Hnde. Diorite		Syenodiorite							Monzonite						
Sample #	36	8	340	29	6	2	296	11	80	123	78	176	109	160	213	326	158	19	182	304	246	285	362	16
Diop. Aug.	24	28	26	32	30	27	34	32	15	5	23	21	26	19	19	29	25	17	21	12	26	18	14	16
Olivine	16	13	17	3	8	11	-	6	-	-	-	3	-	3	-	-	1	-	-	-	2	-	3	-
Plagioclase	52	53	47	55	44	51	55	54	46	50	53	48	46	46	58	44	48	43	31	41	28	37	43	49
Potassic-Feld.	-	-	-	3.5	9	6	4.5	3.8	5.4	4	11	15	15	18	18	22	16	32	38	32	39	33	37	28
Biotite	2.6	1.3	4.1	-	3	-	-	-	4.5	8	4	6	8	7	-	-	3	-	3	8	3	5	-	4
Hnde.	0.8	-	1.3	2.1	1.3	-	3.1	-	14	30	2	-	1.8	3	-	1	2	-	-	-	-	-	-	-
Magnetite	5.3	4.7	3.9	3.7	3.8	4.7	3.4	4.2	3.8	2.5	3	3.5	2.6	2.5	3	3	3.6	2	3	2.4	1.7	3.2	2.1	1.6
Analcite	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	0.3
Nepheline	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	1.6	-	1.4	-	0.1
Apatite	0.3	-	0.2	0.7	0.6	0.1	-	-	0.9	0.5	2	1.5	1.4	1.2	2	1.6	1.1	1.3	0.8	1	0.3	1.1	0.9	1
Aeg. Aug.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.7	2.2	5	-	-	-	-
Sphene	-	-	-	-	0.2	0.2	-	-	0.1	-	-	1	-	0.3	-	0.4	-	-	-	-	-	-	-	-
Sulphide	-	-	0.1	-	-	-	-	-	0.2	-	-	-	0.2	-	-	-	0.3	-	-	-	-	0.3	-	-
An %	68	66	70	65	61	59	60	58	56	38	48	47	39	47	41	36	40	37	40	34	36	37	33	42
	61	60	62	54	51	46	45	51	48		31	29	23	39	28	22	29	31	28		28	29	21	30

Appendix A (cont.)

	Syenodiorite					Monzonite						Syenite					
Sample #	141	50	217	371	101	122	308	343	68	262	158	264	63	218	360	52	313
Diop. Aug.	23	26	19	24	21	22	24	19	26	21	17	9	13	7	8	4	14
Olivine	2.1	1.3	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-
Plagioclase	45	51	45	49	53	39	32	36	31	29	43	16	22	27	25	16	31
Potassic-Feld.	19	14	20	16	17	29	38	28	39	36	32	59	46	53	58	66	47
Biotite	6	3.7	11	3	5.4	3	-	8.3	-	5	4	3	11	2	6.3	1	-
Hnde.	-	-	2.4	1	-	-	1.9	2.7	-	1.4	-	-	1	-	-	-	2
Magnetite	3.5	2.6	1.9	3.4	2.4	1.7	1.9	2.1	3.3	2.8	2.5	1.2	0.6	1.7	2.3	0.2	1.3
Apatite	1.4	1.1	0.4	1.7	1.2	2.1	1.8	2	1.6	2.1	1.7	2.0	2.8	2.3	0.4	0.8	2.6
Analcite	-	-	-	0.6	-	-	-	0.5	-	0.4	-	-	0.4	-	-	-	-
Nepheline	-	-	-	0.9	-	2.2	-	2.2	-	2.3	0.8	3.1	-	-	-	1.2	-
Aeg. Aug.	-	-	-	-	-	-	-	-	-	-	-	6.4	3.2	7.7	-	11	2.1
Sphene	-	0.3	-	0.4	-	-	-	-	-	-	-	-	-	-	-	-	-
Sulphide	-	-	-	-	-	-	0.4	0.2	0.1	-	-	0.3	0.5	0.3	-	0.1	-
An %	58	60	57	61	55	44	47	43	38	39	41	19	22	25	15	20	21
	46	40	38	41		26	30	24	27	30	29	7	9	13	7	10	11

Appendix A (cont.)

	Syenite							Latite		Trachyte			
Sample #	79	110	311	44	125	214	49	123	379	85	128	118	229
Phenocrysts													
Potassic-Feld.	14	-	11	21	16	5	-	5	-	11	6	15	19
Plagioclase	9	-	5	-	14	8	-	8	13	-	2	9	3
Diop. Aug.	2	-	-	-	-	-	-	6	7	-	-	-	-
Aeg. Aug.	-	-	-	-	3	-	-	-	-	5	-	6	8
Biotite	-	-	-	5	-	11	-	2	-	-	2	-	-
Hnde	-	-	-	-	-	3	-	-	-	4	5	-	4
Matrix													
Potassic-Feld.	39	56	42	20	34	47	49	25	29	55	45	47	22
Plagioclase	14	28	16	37	18	6	26	33	34	11	23	10	25
Aeg. Aug.	12	4.2	6.3	2.3	9.4	7	5.1	-	4.2	6.4	8	5	7
Diop. Aug.	8.4	3.4	11	4.5	-	-	11	13	9	-	-	-	-
Nepheline	-	2.3	2.4	1.5	-	-	-	-	-	-	-	-	-
Analcite	-	0.2	0.6	-	1.2	-	-	-	-	2.8	-	1.7	-
Hnde.	-	-	-	-	-	6	-	-	-	3.2	2.4	-	9.5
Biotite	-	2.4	2.5	6.7	1.3	6.6	6.3	4.4	-	-	4	3	-
Magnetite	0.3	1.4	0.7	0.4	1.1	0.2	1.2	2.4	2.7	0.1	0.2	0.6	0.3
Apatite	1.7	2.1	2.3	1.6	2.0	1.2	1.0	1.1	0.8	1.5	2.4	2.7	2.2
Sulphide	-	-	-	-	-	-	-	0.1	0.3	-	-	-	-
An %	20	13	10	21	15	22	18	-	39	10	-	12	14
	9			14	6	13	10		26			4	7

Appendix A (cont.)

	Tephrite			Nepheline Trachybasalt		Nepheline Monzonite			Nepheline Syenodiorite			Nepheline Basalt
Sample #	41	245	22	211	281	207	142	273	21	96	17	320
<u>Phenocrysts</u>												
Diop. Aug.	15	12	17	10	16	-	-	-	6	-	-	37
Olivine	-	-	2	-	-	-	-	-	-	-	-	3
Plagioclase	12	11	7	16	13	-	-	-	28	23	32	-
Nepheline	6	5	11	5	6	-	-	3	2	-	3	4
Potassic-Feld.	-	-	-	-	-	-	12	9	-	-	-	-
<u>Matrix</u>												
Diop. Aug.and Aeg. Aug.	14	18	14	9	11	16	17	18	13	17	15	9
Olivine	9	6	11	-	1	-	-	-	-	-	-	3
Nepheline	5	7	6.8	7.5	5.3	14	9	9.6	4	3.5	4.6	4
Potassic-Feld.	-	-	-	9.7	5.4	24	22	19	19	19	13	-
Plagioclase	27	26	23	33	34	39	32	33	24	30	26	30
Biotite	2.5	3	-	-	2.1	1.4	1.7	2.2	-	2.2	1.4	-
Analcite and Zeolite	3.8	4.5	2.6	3.4	2.3	2.1	1.2	1.6	-	1.2	1.6	2.4
Apatite	0.5	0.4	0.8	1.1	0.8	0.9	1.3	1.6	1.1	1.2	1.1	0.1
Magnetite	4.3	4.6	4.1	2.9	3.1	2.4	2.3	2.4	2.6	3.2	3.3	4.5
Sphene	-	-	-	-	-	0.2	-	-	-	-	-	-
Calcite	2.9	2.5	1.7	2	-	-	-	-	-	-	-	3
Sulphide	-	-	-	-	-	-	0.1	-	-	0.1	-	-
An %	61	58	56	52	53	33	38	31	47	39	48	66
						21	29	19	32	33	40	53

Appendix A (cont.)

	Teschenite				Analcite Basalt to Trachybasalt					Analcite Monzonite				Phonolite	
Sample #	289	172	389	92	38	299	287	291	115	254	273	231	268	119	211
Phenocrysts															
Analcite	11	13	8	–	8	14	17	7	–	–	–	4	–	13	9
Plagioclase	8	6	14	–	–	–	–	–	–	–	–	6	–	–	–
Diop. Aug.	10	8	5	–	13	16	8	9	12	–	–	–	–	–	–
Olivine	–	–	–	–	5	–	7	–	–	–	–	–	–	–	–
Potassic-Feld.	–	–	–	–	–	–	–	–	–	9	–	13	17	10	17
Matrix															
Analcite	14	16	13	16	6.2	10	14	13	13	18	11	12	9	11	18
Diop. Aug., Aeg. & Aeg. Aug.	12	13	18	26	15	13	9	16	11	13	22	20	21	14	9
Olivine	18	7	5	11	7	3	5	–	3	–	–	–	–	–	–
Plagioclase	20	27	28	43	41	37	43	38	45	29	23	16	32	9	12
Potassic Feld.	–	–	–	–	–	–	–	13	9	27	40	23	19	37	41
Magnetite	4.6	4.2	3.7	3.6	4.3	4.6	3.9	3.1	2.9	2.8	2.4	3.1	1.5	1.9	0.7
Apatite	0.5	0.8	1.2	0.4	0.5	0.8	0.3	0.9	0.4	1.1	1.3	0.8	1.4	2.1	1.8
Bioti	0.6	1.9	2.3	–	–	1.2	–	–	1.7	–	1.3	–	–	1.2	–
Hnde.	–	–	–	–	–	–	–	–	–	–	–	–	–	0.8	1.5
Calcite and Zeolite	1.3	3.1	1.8	–	–	–	2.8	–	2.1	–	–	1.9	–	–	–
Sulphide	–	–	–	–	–	–	–	–	0.1	0.1	–	0.2	0.1	–	–
An %	62	59	64	60	68	71	67	63	55	61	22	26	14	11	9
	58		53	51	57	59	56	51	46	49	14	16		6	5

APPENDIX B

Petrographic description of alteration minerals associated with Cycles I and III intrusive rocks.

Alteration Products Associated with Monzonite

Type I

Orthoclase: Occurs as rims around plagioclase feldspar or as elongate-irregular blebs along albite twin lamellae or (001) cleavage directions. In places the orthoclase blebs have coalecsed to leave only 'islands' of plagioclase surrounded by orthoclase. Orthoclase is also found as irregular patches (C.1 - 2 mm) throughout the monzonite or as stringers and fracture fillings Here it is associated with various sulphides, aegirine, fluorite, scapolite, epidote, and biotite. Where sulphide minerals are least abundant the rock is frequently 'flooded' by orthoclase and epidote, all pre-existing minerals having been replaced by these two secondary products. The orthoclase has a 2V of 68 to 71° and extinction angles $a \wedge x$ of 7 - 10°.

Biotite: Occurs primarily as flakes or rims around pyroxene or as interleaved patches within orthoclase rich areas. In places biotite and epidote form pseudomorphs after pyroxene. It also occurs in stringers with orthoclase, magnetite and epidote.

Aegirine: Found as acicular or ragged crystals with orthoclase in fractures, veins, and orthoclase rich areas, The aegirine is pleochroic from dark green(Y) to light green (Z), with a 2V of 62-66 .

Epidote: Varies from clear to pale·yellow and is slightly pleochroic. It occurs as individual grains or as clusters and is invariably associated with orthoclase or biotite.

Magnetite: Small grains within or adjacent to pyroxene, also in stringers with orthoclase and biotite. Coats shears where it comprises up to 30% of the alteration products present.

Scapolite: Is uniaxial negative and colourless with second order birefringence. It is found only with orthoclase in stringers and intensely altered monzonite. Frequently in the form of columnar aggregates.

Fluorite: Isotropic with high relief and octahedral cleavage (rare). In stringers with apatite, scapolite and epidote or orthoclase.

Apatite: Occurs in stringers with orthoclase and aegirine.

Appendix B (cont.)

Type II

Epidote: Varies in mode from pale yellow, as in type I, to fine mosaics that contain numerous opaque inclusions. Found dominantly as blebs in plagioclase, mosaics throughout syenodiorite, or along fractures and cleavages in pyroxene grains.

Albite: Varies from clear, partly twinned crystals to crystals full of opaques (hematite), occurs as rims around plagioclase or as patches and blebs in plagioclase, generally having formed along cleavage directions or twin lamellae and spread from there. Also found with orthoclase in fractures along with epidote, and zoisite.

Orthoclase: Occurrence similar to I though areas of flooding are absent.

Zoisite: Colourless with a deep blue interference colour, parallel extinction and high relief. Occurs as irregular patches or aggregates throughout the syenodiorite, associated with albite, and orthoclase. Rarely found with epidote in pyroxene. Zoisite frequently contains pyrite inclusions.

Biotite: Varies from pale green to light brown with a mode that is similar to that in type I.

Magnetite: Same as I.

Type III

Carbonate: Pink in hand specimen, in thin section is found as patches (0.05 to 1.5 mm) in plagioclase, irregular blebs throughout the matrix of volcanic flow and pyroclastic rocks, in stringers with zoisite, albite, and chlorite, as amygdaloidal fillings and rarely as lenses along pyroxene cleavage planes.

Chlorite: Pleochroic pale green to colourless, low birefringence and parallel extinction. Replaces entire matrix of some basaltic flows and gabbros, replaces plagioclase and pyroxene, often forming finger-like lenses that coalesce around these minerals. Occurs in stringers and amygdules with albite, epidote, carbonate, and zeolites.

Albite: In stringers or as a replacement of plagioclase. Also found in amygdules and throughout the matrix of more basic rock types.

Appendix B (cont.)

Epidote: Associated with chlorite, occurring as mosaics of grains in chlorite rich areas, and as individual grains in plagioclase and pyroxene.

Zeolites: Found as fine acicular or clusters of radiating crystals in the matrix of flow rocks. Also in stringers with carbonate, zoisite and chlorite.

Zoisite: Mode similar to that of type II.

Alteration Products Associated with Syenite

Type I

Perthite: Composed of potassium feldspar with an exsolved sodium rich phase. Sodium feldspar comprises 10 to 50% of the potassium feldspar crystal in the form of rods, strings, or elongate blebs. Perthite occurs with aegirine in stringers that transect the syenite and adjacent rock types.

Aegirine: Occurs with perthite, as acicular crystals or ragged clusters. It is pleochroic from pale green to green with a 2V of 61-69° and extinction angles of 3 to 7° c∧X.

Epidote: Found with perthite in stringers, also occurs as a replacement of clinopyroxene and plagioclase adjacent to stringers in volcanic rocks.

Type II

Chlorite: Replaces potassium feldspar and aegirine-augite in syenite, associated with carbonate, zeolites, and epidote in vein envelopes adjacent to perthite-aegirine veins. Small grains of pyrite often occur as inclusions in chlorite.

Carbonate: Grey to pink in hand specimen. In thin section found as blebs throughout syenite, in veins with chlorite, epidote, and zeolites. As a replacement of plagioclase and olivine in basic rocks adjacent to stringers or veins.

Zeolites: Clusters of radiating crystals in veins with chlorite and carbonate. Varies from clear to pale green and yellow in colour.

Appendix B (cont.)

Alteration Products Associated with Analcite Monzonite

Analcite: Pale pink, occurs as irregular blebs which vary from 0.2 to 2mm in diameter, or as narrow stringers alone, or with zeolites, aegirine, and sodalite. Replaces albite, nepheline and potassic feldspar.

Sodalite: Isotropic with a patchy blue colour. Found with analcite as stringers and blebs, also in amygdules where analcite forms the core and sodalite the rims.

Aegirine: Acicular crystals in stringers with analcite, crystals in amygdules, frequently bordering stringers with carbonate and albite, analcite and sodalite form the centres.

Carbonate: Irregular patches in plagioclase, in stringers with aegirine and albite, also with analcite or zeolites. In amygdules with zeolites, chlorite, and epidote.

Albite: Blebs and small crystals in matrix of volcanic rocks, replaces calcic-plagioclase and nepheline. In stringers with carbonate, aegirine, and analcite. In places albite replaces the matrix of volcanic rocks adjacent to analcite intrusives.

Zeolites, Chlorite, and Epidote: Mode much the same as that of Cycle I.

APPENDIX C

Major element chemistry and normative mineralogy

of analyzed samples from the Horsefly Group

Appendix C, Table 1: Major element contents of analyzed rocks from the Horsefly Group. Table 3, Appendix C lists rock types and corresponding sample numbers. Results in weight per cent and all totals vary from 99.01 to 101.10%

Oxides	RM-40	RM-13	RM-30	RM-35	RM-45	RM-33	RM-36	RM-44	RM-21	RM-2	RM-1	RM-23	RM-22	RM-46	RM-49
SiO_2	41.86	48.64	48.39	46.68	47.02	48.83	49.76	49.82	48.01	49.31	47.12	49.46	54.03	53.08	55.18
Al_2O_3	9.67	12.69	12.00	13.38	14.74	13.36	13.84	13.70	14.88	13.00	14.06	12.75	16.51	16.23	16.89
Fe_2O_3	2.95	3.25	2.78	2.84	2.80	2.72	2.39	2.39	2.65	2.07	2.76	1.87	1.68	2.01	1.64
FeO	8.86	9.17	7.83	8.21	7.89	7.74	6.76	6.75	7.55	6.19	8.25	6.26	4.75	5.73	5.32
MgO	8.63	6.99	10.49	9.90	8.30	8.00	7.44	7.72	6.80	4.26	5.89	3.92	4.02	5.71	2.91
CaO	20.32	10.49	10.73	8.25	10.60	9.96	10.70	10.21	10.31	13.30	11.59	14.08	7.13	5.90	5.81
Na_2O	1.99	2.78	2.52	2.85	2.98	2.71	2.99	3.24	2.95	3.78	2.94	4.08	3.85	4.83	4.11
K_2O	0.94	2.39	1.90	2.70	1.45	2.56	2.66	2.18	2.43	2.66	2.88	2.43	4.24	2.48	4.73
H_2O	2.22	2.14	2.18	3.84	1.74	2.33	1.72	2.14	2.01	2.49	2.61	1.76	2.38	2.68	2.01
CO_2	1.18	0.06	0.00	0.00	0.35	0.34	0.37	0.03	0.88	1.16	0.57	1.58	0.00	0.00	0.00
TiO_2	0.90	0.90	0.75	0.93	1.28	0.79	0.73	1.07	0.94	0.98	0.83	0.98	0.74	0.76	0.70
P_2O_5	0.24	0.32	0.21	0.23	0.55	0.39	0.32	0.42	0.33	0.52	0.28	0.51	0.44	0.42	0.53
MnO	0.19	0.17	0.19	0.17	0.19	0.24	0.20	0.17	0.22	0.28	0.20	0.28	0.22	0.15	0.16

Appendix C, Table 1 (cont.)

Oxides	RM-28	RM-38	RM-37	RM-14	RM-26	RM-3	RM-34	RM-50	RM-31	RM-17	RM-18	RM-48	RM-47	RM-39	RM-42
SiO_2	40.64	48.78	49.34	50.67	51.50	51.97	51.43	52.56	52.07	55.29	59.03	56.18	54.17	43.00	46.76
Al_2O_3	15.84	13.58	13.63	14.96	15.15	16.07	15.76	16.23	16.45	16.71	18.27	16.89	16.40	11.60	13.30
Fe_2O_3	3.11	2.73	2.43	2.71	2.58	1.54	2.18	2.10	2.17	1.69	1.22	1.54	1.67	2.89	2.21
FeO	9.00	7.67	6.85	7.72	6.85	6.66	6.28	6.01	6.21	4.81	3.43	5.22	5.01	8.48	9.40
MgO	7.68	7.21	8.39	4.86	5.65	4.17	3.86	3.04	3.08	2.74	2.01	2.81	3.01	6.43	8.61
CaO	13.39	11.83	11.18	7.24	7.84	6.89	6.65	7.62	5.79	5.84	3.24	5.71	5.54	18.08	11.84
Na_2O	1.97	3.46	3.06	3.82	4.28	3.05	3.87	4.15	2.23	4.94	4.33	4.17	3.23	2.84	3.94
K_2O	0.85	1.23	1.96	2.88	2.85	4.96	4.80	3.50	7.05	3.87	6.13	6.03	6.83	0.06	0.93
H_2O	4.44	1.66	1.85	2.72	1.40	2.00	2.12	1.65	3.32	1.44	1.30	0.20	1.80	3.47	2.23
CO_2	0.00	0.00	0.05	0.53	0.51	1.29	1.73	1.67	0.00	1.26	0.00	0.00	0.00	1.45	0.00
TiO_2	1.62	1.10	0.72	1.30	0.94	0.78	0.75	0.76	0.63	0.71	0.52	0.70	0.51	1.23	1.19
P_2O_5	1.23	0.53	0.29	0.35	0.30	0.40	0.38	0.44	0.81	0.46	0.31	0.53	0.78	0.16	0.31
MnO	0.22	0.22	0.21	0.22	0.14	0.21	0.17	0.26	0.18	0.22	0.11	0.12	0.14	0.17	0.18

Appendix C, Table 1 (cont.)

Oxides	RM-32	RM-15	RM-19	RM-25	RM-43	RM-24	RM-6	RM-7	RM-11	RM-29	RM-51	RM-27	RM-20	RM-9	RM-8	RM-4
SiO_2	49.74	45.52	45.35	52.41	51.37	52.46	45.84	48.53	49.96	51.48	53.59	53.25	47.72	47.03	58.06	53.51
Al_2O_3	15.24	13.42	13.45	16.60	16.19	16.26	14.45	14.10	13.86	17.69	18.01	16.50	11.61	14.69	14.23	17.16
Fe_2O_3	2.56	2.94	2.79	1.68	2.02	2.11	2.82	2.62	2.47	1.79	1.76	2.00	2.98	3.19	2.29	1.66
FeO	7.30	8.62	8.09	6.73	6.77	6.02	7.89	7.46	7.04	5.17	5.21	5.63	8.44	8.97	6.55	4.77
MgO	5.31	8.79	8.12	5.06	4.94	3.05	11.53	7.04	6.33	4.12	4.18	3.25	9.73	8.57	4.02	5.18
CaO	8.43	10.27	10.54	6.86	8.03	7.61	9.41	10.01	8.80	4.14	4.20	5.62	10.17	8.72	5.20	5.71
Na_2O	4.90	3.75	3.31	4.47	4.12	5.69	2.60	3.61	5.07	4.55	4.11	4.79	2.89	3.29	3.40	4.62
K_2O	1.64	1.51	2.25	2.31	2.04	2.02	2.59	2.08	2.07	5.51	5.01	5.65	1.59	1.66	1.11	2.72
H_2O	2.14	2.51	3.07	2.15	1.95	1.65	1.43	1.79	2.85	4.39	2.51	1.83	2.30	2.09	3.47	2.45
CO_2	0.90	1.12	1.44	0.00	0.88	1.67	0.02	0.96	0.17	0.00	0.00	0.06	0.12	0.00	0.00	0.90
TiO_2	1.09	0.80	0.91	0.98	0.94	0.75	0.92	1.11	0.79	0.74	0.79	0.58	1.11	1.11	1.11	0.79
P_2O_5	0.51	0.44	0.40	0.49	0.55	0.44	0.26	0.40	0.43	0.48	0.43	0.66	0.34	0.31	0.23	0.41
MnO	0.22	0.28	0.23	0.25	0.19	0.26	0.20	0.15	0.17	0.20	0.15	0.17	0.20	0.26	0.22	0.12

Appendix C, Table 2: Normative mineralogy of analyzed rocks from the Horsefly Group. See Table 3, Appendix C for list of sample numbers and rock types.

Minerals	RM-40	RM-13	RM-30	RM-35	RM-45	RM-33	RM-36	RM-44	RM-21	RM-2	RM-1	RM-23
Qtz	-	-	-	-	-	-	-	-	-	-	-	-
Neph	7.98	3.06	2.94	5.73	2.39	1.79	4.05	2.77	2.58	3.59	2.01	6.83
Or	5.73	14.42	11.49	16.59	8.72	15.48	16.52	13.14	14.62	16.11	17.45	14.63
Ab	2.65	18.40	16.40	14.46	21.24	20.14	15.43	22.89	20.73	26.13	25.56	22.49
An	15.15	15.41	16.14	16.38	22.93	17.14	17.01	16.70	20.60	18.81	18.10	14.75
Diop	48.72	28.89	29.72	19.86	19.94	23.23	27.71	25.76	19.28	19.21	14.35	29.97
Hyp	-	-	-	-	-	-	-	-	-	-	-	-
Ol	11.20	12.29	17.14	20.23	15.80	14.81	10.97	11.43	13.48	7.46	12.47	3.29
Mt	4.42	4.81	4.12	4.28	4.12	4.04	3.53	3.53	3.92	3.07	4.10	2.75
Ill	1.77	1.74	1.45	1.83	2.48	1.54	1.41	2.06	1.82	1.90	1.62	1.89
Ap	0.59	0.76	0.50	0.57	1.33	0.95	0.76	1.02	0.80	1.26	0.68	1.24
Cal	2.50	0.14	0.00	0.00	0.81	0.79	0.86	0.07	2.04	2.40	1.01	3.29
H_2O	2.22	2.14	2.18	3.84	1.74	2.33	1.72	2.14	2.01	2.49	2.61	1.76

Appendix C, Table 2(continued)

Minerals	RM-22	RM-46	RM-49	RM-28	RM-38	RM-37	RM-14	RM-26	RM-3	RM-34	RM-50	RM-31
Qtz	-	-	-	-	-	-	-	-	-	-	-	-
Neph	1.50	0.96	1.97	5.94	4.35	4.32	0.16	2.84	-	2.28	1.80	1.61
Or	25.65	15.02	31.73	5.23	7.38	11.77	17.50	17.15	29.90	28.99	20.02	43.10
Ab	30.62	40.23	30.87	6.48	21.73	18.42	33.19	32.41	26.36	29.20	38.31	16.49
An	15.59	15.70	13.73	33.34	18.19	18.00	15.58	14.14	15.79	11.72	13.19	14.54
Diop	14.42	9.73	5.84	22.58	30.87	29.31	12.79	11.31	6.61	6.83	9.62	8.08
Hyp	-	-	-	-	-	-	-	-	2.22	-	-	-
Ol	7.15	13.14	7.11	15.43	10.02	12.26	12.04	13.17	11.27	11.30	8.53	9.68
Mt	2.49	2.99	2.81	4.71	4.03	3.58	4.03	3.79	2.27	3.22	3.09	3.25
Ill	1.43	1.49	1.30	3.21	2.12	1.39	2.55	1.89	1.51	1.46	1.46	1.24
Ap	1.07	1.02	1.61	3.05	1.26	0.69	0.85	0.71	0.96	0.91	1.05	1.97
Cal	0.00	0.00	0.00	0.00	0.00	0.12	1.24	1.18	2.99	4.02	3.86	0.00
H_2O	2.38	2.68	2.01	4.44	1.66	1.85	2.72	1.40	2.00	2.12	1.65	3.32

Appendix C, Table 2(continued)

Minerals	RM-17	RM-18	RM-48	RM-47	RM-39	RM-42	RM-32	RM-15	RM-19	RM-25	RM-43	RM-24
Qtz	-	-	-	-	-	-	-	-	-	-	-	-
Neph	-	-	1.91	2.71	5.19	9.85	4.17	10.06	7.27	0.51	1.70	12.21
Or	23.20	36.70	35.09	40.10	0.35	3.88	9.89	10.55	13.69	13.97	15.30	14.14
Ab	42.35	37.10	34.82	24.30	10.87	15.48	34.65	14.62	15.50	37.71	35.42	34.82
An	12.19	12.49	12.50	12.32	24.36	17.80	15.07	12.09	15.68	18.77	17.04	11.09
Diop	5.04	1.86	5.30	5.24	44.95	26.65	15.12	26.88	21.25	10.41	11.61	9.68
Hyp	4.17	6.84	-	-	-	-	-	-	-	-	-	-
Ol	5.14	1.47	4.45	6.92	3.54	16.64	11.81	15.87	16.19	13.00	10.71	8.55
Mt	2.49	1.79	2.81	3.05	4.38	4.31	3.80	4.49	4.18	2.50	2.98	3.11
Ill	1.37	0.99	1.30	1.11	2.44	2.21	2.12	1.58	1.79	1.89	1.82	1.44
Ap	1.10	0.74	1.61	1.86	0.40	0.84	1.23	1.08	0.99	1.19	1.32	1.05
Cal	2.91	0.00	0.00	0.00	3.45	0.00	2.09	2.67	3.38	0.00	2.04	3.86
H_2O	1.44	1.30	0.20	1.80	3.47	2.23	2.14	2.51	3.07	2.15	1.95	1.65

Appendix C, Table 2(continued)

Minerals	RM-6	RM-7	RM-11	RM-29	RM-51	RM-27	RM-20	RM-9	RM-8	RM-4
Qtz	-	-	-	-	-	-	-	-	15.12	-
Neph	8.44	3.42	10.01	8.13	8.74	10.55	1.60	3.87	-	-
Or	15.55	12.49	12.58	32.19	31.33	34.01	9.52	10.01	6.77	16.45
Ab	6.77	24.72	25.62	25.23	26.23	21.84	21.83	21.18	29.77	40.05
An	20.37	16.41	9.23	13.02	12.14	6.94	14.23	20.82	20.98	18.53
Diop	20.22	20.48	25.81	4.22	4.79	13.80	27.27	17.29	3.39	1.59
Hyp	-	-	-	-	-	-	-	-	17.33	9.38
Ol	21.79	12.75	10.00	11.70	9.50	7.02	14.81	18.72	-	6.89
Mt	4.15	3.86	3.68	2.71	2.11	2.95	4.39	4.71	3.43	2.46
Ill	1.78	2.14	1.54	1.47	1.38	1.13	2.14	2.15	2.18	1.53
Ap	0.62	0.97	1.05	1.19	1.05	1.59	0.81	0.74	0.57	0.99
Cal	0.05	2.22	0.40	0.00	0.00	0.14	0.28	0.00	0.00	2.10
H_2O	1.43	1.79	2.84	4.39	2.51	1.83	2.30	2.09	3.47	2.45

Appendix C, Table 3: Sample numbers and corresponding rock types for Tables 1 and 2, Appendix C, and Table 1, Appendix D

Rock Type	Sample Numbers
Ankaramite	RM-40
Alkali-Olivine Basalt	RM-13, 30, 35, and 45
Alkali Basalt	RM-33, 36, 44, and 21
Trachybasalt	RM-1, 2, and 23
Trachyte	RM-22, 46, and 49
Olivine Gabbro	RM-28
Alkali Gabbro	RM-37, and 38
Syenodiorite	RM-14 and 26
Monzonite	RM-3, 4, 31, 34, and 50
Syenite	RM-17, 18, 47, and 48
Tephrite	RM-15 and 19
Nepheline Trachybasalt	RM-32
Nepheline Syenodiorite	RM-25 and 43
Nepheline Monzonite	RM-24
Nepheline Basalt	RM-42
Nepheline Ankaramite	RM-39
Olivine Teschenite	RM-6
Teschenite	RM-7 and 11
Analcite Basalt	RM-9 and 20
Analcite Monzonite	RM-29 and 51
Analcite Phonolite	RM-27
Quartz Diorite(Cretaceous?)	RM-8

APPENDIX D

Trace element chemistry of analyzed samples

from the Horsefly Group

Appendix D, Table 1: Trace element contents of analyzed rocks from the Horsefly Group. See Table 3, Appendix C for list of sample numbers and rock types. Results in ppm.

Sample #	RM-40	RM-13	RM-30	RM-35	RM-45	RM-36	RM-44	RM-33	RM-21	RM-2	RM-1	RM-23
Ba	252	616	657	594	728	910	721	890	896	989	994	826
Sr	638	1084	935	915	1020	1367	1096	1221	1065	1410	1281	1252
Rb	17	61	33	64	49	68	57	68	63	45	55	38
Nb	5	7	4	3	4	5	5	5	3	7	2	6
Zr	50	63	42	69	40	54	66	53	66	97	86	101
Y	17	20	16	22	23	18	24	19	21	27	24	25
Ni	124	80	74	69	70	23	29	35	18	6	14	12
Cr	378	326	322	404	317	123	131	107	73	17	26	20
Cu	115	146	148	113	123	65	83	89	79	43	69	63
Zn	76	101	83	97	86	60	45	82	58	69	63	72

Appendix D, Table 1(continued)

Sample #	RM-22	RM-46	RM-49	RM-28	RM-38	RM-37	RM-14	RM-26	RM-3	RM-34	RM-50	RM-4	RM-31
Ba	1165	1216	1248	521	649	738	1086	959	1390	1196	1187	1087	1073
Sr	750	810	830	1333	1007	941	1445	1328	1159	1231	1191	1246	1278
Rb	76	78	81	7	31	53	71	159	111	113	93	61	74
Nb	9	7	9	6	3	4	6	5	6	6	8	7	4
Zr	113	134	117	32	56	40	107	108	138	103	103	94	111
Y	28	29	27	29	23	17	24	22	20	22	24	23	25
Ni	5	11	7	46	29	29	6	2	7	4	3	4	14
Cr	23	11	14	219	129	105	25	19	24	19	8	16	25
Cu	25	21	11	77	84	86	139	119	188	161	198	175	159
Zn	122	87	82	100	94	95	86	55	53	106	87	51	65

Appendix D, Table 1(continued)

Sample #	RM-17	RM-18	RM-48	RM-47	RM-39	RM-42	RM-32	RM-15	RM-19	RM-25	RM-43	RM-24
Ba	1455	1690	1410	1392	135	529	763	1083	1313	841	841	1287
Sr	671	885	793	854	138	900	1072	983	1085	1337	1359	1572
Rb	125	110	120	117	0	38	51	41	40	55	53	30
Nb	6	6	3	3	3	4	5	5	6	6	7	5
Zr	131	137	140	159	40	65	96	52	47	114	116	94
Y	32	29	27	24	13	20	24	18	16	26	29	22
Ni	6	0	1	3	21	59	7	53	47	9	6	6
Cr	9	11	8	11	70	68	31	115	142	20	26	12
Cu	15	13	7	12	79	81	114	120	110	62	73	105
Zn	29	48	39	22	49	71	102	112	88	125	65	108

Appendix D, Table 1(continued)

Sample #	RM-6	RM-7	RM-11	RM-29	RM-51	RM-27	RM-20	RM-9
Ba	591	567	948	1534	1514	1643	376	550
Sr	817	1075	711	999	1034	997	654	685
Rb	65	54	50	84	88	105	35	37
Zr	46	70	53	91	92	59	62	66
Y	19	21	19	25	24	20	24	21
Ni	34	34	20	1	3	2	22	25
Cr	179	86	84	15	11	16	23	94
Cu	92	58	118	136	101	64	63	62
Zn	49	41	84	96	91	115	54	33