PETROLOGY AND GEOCHEMISTRY OF SOME EARLY TERTIARY LAVAS OF THE OKANAGAN LAKE REGION, SOUTH CENTRAL BRITISH COLUMBIA

PETROLOGY AND GEOCHEMISTRY OF SOME EARLY TERTIARY LAVAS OF THE OKANAGAN LAKE REGION, SOUTH CENTRAL BRITISH COLUMBIA

by
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SCOPE AND CONTENTS:

A petrological and geochemical study has been carried out on some early Tertiary lavas of the Okanagan Lake region of south-central British Columbia. Included are a discussion on stratigraphy and petrographic descriptions, along with some chemical investigations of the rocks and a discussion concerning the general problem of petrogenesis. Analytical methods used are explained, and a discussion of the results is included.

ACKNOWLEDGEMENTS

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ABSTRACT

The geology of the Okanagan Lake region of south-central British Columbia is characterized by a very diverse sequence of early Tertiary lava flows and pyroclastic flows, which are slightly deformed in response to tectonic activity which prevailed at the time.

The lavas range from basic to semi-basic to acid composition, with intermediate types, andesites, trachyandesites and trachytes predominating. The stratigraphic distribution of the lavas reveals no consistent trends to either acid or basic compositions.

Evidence from mineralogical and chemical variation indicates that the rocks can be divided into three separate series, namely, the "A", "B" and "C" series. "A" series is similar to the silica-enrichment calc-alkali trend, showing typical mineral and chemical progression from andesites to dacites to rhyolites. "B" series is defined by a two-feldspar group of trachyte and trachyandesite flows. "C" series is less well defined and is characterized by thick flows of analcitic mafic phonolites.

These three series are believed to be genetically unrelated, in spite of their close age and spatial relationships. It is quite possible, however, that the "A" and "B" series are linked by a common parent magma.

The most probable origin for the "A" series lavas is normal magmatic differentiation of a basaltic andesite or andesite parent. The origin of the "B" series lavas is envisaged as being a result of magmatic differentiation of an alkaline basaltic andesite. If the "A" and "B" series lavas are related by a common parent (alkaline basaltic andesite), then the differentiation process was complicated by the segregation of alkalies in the water-rich upper portions of the magma column. Eruption of this portion of the column would leave the residual magma depleted in alkalies and

further differentiation would give rise to the "A" series lavas. The most probable origin of the "C" series lavas is a slow magmatic differentiation of an alkaline basalt at great depth, with possible lime assimilation accompanying the fractionation.

Because the "B" series lavas are intermediate to the "A" and "C" series lavas in composition, it is quite possible that mixing of the "A" and "C" series lavas produced the "B" series lavas.

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CHAPTER 1

INTRODUCTION

The early Tertiary in British Columbia was a time of widespread intrusive and volcanic activity as a result of regional tectonism. In south-central and central B.C., large masses of volcanic rock were erupted from a multitude of fissures and vents. Their eruption was accompanied by uplift, block faulting, tilting, and local folding (Souther, 1967; 1970). This volcanic and tectonic activity subsided in late Eocene time, but was renewed in the Miocene, giving rise to thin sheets of flood basalts of great lateral extent. The lavas have since been dissected by more recent glaciation and weathering processes.

Fig. 1 shows the distribution of early Tertiary volcanic rocks in British Columbia. This study deals with a small section of the Kamloops-Midway Province, which consists of a complicated sequence of volcanic rocks varying a great deal in composition. Many geologists have noted the presence of these lavas, but very little information regarding their petrological character is available. It is the purpose of this study to examine the mineralogy and chemistry of some of these lavas in order that some ideas may emerge concerning the compositional variations of the lavas, as well as their origins.

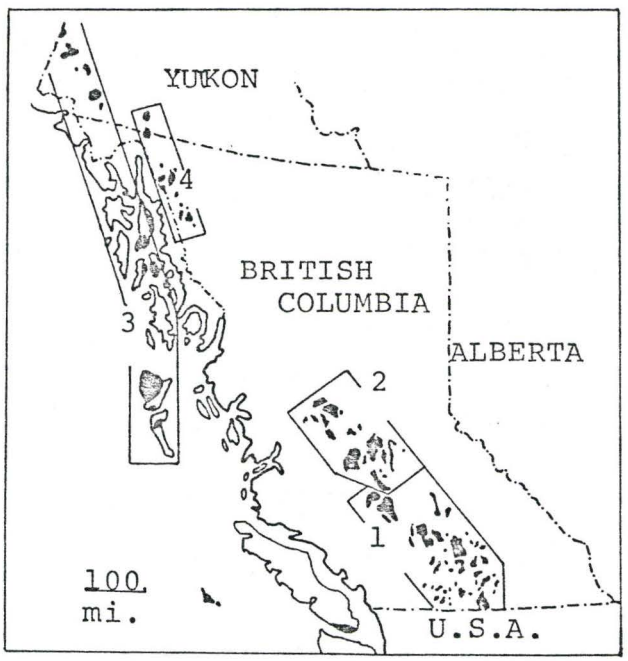
LOCATION AND ACCESSIBILITY

The study area is in the Okanagan Lake region of south central British Columbia, and is a part of the Kamloops-Midway volcanic Province. The area is bounded by coordinates $48^{\circ}00'N$, $50^{\circ}00'N$, $118^{\circ}30'W$, $120^{\circ}00'W$. It is subdivided into 4 sampling areas, namely, the Kelowna area, Summerland area, Skaha Lake region, and Rock Creek area (Fig. 2). Accessibility to all the sampling areas is very good by major highways, gravel roads, and logging roads.

SAMPLING

Sampling of rock specimens was carried out by Dr. B. N.

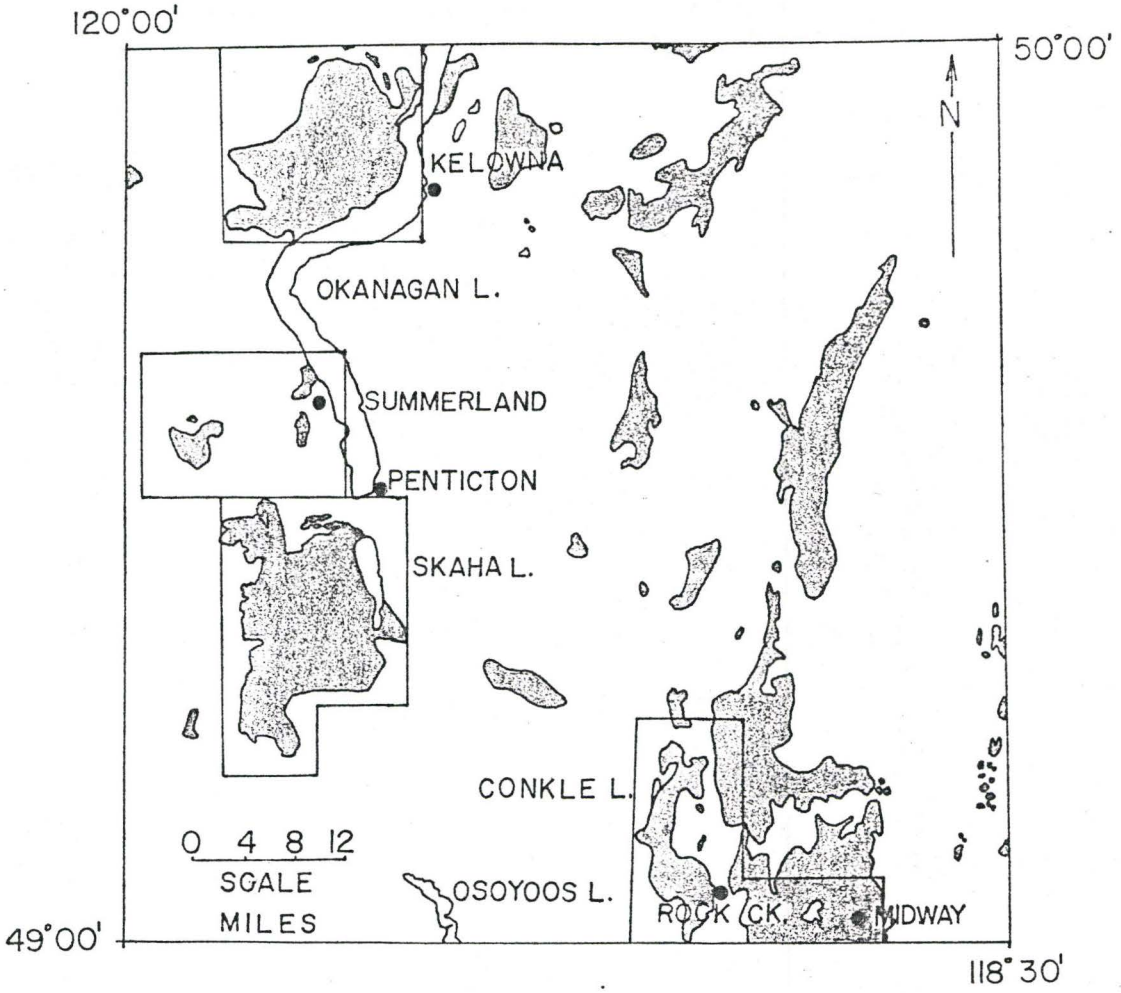
Fig. 1 DISTRIBUTION OF EARLY TERTIARY VOLCANIC ROCKS IN BRITISH COLUMBIA



1. Kamloops-Midway Province
2. Ootsa Lake Province
3. Queen Charlotte-St.Elias Province
4. Sloko Province

(From Souther, 1967)

Fig. 2 THE OKANAGAN LAKE REGION, B.C.



Church of the B.C. Dept. of Mines and Petroleum Res. in the summer of 1977.

PREVIOUS WORK

The volcanic rocks of south central B.C. were first reported by Bauermann in 1884. It was not until the late 1800's and early 1900's that the area became geologically important as local gold and copper deposits were discovered. In 1901-02, Brock mapped a 13-mile wide belt extending from Grand Forks to Midway and in the six years that followed, Daly mapped a 5-mile wide strip along the 49th parallel. In his report (1912), he briefly describes the petrography and stratigraphy of an early Tertiary sequence at Midway. Correlation of the Tertiary volcanics began in 1912 when LeRoy correlated a sequence of Tertiary rocks with Daly's Midway sequence. Reinecke (1915) also suggested a correlation of volcanics in the Beaverdell area with the Midway suite. Bostock (1926-30) first defined the Tertiary "Marron" volcanic sequence when he mapped and studied the geology in the area bounded by coordinates $49^{\circ}00'N$, $49^{\circ}30'N$ and $119^{\circ}30'W$, $120^{\circ}00'W$. Cairnes (1936) first examined the Tertiary rocks near Kelowna in detail. Little (1957) mapped and described the geology of the Kettle River area bounded by coordinates $59^{\circ}00'N$, $50^{0}00'N$ and $118^{\circ}00'W$, $119^{\circ}00'W$. In the two years that followed, he continued to map and study the geology of the Kettle River area bounded by coordinates $49^{\circ}00'N$, $50^{\circ}00'N$ and $119^{\circ}00'W$, $120^{\circ}00'W$. The first detailed petrological study of the early Tertiary lavas was carried out by Church (1963). Bostock (1966) studied one particular Tertiary volcanic unit, namely, the Shingle Creek Porphyry. Church (1973) mapped and studied in detail the geology of a 70 square mile area about 8 miles south of Penticton. In his report entitled The Geology of the White Lake Basin, the stratigraphy, structure and petrology are dealt with in detail.

GENERAL GEOLOGY

Fig's 3, 4, 5 and 6 depict the geology in each of the sampling areas outlined in this study.

The oldest rocks in the Okanagan Lake Region are those of the Shuswap terrane (Map unit 1). They are pre Cambrian in age and consist largely of layered gneisses, and locally, less metamorphosed sediments. The two major groups of the Shuswap terrane are the Monashee Group and the Chapperon Group, which are both intruded by younger, serpentinized ultrabasic rocks of the Old David Intrusions.

The Paleozoic rocks consist largely of sediments, metasediments, and minor intrusions of diorite. They include greenstone, argillite, chert, limestone, quartzite, and greywacke units (Map unit 2). The ages of these rocks is based largely on fossil evidence and faulting has made correlation a difficult task.

Upper Paleozoic sediments of the Permian grade into Mesozoic sediments of the Triassic and Jurassic (Map unit 2). These rocks also include greenstone, argillite, limestone, tuff and schist. They are intruded by ultramafic rocks of late Jurassic age (Map unit 3).

Upper Mesozoic rocks consist of the Nelson and Valhalla acid plutonic rocks (Map unit 4). They intrude the underlying sediments and meta sediments and are believed to be Cretaceous in age.

The Tertiary rocks of the area consist largely of extrusive flows and lesser amounts of sediment. They lie unconformably on the Cretaceous (?) plutonic rocks and pre Jurassic sediments and metasediments. The lower Tertiary units consist of conglomerates, sandstone, shale and tuff (Map unit 5). Overlying these, and believed to be contemporaneous, are the Paleocene or Eocene porphyritic granites and rhyolites (Map unit 6a).

Map unit 6 consists of shallowly dipping to flat lying undeformed bedded volcanic flows of phonolitic, trachytic, andesitic and dacitic composition. Unconformably overlying them are sediments. Fossil and radio-isotope evidence for these rocks indicate they are Paleocene or Eocene in age (Church 1963). These rocks are intruded in many locations by the Coryell Plutonic

rocks which are believed to be Oligocene in age (Map unit 7).

The Miocene plateau basalts which commonly show columnar jointing, are thin flows with great lateral extent and unconformably overlie the Coryell plutonic rocks and the early Tertiary volcanics and sediments.

A thin blanket of Pleistocene deposits and Recent alluvium cover the uppermost rocks.

The general lithological sequence of early Tertiary volcanics in the Okanagan Lake region is very similar to those found in other regions of south-central B.C., which contain early Tertiary rocks (Church, 1963). This evidence, along with radioisotope data suggests that contemporaneous widespread volcanic activity took place in southern B.C. during early Tertiary times.

The entire area has also undergone structural deformation due to extensive tectonic activity. A chain of large zigzag faults occurs along the Okanagan Valley, and serves to separate the metamorphic rocks of the Shuswap terrane from the younger Paleozoic and Mesozoic sediments. Structural data on the faults is limited, but they are believed to be steeply-dipping. Although they are presumed to be normal dip-slip faults, it is possible that they may also be strike-slip in nature. In either case, evidence of intense shearing exists, suggesting that displacements must be large (Map 15 – 1961).

The sequence of Tertiary volcanic rocks are also structurally deformed. In the Kelowna area (Fig. 3), the bedded flows are essentially horizontal. Many vertical faults are present and strike dominantly in a northerly direction, and downthrow is normally to the east (Church, 1963).

In the Rock Creek area (Fig. 6), the Tertiary strata have been folded into a broad, open, northerly-trending and shallow-plunging synformal structure, with an undissected east limb and a west limb dissected by north-south trending, steeply-dipping faults (Church, 1963).

In the Skaha Lake and Summerland regions (Fig's 4 and 5), rocks are folded into an open syncline with both normal and strike-

slip faulting being evident (Church, 1963). A large proportion of the strata remains near horizontal, and the severity of deformation appears to have been quite variable throughout this area.

LEGEND TO MAPS ON PAGES TO FOLLOW

TERTIARY

Miocene:

[8] Basalts

Oligocene: (?)

[7] Coryell Plutonic Rocks: Syenites, granites, monzonites, shonkinites.

Oligocene, Eocene:

[6] Bedded Flows: Phonolites, trachytes, andesites, dacites.

Eocene, Paleocene:

[6a] Porphyritic granite and rhyolite.

[5] Conglomerates, sandstones, shales, tuffs.

CRETACEOUS

[4] Valhalla and Nelson Plutonic Rocks: Granites, granodiorite, diorite, quartz monzonites, monzonites, syenites.

JURASSIC

[3] Pyroxenite, hornblendite, serpentinite.

TRIASSIC, PERMIAN, PENNSYLVANIAN

[2] Greenstone, tuff, quartzite, argillite, greywacke, limestone.

PRE PERMIAN

[1] Gneiss, schist, amphibolite, quartzite, marble, pegmatite.

Geological boundaries. (Defined, approximate) -----

Strike and dip ----------

Faults ----------

Fig. 3

KELOWNA REGION

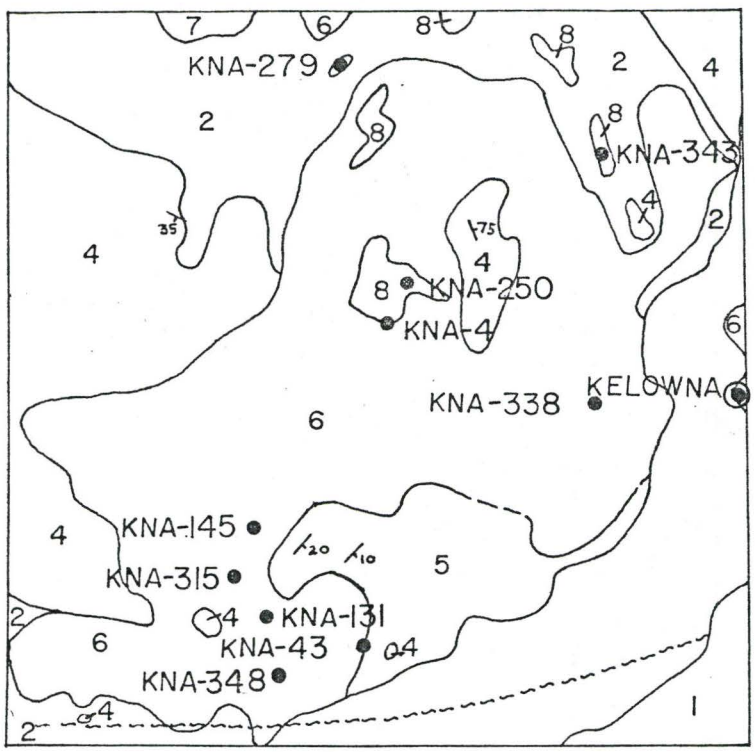


Fig. 4

SUMMERLAND REGION

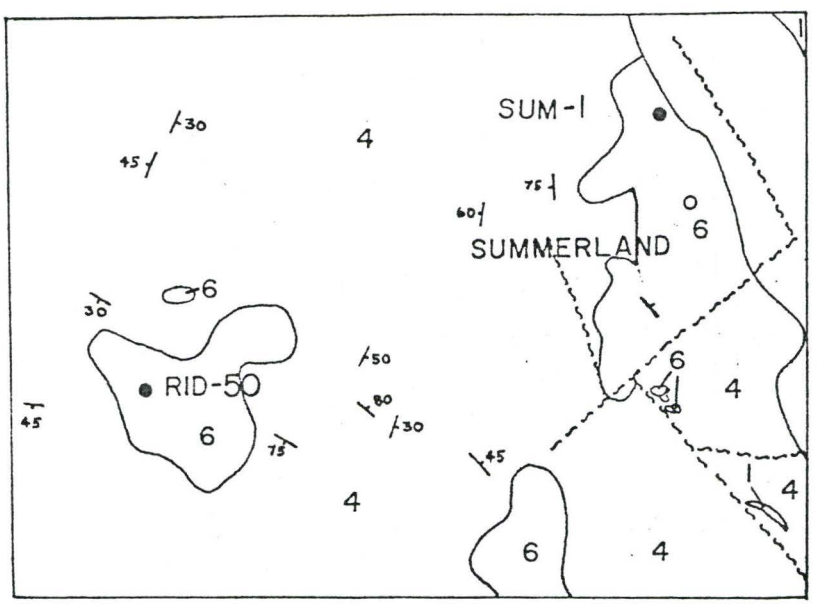


Fig. 5

SKAHA LAKE REGION

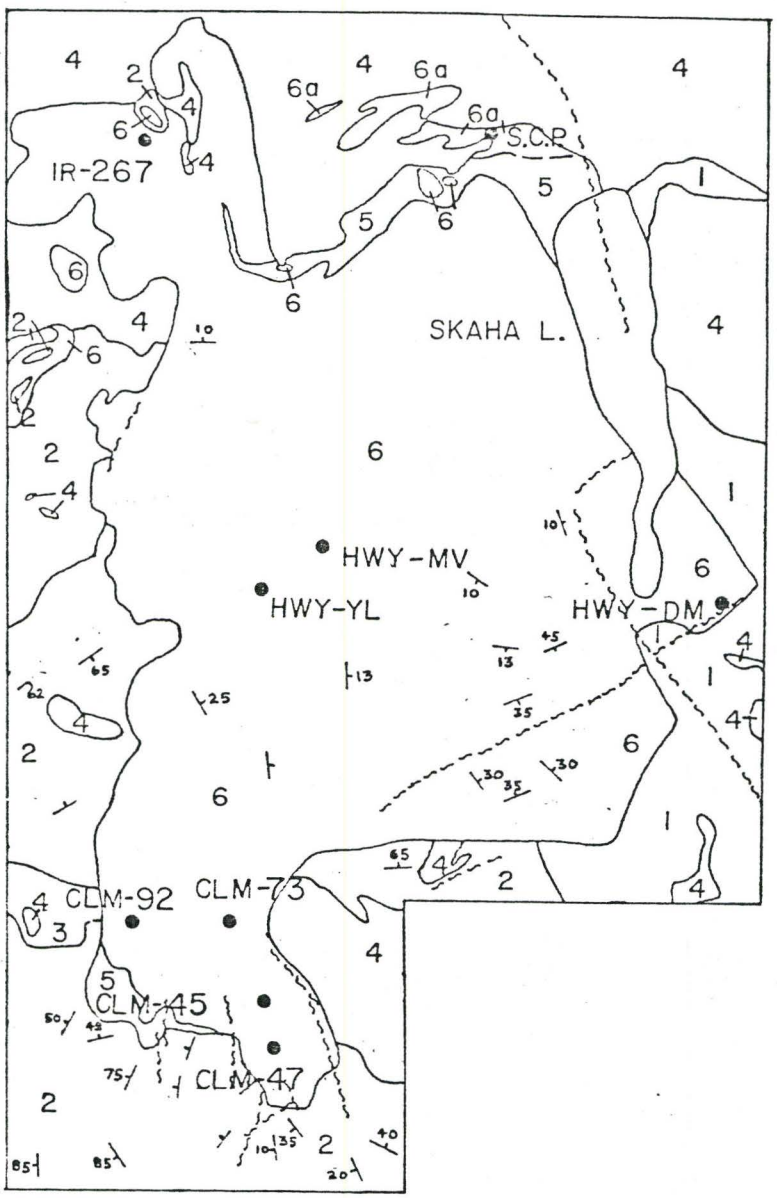
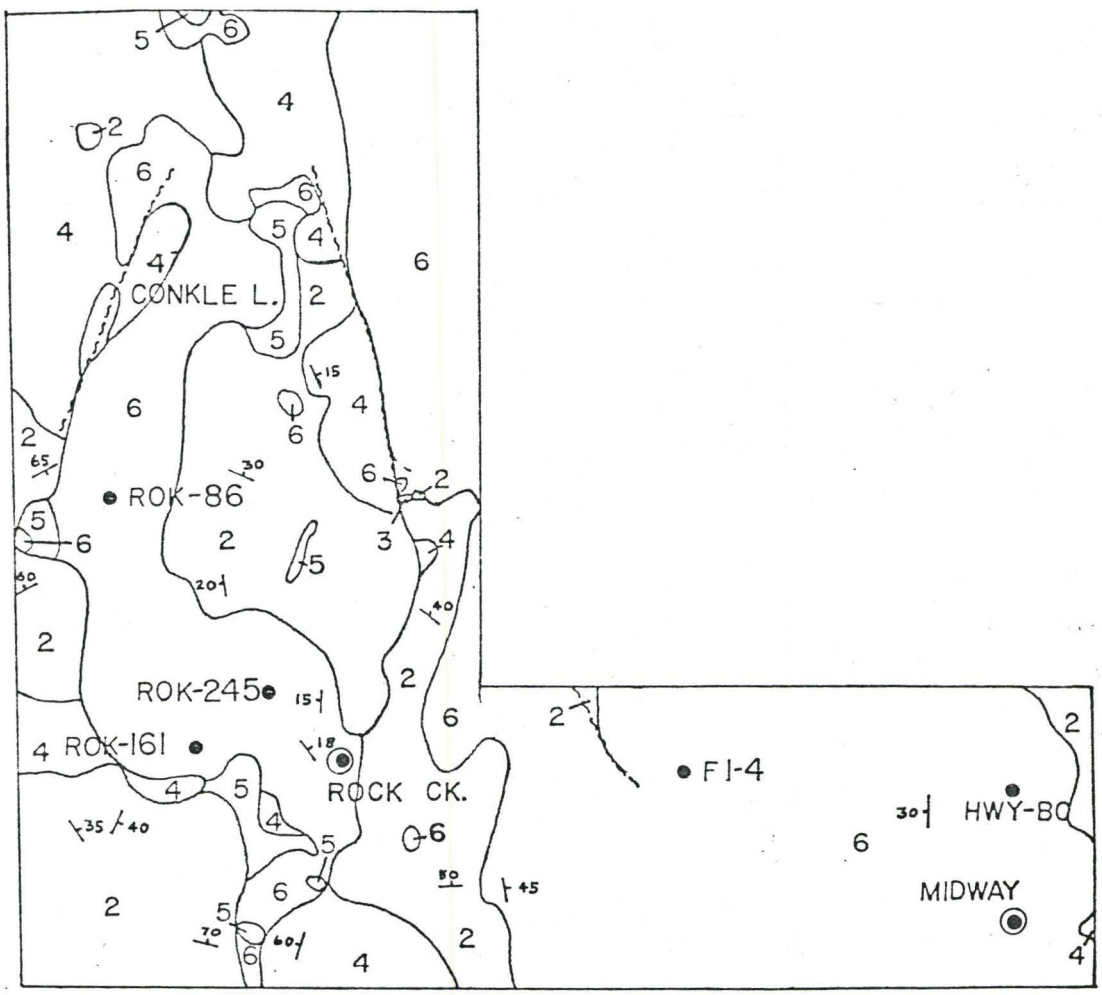


Fig. 6

ROCK CREEK REGION



CHAPTER II

STRATIGRAPHY

Fig. 7 is a representation of the general stratigraphy of the early Tertiary volcanic rocks. Not all units are present in the four sampling areas, and the thicknesses of the individual units may vary considerably from one location to another. The stratigraphic section was based on known maximum thicknesses. The base of the Tertiary sequence is characterized in all areas by a thick unit composed of conglomerate and sandstone, usually containing fragments of the underlying pre-Tertiary complex (Church, 1963). These sediments are referred to as the Springbrook Formation locally, but are better known as the Kettle River Formation (Church, 1973; Daly, 1912).

Lying unconformably on top of the basal sediments is the Trepanier basal rhyolite. Their occurence has been reported in all four sampling locations (Church, Personal Communication, 1977), but no reliable data on the thickness of these flows has been obtained. Overlying the basal rhyolites is the Marron Formation which consists of the Yellow Lake Member, the Kitley Lake Member, the Kearns Creek Member, the Nimpit Lake Member, and the Park Rill Member.

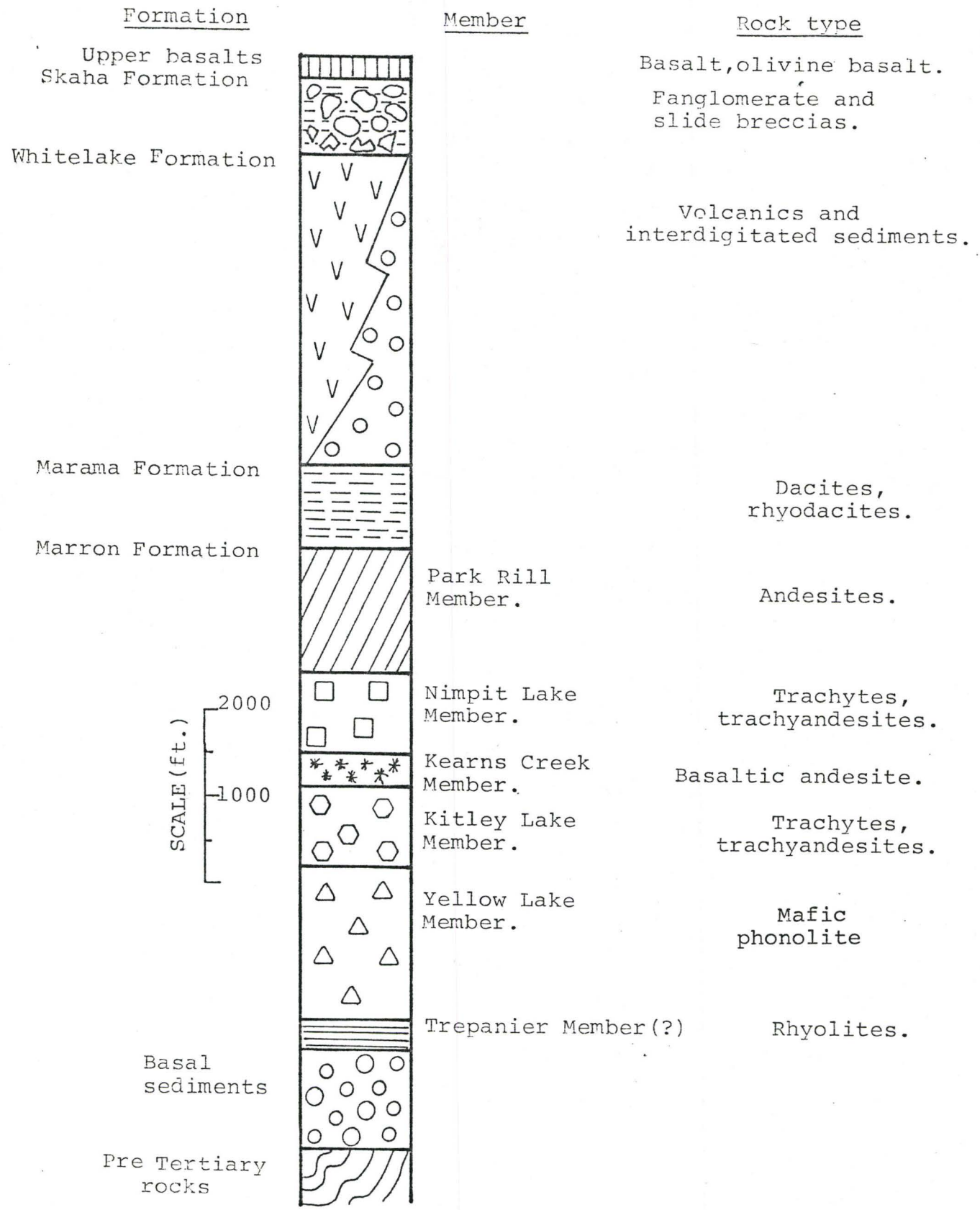
Phonolites of the Yellow Lake Member form thick units in the Skaha Lake, Summerland and Rock Creek region, but they have not been found in the Kelowna region.

Trachytes and trachyandesites of the Kitley Lake Member can be found in all four sampling areas. They are usually found as thick flows, and are conformably overlain by the Nimpit Lake trachyte-trachyandesite unit, except in the Skaha Lake region where they are overlain conformably by a thinner basaltic andesite flow. The Nimpit Lake trachyte is also found in abundance in all locations.

The Park Rill andesite which overlies the Nimpit Lake trachyte is found in all areas. They form thick flows in the Rock Creek and Skaha Lake regions (Church, 1963; Church, 1973).

Fig.7

GENERALIZED STRATIGRAPHIC SECTION FOR THE TERTIARY VOLCANIC SEQUENCE IN THE OKANAGAN LAKE REGION, B.C.



The dacites and rhyodacites of the Marama Formation, which conformably overlie the Marron Formation, are quite variable in thickness throughout the study area, and were not found at all in the Rock Creek area.

The Whitelake and Skaha Formations overlie the Marama Formation and are not dealt with in this study. The Whitelake Formation, though, contains a tephrite believed to be genetically related to the mafic phonolites of the Yellow Lake Member (Church, 1973).

The Upper basalts lie unconformably on top of the Skaha Formation, and according to Little (1957), can be correlated with the Columbia Plateau basalts, also believed to be Miocene in age.

CHAPTER III

PETROGRAPHY

A. Modal Analysis:

For each thin section, between 800 and 1200 points were counted. The maximum error in the final results is in the neighbourhood of 3 percent (Vander Plas and Tobi, 1965). If 1500 points were counted, the error would decrease only by about 1 percent. If the phenocrysts were larger than the point disstance used, then a larger error may result. The modal analysis of the early Tertiary flows are given in Table 1. The modal analysis for each sample is given in Appendix C.

DESCRIPTIONS OF THE LAVAS

1. The Trepanier Member (KNA-348)

The Trepanier Member at the base of the Tertiary sequence consists of rhyolite flows, pyroclastic flows and intrusive rhyolite porphyry feeder dikes. The latter two are discussed in Appendix A

The rhyolite flow is a pinkish porphyritic rock containing phenocrysts of feldspar up to 4.0 mm. in length, and smaller phenocrysts of quartz and biotite set in a glassy matrix.

Microscopic examination of the rock reveals that both plagioclase and alkali feldspar are present as phenocrysts, as well as quartz and biotite. Alkali feldspar occurs as subrectangular to rectangular laths and stubby subhedral sections. They reach up to 4.5 mm. in maximum dimension, and average about 1.7 mm.

Plagioclase feldspar occurs as rectangular laths and occupies the same size range as the alkali feldspars. Polysynthetic albitetwinning and Carlsbad twins are common. A rough estimate of the composition based on extinction angles is An_{40}-An_{46}.

Quartz occurs in welded clusters of many individual small grains where average size is about 0.1 mm. It also occurs as large, free-floating individuals measuring up to 4.0 mm. in diameter. They are characteristically rounded and contain rounded inclusions of devitrified glass and smooth embayments filled

with devitrified glass (Fig. 8). These textures are indicative of resorption.

A highly pleochroic, reddish-brown variety of biotite occurs as randomly scattered, slender and stubby equant grains measuring up to 0.75 mm. in length. They are commonly oxidized around the edges, indicating magmatic corrosion, and contain inclusions of magnetite and oxide dust.

Magnetite, other than inclusions in biotite, is rare and is scattered throughout the groundmass as tiny granules.

The groundmass consists entirely of devitrified glass. Spherulites composed of cristobalite or trydimite and feldspar are a prominent feature (Fig. 9). In some instances minute quartz or magnetite grains form a nucleating center for the spherulites. Spherulites not containing these "seeds" may have formed as a primary feature in the viscous magma. Primary spherulites are typical of siliceous flows and are indicators of rapid crystallization (Williams et al, 1954, 24).

Alterations in the form of clay minerals, sericite and carbonate minerals replacing the feldspar are common in the rhyolite.

2. The Yellow Lake Member (ROK-86, ROK-245, CLM-92, RID-50)

The Yellow Lake Member of the Marron Formation is a grey porphyritic mafic phonolite containing rectangular and rhombahedral phenocrysts of feldspar, anhedral to euhedral phenocrysts of pyroxene, and slightly rounded analcite crystals, measuring up to 7.0 mm. in diameter. They are all set in a dense crystalline groundmass.

Thin section analysis indicates that alkali feldspar, clinopyroxene, analcite, olivine, biotite and magnetite, occur as phenocrysts set in a felty groundmass.

Optical methods indicate that the alkali feldspar is anorthoclase. Their size ranges from less than 0.5 mm. up to 7.00 mm., with an average size of about 3.0 mm. Anhedral subrectangular stubby crystals with corroded edges, and subhedral

KEY FOR TABLE I

(Q) = Quartz
(H) = Hornblende
(S) = Sphene
(A) = Analcite
Tr. = Trace

Modal analyses for the Trepanier rhyolite ash flow and the Nimpit Lake trachytic ash flow accompany the petrographic descriptions in Appendix A.

TABLE I

MODAL VARIATIONS IN ROCK UNITS (%)

Rock Unit	Number of analyses	Plagioclase feldspar	Alkali feldspar	Clino-pyroxene	Biotite	Magnetite	Olivine	Others	Groundmas
Trepanier Member	1	10.4	7.0	--	1.6	1.0	--	20.0(Q)	55.0
Yellow Lake Member	4	--	23.2-64.9	8.0-10.0	0.4-1.2	1.8-8.5	0.0-3.2	4.5-6.3 (A)	10.9-73.3
Kitley Lake Member	4	14.3-24.6	3.5-13.6	1.0-4.4	0.8-3.0	Tr.-2.0	0.0-3.0	Tr.(H)	58.2-80.2
Kearn's Crk. Member	1	9.2	2.2	14.2	--	0.9	7.6	--	65.9
Nimpit Lake Member	4	1.7-11.7	0.0-8.0	1.3-4.4	0.0-3.0	Tr.-2.0	0.0-4.0	--	83.0-92.3
Park Rill Member	2	26.9-32.5	--	1.3-8.9	0.6-2.9	2.7-2.8	0.0-2.3	Tr.-31.1 (H)	47.4-58.7
Marama Formation	2	2.0-7.0	--	0.0-3.0	0.0-1.0	--	--	--	89.0-98.0
Carrot Mtn. Basalts	2	31.0-34.0	--	2.4-4.0	Tr.-3.0	5.0-16.3	--	--	50.3-54.0
Lambly Crk. Basalts	2	45.5-50.0	--	22.4-28.6	--	10.5-21.5	0.0-13.6	0.0-6.0 (S)	--

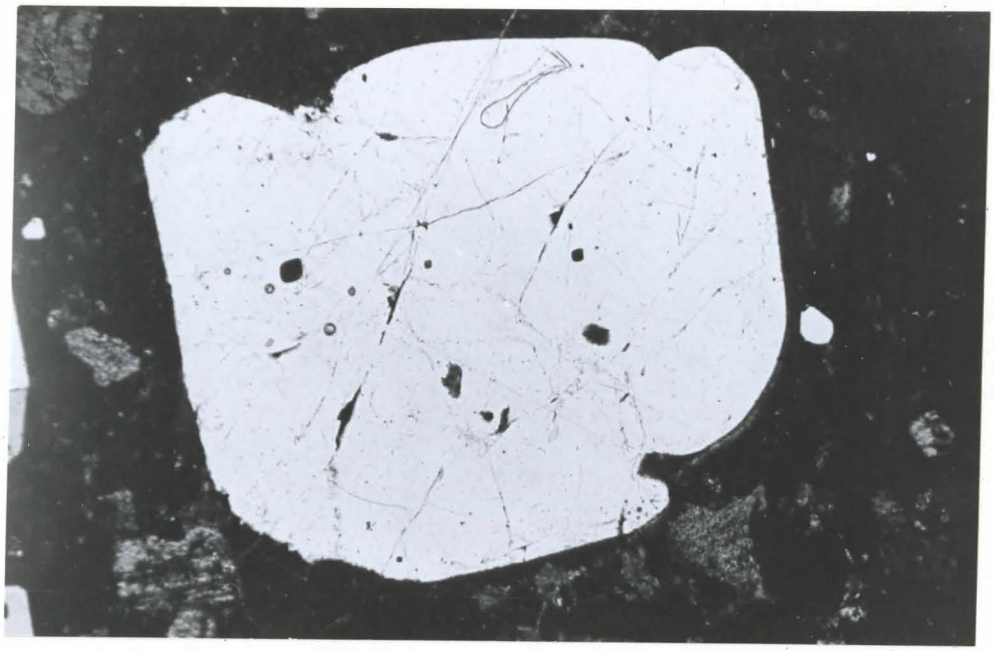


Fig. 8 Photomicrograph of quartz showing rounded embayments and inclusions of devitrified glass (KNA-348) (Crossed Nicols). Magnification is 40 X.

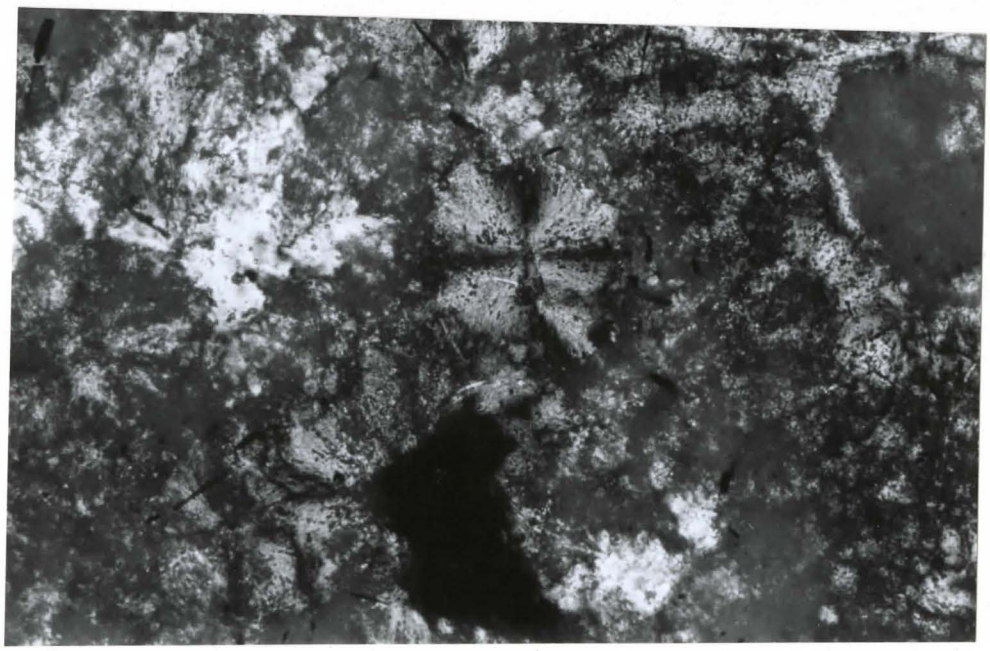


Fig. 9 Photomicrograph of spherulite with extinction cross in Trepanier rhyolite flow. (KNA-348) (Crossed Nicols). Magnification is 100 X.

rhomb-shaped crystals are common forms, with euhedral grains occurring only rarely. Compositional zoning and grid twinning are frequent, and poikilitic inclusions of apatite are common.

Clinopyroxene occurs as free-floating basal and longitudinal sections, averaging 0.6 to 1.0 mm. in size, but reaching up to 6.0 mm. Subhedral to euhedral grains are very common. Glomerophenocrysts are also present, and consist of 5-10 grains of varying size. Optical properties indicate that the clinopyroxene is a pale green variety of augite. Simple twins with (100) as the twin plane, and polysynthetic twins with (001) as the twin plane are common features. Oscillatory compositional zoning is a less common feature, and poikilitic inclusions of feldspar, magnetite, and prismatic apatite are abundant (Fig. 10).

Olivine very rarely occurs as fresh unaltered grains. Serpentine, bowlingite, magnetite and mixtures of these three minerals commonly form pseudomorphs after the olivine. Some of the outlines indicate that olivine was present in a euhedral form, and that they may have reached sizes of 5.0-6.0 mm.

A highly pleochroic, brownish-orange variety of biotite is common as subrectangular, randomly distributed laths, averaging about 0.3 mm. in length. Oxidized and corroded margins indicate resorption. Tiny inclusions of magnetite are common in the biotite.

Other than in biotite, phenocrysts of magnetite are rare. They are small, anhedral, and in close proximity with pyroxene clusters and biotite.

The groundmass is composed of felty feldspar microlites arranged in a random fashion. Staining indicates they are largely alkalic. Evenly-spaced granular magnetite, oxide dust, and a few granular pyroxenes and biotite flakes fill the interstices. Round-to-polygonal grains of analcite about 0.1 mm. in diameter are also present in the groundmass in some of the sections.

The analcite also occurs as phenocrysts up to 7.0 mm. in diameter, and contains poikilitic inclusions of feldspar.

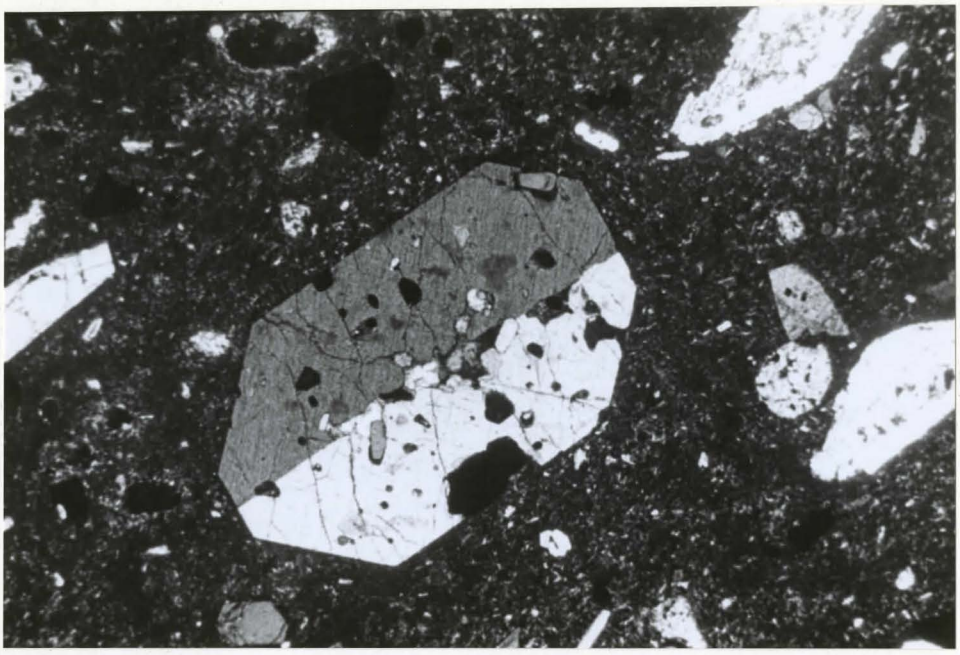


Fig. 10 Photomicrograph of clinopyroxene showing Carlsbad twin and containing poikilitic inclusions of feldspar, magnetite and apatite (not visible). (RID-50) (Crossed Nicols). Magnification is 40 X.

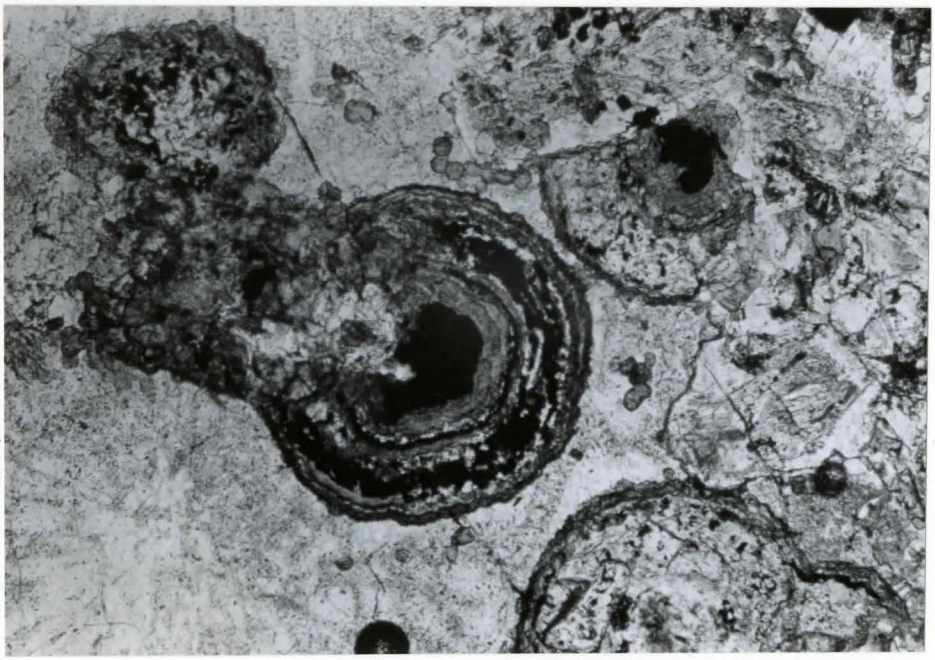


Fig. 11 Photomicrograph of microvugs in large analcite phenocryst. (ROK-245) (Crossed Nicols). Magnification is 100 X.

Microvugs filled or partially filled with concentric layers of chlorite, serpentine and oxide are common in the analcite (Fig.11). The analcite phenocrysts approach a trapezohedral habit indicating that they may be primary.

Apatite is abundant and is scattered randomly as tiny rods throughout the ground mass.

3. The Kitley Lake Member (KNA-315, ROK-161, CLM-73, HWY-YL)

Trachytes and trachyandesites comprise the Kitley Lake Member of the Marron Formation. They are grey to greyish-brown, slightly weathered porphyries. Glomerophenocrysts and individual laths of feldspar, along with small phenocrysts of biotite and pyroxene are set in a microcrystalline to glassy groundmass.

Plagioclase occurs as free-floating, often zoned, rectangular laths with slightly corroded edges. A composition based on extinction angles is An38-An42. They measure up to 6.0 mm. in length and average about 2.0 mm. Glomerophenocrysts consist of 5-10 assymetrically arranged stubby rectangular grains and measure between 4.0 and 6.0 mm. in diameter. They frequently occur with minor amounts of pyroxene, biotite and magnetite. A jacket of alkali feldspar of varying thickness rimming the plagioclase is very common in the Kitley Lake Member (Fig. 12). A sharp contact between the alkali and plagioclase feldspar is only rarely present. Polysynthetic albite and Carlsbad twins in the plagioclase are well developed.

Alkali feldspar is rare as phenocrysts. Poikilitic inclusions of prismatic apatite are fairly common in the feldspars.

The clinopyroxene is a pale green variety of augite. Its size is quite variable, ranging from 0.1 mm. up to 5.0 mm. for both basal and longitudinal sections. Anhedral to subhedral free-floating grains and glomerophenocrysts of 7 to 12 subhedral, subequant grains are present (Fig. 13). The glomerophenocrysts measure up to 4.0 to 5.0 mm. in diameter. Compositional zoning is often present and simple twins on the (100) twin plane, and polysynthetic twins on the (001) twin plane are

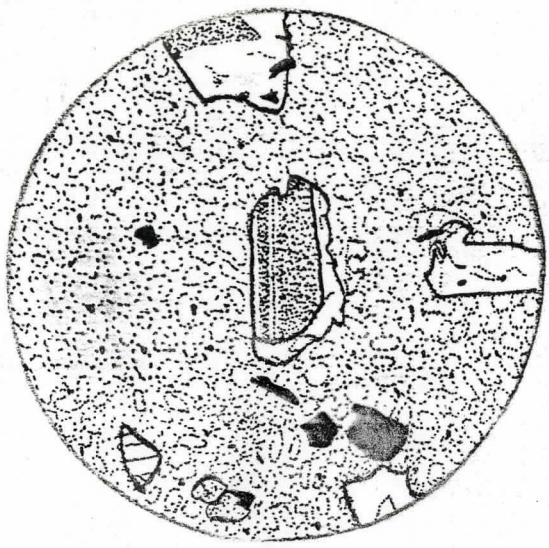


Fig. 12 Sketch showing alkali feldspar mantling plagioclase (Centre of photo). Field of view = 7.0 mm.
(HWY-YL) (Crossed Nicols).

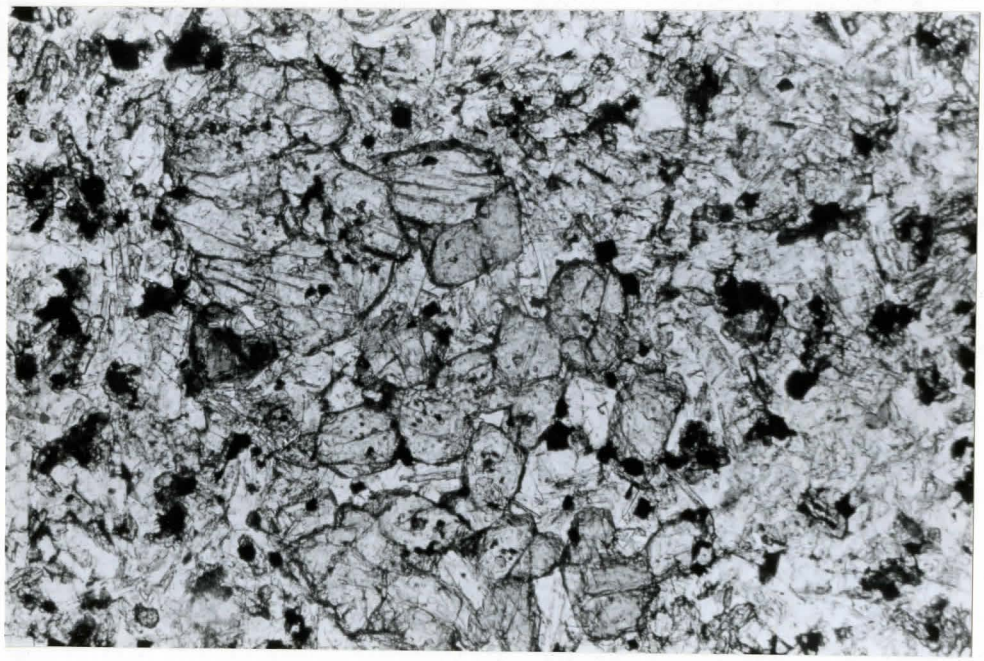


Fig. 13 Photomicrograph of clustered pyroxene phenocrysts.
(CLM-73) (Plain Light).
Magnification is 40 X.

well-developed. Inclusions of feldspar, magnetite, and apatite rods are common in the pyroxenes.

Olivine is never present, but serpentine is present as perfect pseudomorphs after it.

Biotite occurs as a strongly pleochroic, reddish-brown variety. It occurs as slender laths and as stubby rectangular laths, measuring up to 6.0 mm. in length, and averaging 1.5 mm. Magmatic corrosion has left irregular oxidized margins charged with fine granular magnetite.

When present as phenocrysts, magnetite forms equant anhedral to subhedral small and scattered grains.

The groundmass is composed of felty feldspar microlites with fine granular magnetite, oxide dust, some fine grained pyroxene, and a few biotite flakes occupying the interstices. Staining shows that the groundmass feldspar is largely alkalic. When in close proximity with phenocrysts, the feldspars are aligned in a subparallel fashion in response to flowage.

Alterations are not common, and usually take the form of clay minerals, sericite and carbonate minerals replacing the feldspar.

4. The Kearns Creek Member (CLM-45)

The Kearns Creek Member of the Marron Formation is composed of a porphyritic, dark grey, slightly vesicular basaltic andesite which has undergone some weathering. Plagioclase feldspar phenocrysts up to 5.0 mm. in length, and small pyroxene phenocrysts are present in a microcrystalline matrix.

Microscopic examination reveals that plagioclase feldspar, clinopyroxene, olivine and magnetite occur as phenocrysts in a groundmass of feldspar, chlorite and oxides.

Plagioclase feldspar occurs as randomly oriented lath-shaped, free-floating grains, measuring up to 5.0 mm. in length. Normal and oscillatory zoning is common with cloudy cores and cloudy rings paralleling the concentric oscillations. Albite and Carlsbad twinning are characteristic. An estimate of the plagioclase composition based on extinction angles is An28. Alkali feldspar is frequently found mantling the plagioclase feldspar.

The clinopyroxene is a pale green variety of augite. Subhedral rounded basal sections and corroded longitudinal sections range in size from less than 0.1 mm. to 2.0 mm. Glomerophenocrysts of 7-12 grains are common. Compositional zoning, simple twins and polysynthetic twinning are well-developed features. Poikilitic inclusions of feldspar, magnetite and less commonly, apatite rods, occur in the pyroxenes.

Anhedral to euhedral grains of olivine were present, but have been completely replaced by serpentine (Fig. 14).

The groundmass is composed of equant felty microlites of plagioclase feldspar randomly oriented with fine granular magnetite, volcanic dust, and chlorite (secondary), filling the interstices.

Mineral alterations include replacement of plagioclase by clay and carbonate minerals and sericite, chlorite replacing some mineral (pyroxene?) in the ground mass, and serpentine replacing olivine. The cloudy zones in the plagioclase feldspar result from inclusions of foreign material, dust, and unidentifiable minerals within certain zones (usually calcic zones) in the grain (Smith, 1974, 626). They may also be the result of preferential alteration of calcic zones within the feldspar (Barth, 1969, 37).

5. The Nimpit Lake Member (KNA-145, KNA-338, HYW-MV, F1-4)

The Nimpit Lake Member of the Marron Formation is composed of brown to grey-brown porphyritic trachytes and trachyandesites. Phenocrysts and glomerophenocrysts of feldspar measure between 3.0 and 5.0 mm. in length or diameter. Pyroxene phenocrysts up to 2.5 mm. and tiny flakes of biotite give the rock a peppery appearance. The matrix is essentially microcrystalline.

Thin section analysis reveals that phenocysts of plagioclase feldspar, clinopyroxene, olivine, biotite, magnetite and, rarely, alkali feldspar, occur in a felty groundmass of dominantly feldspar.

Plagioclase feldspar occurs as randomly oriented free-floating laths averaging about 3.5 mm. in length. Glomeropheno-

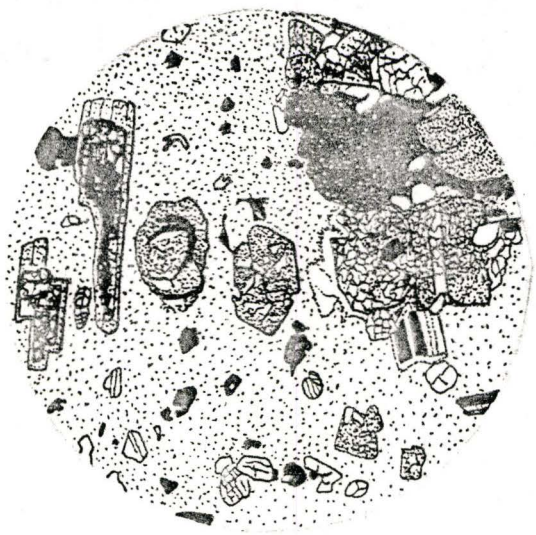


Fig. 14 Sketch showing altered olivine (centre of sketch) and alkali feldspar mantling plagioclase feldspar. To the right is a cluster of feldspar and pyroxenes. Field of view = 7.0 mm. (CLM-45) (Crossed Nicols).

crysts consisting of several to 30 equidimensional laths are frequent (Fig. 15). Alkali feldspar jackets commonly form rims of varying thickness around the plagioclase, and some of the plagioclase exhibits normal compositional zoning. Albite and Carlsbad twinning are usually well-developed. An estimate of the composition of the plagioclase based on extinction angles is An20 to An40 (quite variable).

The clinopyroxene is a pale green variety of augite occurring as anhedral to euhedral basal and longitudinal free-floating sections, and in glomerophenocrysts of 4 to 12 individuals. The size range is quite variable, from less than 0.1 mm. to 3.0 mm., and averaging 0.3 to 0.7 mm. Simple twins on the (100) twin plane, and polysynthetic twins on the (001) twin plane are well-developed. Poikilitic inclusions of feldspar, magnetite and apatite rods are common in the pyroxenes.

A deep reddish-brown, highly pleochroic variety of biotite is present as slender laths scattered at random. Oxidized and corroded margins charged with magnetite dust suggest magmatic corrosion.

The groundmass is composed of felty, randomly oriented feldspar microlites, with fine granular magnetite, volcanic dust, a few biotite flakes, and possibly some devitrified glass occupying the interstices. Staining reveals that a large proportion of the groundmass feldspar is alkalic.

Mineral alteration is represented by partial replacement of feldspar by mixtures of clay, sericite and carbonate. Serpentine, bowlingite and magnetite also form perfect pseudomorphs after olivine, many of which are euhedral (Fig. 16).

6. The Park Rill Member (CLM-47, HWY-BC)

The Park Rill Member of the Marron Formation consists of grey-coloured porphyritic andesite. Evenly distributed phenocrysts of plagioclase feldspar, pyroxene, biotite and, to a lesser extent, hornblende, are set in an essentially glassy matrix.

Microscopic examination of the rock indicates that

Fig. 15 Photomicrograph of plagioclase feldspar glomerophenocryst.
(KNA-145) (Crossed Nicols).
Magnification is 40 X.

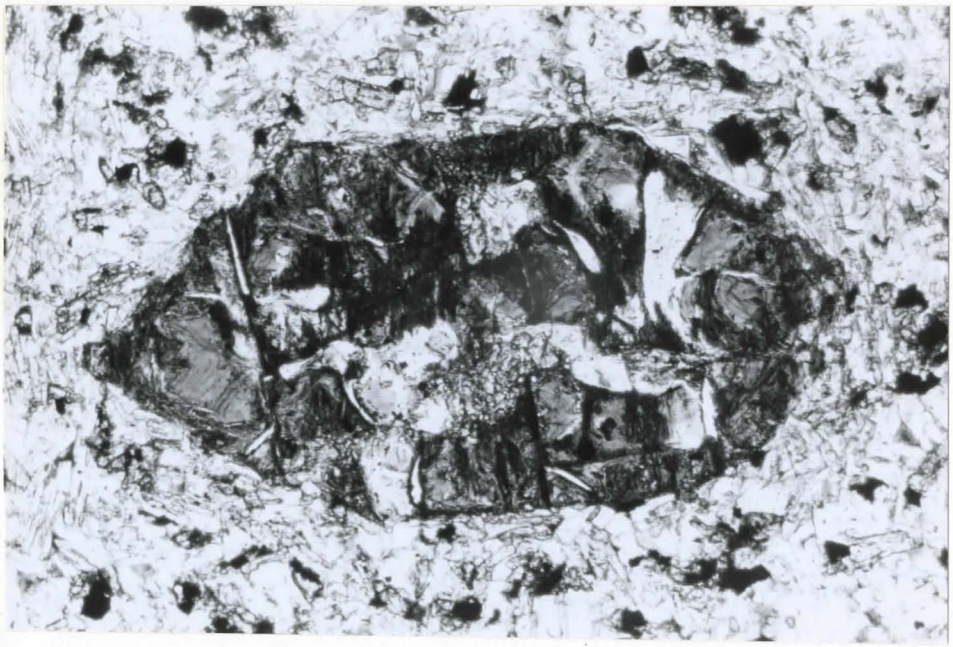


Fig. 16 Photomicrograph of serpentine forming a pseudomorphous aggregate after olivine.
(KNA-145) (Plain Light).
Magnification is 63 X.

phenocrysts of plagioclase feldspar, clinopyroxene, hornblende, biotite, magnetite, and possibly olivine, exist in a groundmass of glass charged with volcanic dust.

Plagioclase feldspar occurs as slender rectangular unzoned laths, stubby subhedral to euhedral grains with compositional oscillatory zones, and, less commonly, as glomerophenocrysts. Composition based on extinction angles is An32. Grain size varies from 1.5 mm. to 5.0 mm., with the stubby grains being the smallest. Albite and Carlsbad twins are well-developed, especially in the unzoned laths. Cloudy areas arranged concentrically in layers parallel to the oscillations and in cores of zoned feldspars are frequent. Inclusions of glass blebs and a few apatite rods occur frequently.

The clinopyroxene is a pale green variety of augite which occurs largely as subhedral to euhedral basal sections, averaging 0.3 to 0.5 mm. in diameter. Glomerophenocrysts consisting of many small basal sections measure 2 to 3 mm. in diameter. Simple twins and polysynthetic twins are usually well-developed. The pyroxenes contain poikilitic inclusions of feldspar, magnetite, and to a lesser extent, apatite rods.

A brown pleochroic variety of biotite occurs as slender laths and as stubby rectangular books. Evidence of magmatic corrosion around the edges is extensive.

A euhedral, highly pleochroic, dark brown variety of hornblende occurs and shows a great size variation, from 0.1 mm. to 3.0 mm., with a large proportion of the grains being in the 0.2 to 0.3 mm. size range (Fig. 17). Magmatic corrosion has affected the small grains a great deal, leaving them riddled with magnetite dust and obliterating the crystallographic planes. The larger phenocrysts, however, have not been affected to such a high degree, and are perfectly euhedral.

Magnetite occurs as anhedral phenocrysts reaching up to 2.0 mm. in diameter, but only rarely. They are usually about .3 mm. in diameter and scattered randomly throughout the groundmass.

The groundmass is composed of a dark greyish-brown

glass, riddled with fine granular magnetite, volcanic dust and microlites of plagioclase feldspar.

Alterations are common and occur as chlorite forming feathery pseudomorphs after pyroxene (Fig. 18), serpentine, bowlingite and magnetite forming pseudomorphs after olivine and clay minerals, carbonate minerals and sericite replacing plagioclase. Chalcedony vein fillings cut through the rock.

7. The Marama Formation (KNA-131, HWY-DM)

The Marama Formation consists of grey to brownish-grey porphyritic vitrophyric dacites composed dominantly of a glassy matrix with a few scattered phenocrysts of plagioclase feldspar.

Microscopic examination indicates that the rock is almost entirely groundmass, with a few phenocrysts of plagioclase feldspar, clinopyroxene, biotite, and, rarely, magnetite.

Plagioclase feldspar occurs as rectangular laths and stubby prismatic sections measuring up to 2.0 mm. in length. Compositional and oscillatory zoning is common (Fig. 19). Carlsbad and albite twins are well-developed, but a scarcity of phenocrysts did not allow an estimate of the plagioclase composition. Many of the plagioclase feldspars approaching groundmass size have "swallow tails", indicating that the lava was quenched rather quickly and the plagioclase did not have time to complete crystallizing (Fig. 20). The abundant glass in the matrix, glass shards, and the fact that the flow texture has been preserved very well, supports this explanation.

The clinopyroxene is a pale green variety of augite occurring as subhedral to euhedral basal and longitudinal sections averaging about 0.6 mm. in diameter. Glomerophenocrysts consisting of as many as 30 minute grains are less common.

A strongly pleochroic brownish variety of biotite occurs only rarely as phenocrysts. Basal and prismatic sections reaching up to 0.2 mm. in length show marginal evidence of magmatic corrosion.

A few devitrified glass shards are scattered throughout the section.

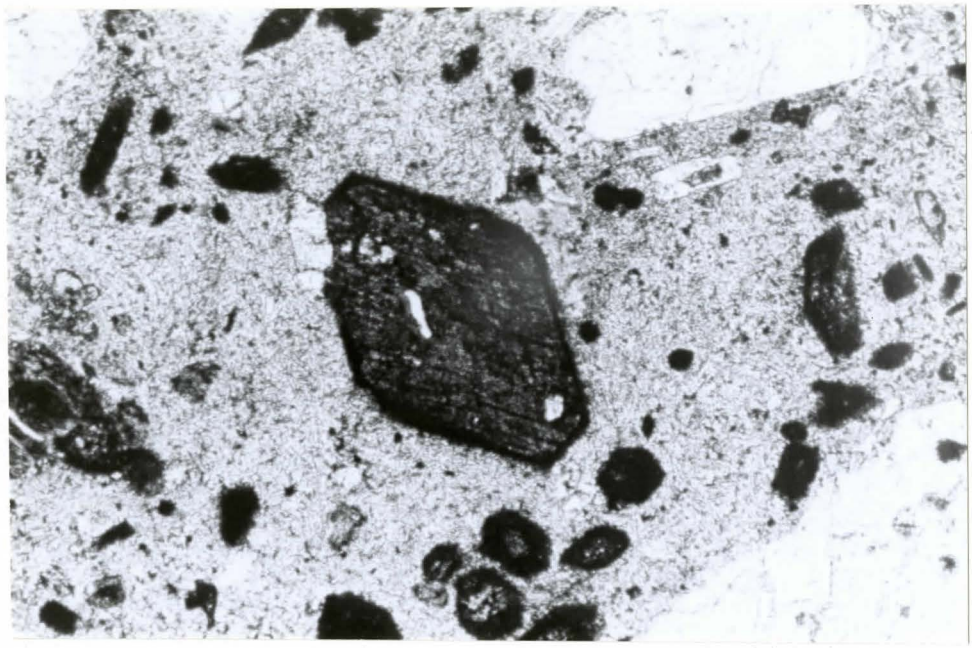


Fig. 17 Photomicrograph of euhedral phenocrysts of hornblende showing evidence of magmatic corrosion. (CLM-47) (Plain Light). Magnification is 40 X.

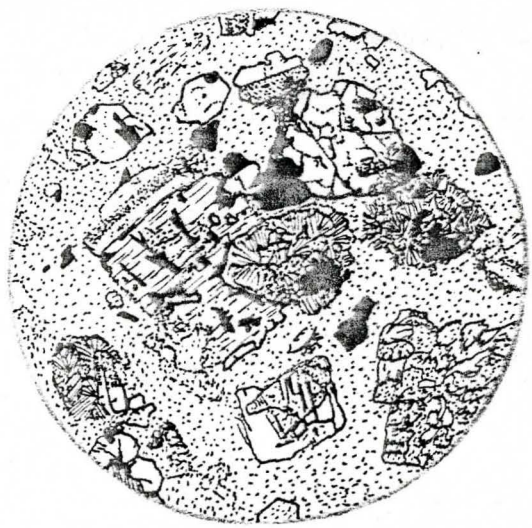


Fig. 18 Sketch of HWY-BC to show chlorite forming radial pseudomorphs after pyroxene (centre of diagram). The grain next to it is biotite. Field of view = 7.0 mm. (Crossed Nicols).

Fig. 19 Photomicrograph showing oscillatory zoning in plagioclase feldspar and flow textures in the ground mass.
(KNA-131) (Crossed Nicols).
Magnification is 63 X.

Fig. 20 Sketch of KNA-131 showing flow texture and feldspar microlites with "swallow tails" (upper centre). Field of view = 3.0 mm.
(Crossed Nicols).

The groundmass consists dominantly of glass and devitrified glass, with lesser amounts of feldspar microlites, fine granular magnetite and dust. The flow texture is preserved in the groundmass and around phenocrysts (Fig. 20).

8. The Upper Basalts (KNA-4, KNA-250, Carrot Mountain. KNA-279, KNA-343, Lambly Creek).

There appear to be two generations of basalts present in the Kelowna area. The Lambly Creek Basalt, as it is locally called, is grey to purplish-brown when weathered, and vesicular, with small phenocrysts of olivine and, rarely, sphene present in a crystalline matrix. The Carrot Mountain Basalt, as it is locally called, is a lighter grey, non-vesicular rock, with glomerophenocrysts and phenocrysts of plagioclase present in a microcrystalline to glassy matrix.

Plagioclase in the Carrot Mountain Basalt occurs as subhedral zoned laths up to 6.0 mm. in length, and as glomerophenocrysts of smaller individual grains (Fig. 21). A composition based on extinction angles is An48.

Plagioclase in the Lambly Creek Basalt occurs as slender, anhedral, unaltered, randomly oriented equant laths, averaging 0.5 mm. in length, and rarely exceeding 1.5 mm. A composition based on extinction angles is An54. Albite and Carlsbad twins are well-developed and the overall texture is sub-ophitic, with clinopyroxene, olivine and sphene occupying interstitial sites (Fig. 22).

Clinopyroxene in all the basalts occurs as subhedral to euhedral basal sections, measuring 0.2 to 0.3 mm. in diameter, although some large grains do occur in the Carrot Mountain Basalt. The clinopyroxene in the Carrot Mountain Basalt is a pale green variety of augite, the Lambly Creek Basalt contains a faintly pleochroic, pinkish-brown variety of titaniferous augite.

A yellowish-brown pleochroic biotite occurs in the Carrot Mountain Basalt as small, free-floating laths, and less commonly, as kelyphytic rims around pyroxene grains.

Magnetite occurs as small, equant, anhedral grains,

Fig. 21 Photomicrograph showing plagioclase glomerophenocryst, flow texture in ground mass and cloudy feldspar (bottom left). (Carrot Mountain Basalt) (Crossed Nicols). Magnification is 63 X.

Fig. 22 Photomicrograph showing slender laths of plagioclase in Lambly Creek Basalt. Note the abundant interstitial magnetite. (Crossed Nicols). Magnification is 63 X.

and is very abundant in the Lambly Creek Basalt (Fig. 22).

Olivine is restricted to one section of the Lambly Creek Basalt (KNA-343) where it occurs as fractured, unaltered grains, measuring up to 4.0 mm. in diameter (Fig. 23).

Sphene is restricted to one section of the Lambly Creek Basalt (KNA-279) where it occurs as euhedral, acute rhomahedral sections, measuring up to 2.5 mm. in length (Fig. 24). They usually occur in groups of 2 or 3.

A groundmass is present in significant amounts in the Carrot Mountain Basalt, and consists of glass charged with volcanic dust, and granular magnetite, as well as feldspar microlites aligned in a sub-parallel fashion in response to flowage (Fig. 21). In one member (KNA-250), the groundmass contained abundant apatite rods scattered at random.

MINERALOGICAL VARIATIONS

Table 2 demonstrates any stratigraphic variations in mineralogy in the Tertiary volcanic sequence in the Okanagan Valley.

There are two major variations, as well as some minor ones.

1) The first major variation is associated with the feldspars. The upper basalts, basaltic andesites, andesites, and dacites contain only plagioclase feldspar. The trachytes and trachyandesites contain plagioclase feldspar characteristically wrapped in alkali feldspar. Staining also indicates that alkali feldspar is fairly abundant in the groundmass of these rocks, whereas it was not present in the groundmass of the previous series. The phonolites, on the other hand, contain only alkali feldspar, both as phenocrysts and in the groundmass, as indicated by staining.

2) The second major variation concerns apatite. It is common to abundant in the upper basalts, and is rarely found in the basaltic andesite, andesite and dacite. It is a common constituent of the trachytes and trachyandesites, and is found in great abundance in the phonolites.

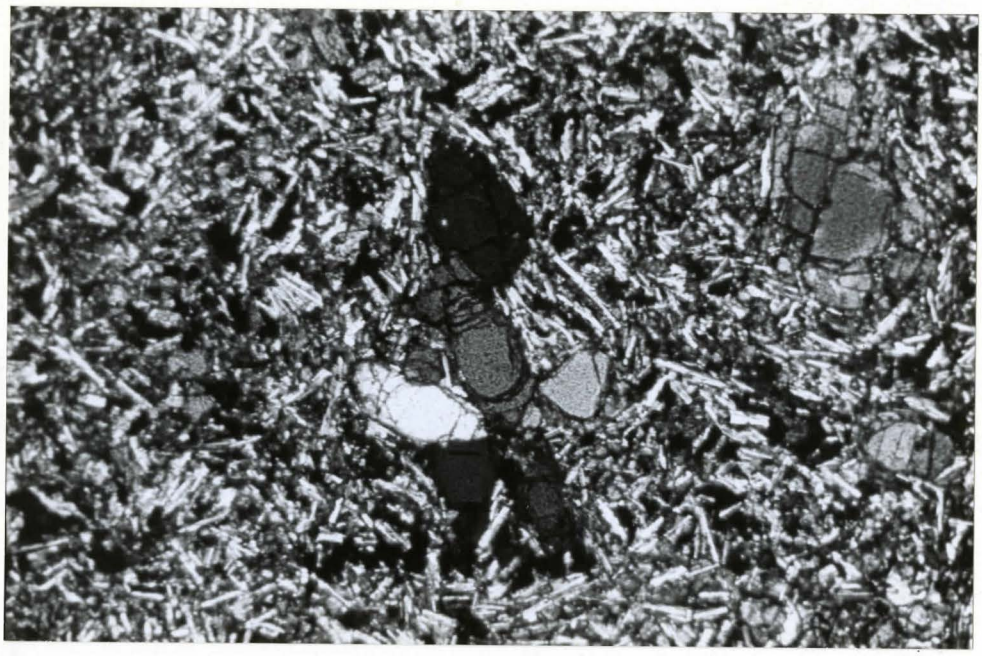


Fig. 23 Photomicrograph showing clusters of olivine in the Lambly Creek Basalt.
(Crossed Nicols).
Magnification is 40 X.

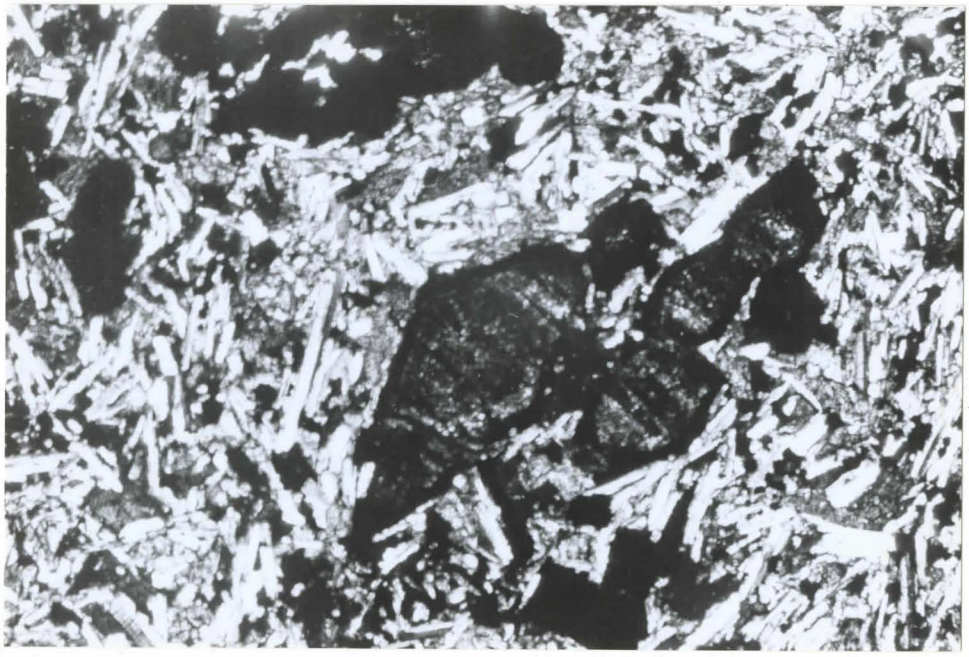


Fig. 24 Photomicrograph of sphene in Lambly Creek Basalt.
(Crossed Nicols).
Magnification is 40 X.

KEY FOR TABLE II

A = Abundant
C = Common
UC = Uncommon
Tr = Trace

Q = Quartz
H = Hornblende
A = Analcite
S = Sphene
P = Pyroxene
B = Biotite

Proportions of minerals as phenocrysts are based on modal analyses; and proportions of minerals in the groundmass are based on subjective appraisal.

TABLE II STRATIGRAPHIC VARIATIONS IN MINERALOGY

	Minerals as Phenocrysts								Minerals in Groundmass					
	Plag.	Alk.	Alk. Jack.	Clpx.	Biot.	Mag.	Oliv.	Others	Ap.	Gran. Mag.	Feld.	Glass	Others	Rock Units
KNA-4	A	-	-	C	C	C	-	-	C	C	A	C	Tr (P,B)	
KNA-250	A	-	-	C	C	C	-	-	A	C	C	UC	C (P,B)	Upper
KNA-279	A	-	-	A	-	A	-	C (S)	C	C	-	-	-	Basalts
KNA-343	A	-	-	A	-	A	A	-	C	C	-	-	-	
KNA-131	C	-	-	C	Tr	-	-	-	Tr	C	C	A	Tr (B)	Marama
HWY-DM	C	-	-	-	-	-	-	-	Tr	C	C	A	-	Formation
CLM-47	A	-	-	C	Tr	C	C	A (H)	Tr	C	C	A	-	Park Rill
HWY-BC	A	-	-	A	C	C	-	Tr (H)	Tr	C	C	A	-	Member
KNA-145	A	-	Tr	C	Tr	Tr	UC	-	C	C	A	-	-	
KNA-338	A	Tr	C	C	Tr	Tr	Tr	-	C	C	A	-	-	Nimpit Lake
HWY-MV	A	Tr	C	C	Tr	UC	-	-	C	C	A	-	-	Member
Fl-4	C	-	C	C	Tr	Tr	UC	-	C	C	A	-	-	
CLM-45	A	-	-	A	-	Tr	C	-	Tr	C	C	A	-	Kearns Crk.Memb.
KNA-315	A	Tr	C	C	UC	Tr	-	-	C	C	A	-	-	
ROK-161	A	Tr	C	C	UC	Tr	UC	-	C	C	A	-	-	Kitley Lake
CLM-73	A	Tr	A	C	UC	Tr	-	-	C	C	A	-	-	Member
HWY-YL	A	Tr	C	C	C	Tr	UC	-	C	C	A	-	-	
ROK-86	-	A	-	C	Tr	C	C	-	A	C	A	Tr	-	
ROK-245	-	A	-	C	Tr	C	-	C (A)	A	C	A	-	-	Yellow Lake
RID-50	-	A	-	A	UC	UC	-	-	A	C	A	Tr	-	Member
CLM-92	-	A	-	A	Tr	C	UC	C (A)	A	C	A	-	-	
KNA-348	C	C	-	Tr	UC	Tr	-	A (Q)	-	Tr	C	A	Tr (B)	Trepanier Memb.

Other minor variations of lesser importance exist as well.

Hornblende is found only in the Park Rill andesites. Analcite was found only in the Yellow Lake phonolites. A titaniferous variety of augite and sphene were found only in the Lambly Creek Basalts. Glass is a common constituent of the groundmass in the Carrot Mountain Basalt, the basaltic andesite, andesites and dacites.

Large glomerophenocrysts of feldspar are found mostly in the trachytes and trachyandesites of the Kitley Lake Member and the Nimpit Lake Member.

CHAPTER IV

CLASSIFICATION OF VOLCANIC ROCKS

Standard methods of classifying medium and coarse grained igneous rocks make use of the modal mineral composition. This method is of very little use when fine-grained volcanic rocks are involved. Instead, a classification scheme based on the chemistry of the rocks must be adopted.

The method used is one developed by Irvine and Baragar (1971), in which rocks can be assigned to either the subalkaline or alkaline divisions. Further classification separates the rocks into the tholeitic basalt series, the alkali olivine basalt series, or the calc-alkali series. The classification makes use of discriminatory functions based on the alkalies-silica diagram (Irvine and Baragar, 1971; Fig. 3), the A.F.M. plot (idem; Fig. 2), the Ne-Qtz-Ol plot (idem; Fig. 4), and the Al_2O_3-An plot (idem; Fig. 6). The use of the discriminatory functions, and their relationships to the above diagrams are given in Appendix D.

Using the method proposed by Irvine and Baragar, the major units of the early Tertiary volcanic sequence in the Okanagan Lake region can be classified as follows:

TABLE III	DIVISION	SERIES
Trepanier Member	Subalkaline	Calc-alkali
Yellow Lake Member	Alkaline	Alkali olivine basalt
Kitley Lake Member	"	" " "
Kearns Creek Member	"	" " "
Nimpit Lake Member	"	" " "
Park Rill Member	Subalkaline	Calc-alkali
Marama Formation	"	"
Carrot Mountain Basalts	"	"
Lambly Creek Basalts	"	Tholeitic

A simple quantitative method for the identification of the main volcanic rock species is achieved by using a three axis

orthogonal plot of $Na_2O + K_2O$ versus $FeO + Fe_2O_3 + \frac{1}{2}(MgO + CaO)$ versus Al_2O_3/SiO_2 (Church, 1973). This diagram (Fig. 25), is useful in that it effectively separates alkali-rich and aluminous volcanic suites from those of more common composition. The term $FeO + Fe_2O_3 + \frac{1}{2}(MgO + CaO)$ contains the refractory elements and is actually a measure of the basicity of the rocks. The purpose of dividing the (CaO + MgO) component by 2 is to correlate the compositions of the most important ferro-magnesium minerals, olivine, orthopyroxene and augite, with the ultramafic rock composition zone (Church, 1973). The results are shown graphically in Fig. 25. Major oxides of 1,486 analyses of volcanic rocks from Washington's tables were plotted on the diagram, and the total array of points was contoured in order to determine the positions of the major subdivisions shown on the diagram (Church, 1973). The rock names used by the field geologists were assigned to the subdivisions as shown.

This method has distinct advantages in that it adopts a simple system of nomenclature of general acceptance, and it makes use of major oxides in a generalized manner which stress the gross differences in whole rock composition.

The major disadvantage to the plot is the considerable degree of overlap among the groups. Mineralogical and textural evidence will assist in the classification when uncertainty exists, and if satisfactory results are still not obtained, the long process of classifying the rocks based on Johanssen's C.I.P.W. norm method can be used (1939, 83-100).

Based on one or more of the above methods, the early Tertiary volcanic rocks in the Okanagan Lake region are classified as follows:

TABLE IV

Trepanier Member	Rhyolites, rhyolite porphyries, rhyolite ash flows.
Yellow Lake Member	Mafic phonolites.
Kitley Lake "	Trachytes and trachyandesites.
Kearns Creek "	(Alkine) Basaltic andesite.
Nimpit Lake "	Trachyte and trachyandesite.
Park Rill "	Andesite.

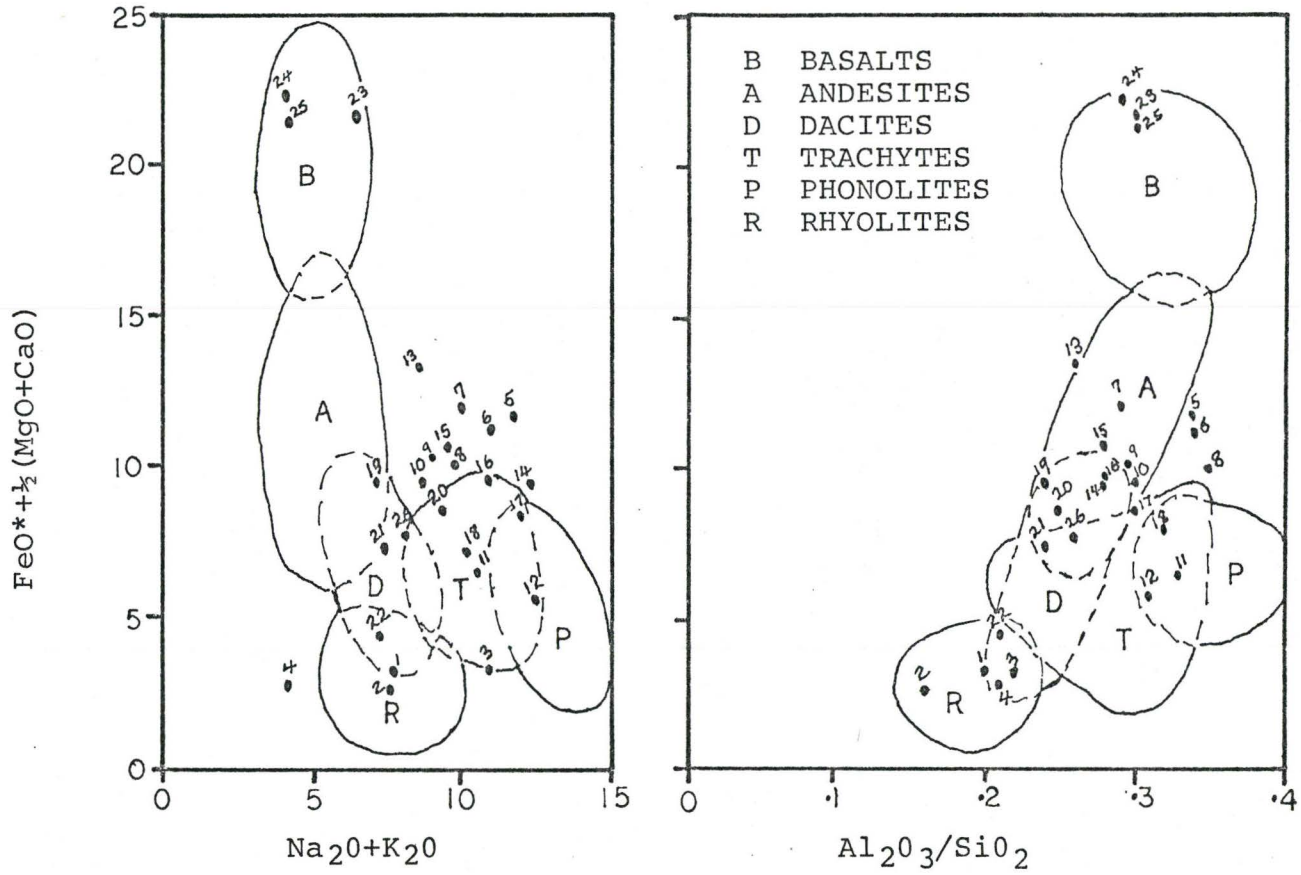
Marama Formation	Dacite and rhyodacite.
Carrot Mountain Basalts	Basalts.
Lambly Creek Basalts	Basalts.

A list of the samples and their rock names can be found in Appendix B.

KEY TO FIG. 25

1	Shingle Creek Porphyry
2	KNA-348
3	KNA-43
4	IR-267
5	ROK-245
6	CLM-92
7	RID-50
8	ROK-86
9	ROK-161
10	HWY-YL
11	CLM-73
12	KNA-315
13	CLM-45
14	SUM-1
15	KNA-145
16	F1-4
17	HWY-MV
18	KNA-338
19	HWY-BC
20	CLM-47
21	KNA-131
22	HWY-DM
23	KNA-250
24	KNA-343
25	KNA-279
26	KNA-4

Fig. 25 VOLCANIC ROCK CLASSIFICATION DIAGRAM



(FeO* = FeO+Fe_2O_3)

(From Church, 1973)

CHAPTER V

GEOCHEMISTRY

Whole rock and trace element analyses for 26 samples were obtained using a Philips Model 1450 AHP automatic sequential X-ray fluorescence spectrometer, housed in the Geology Department, McMaster University. A Cr X-ray tube was used for the major elements, Si, Al, total Fe, Mg, Ca, Na, and K; and minor elements, Ti, Mn and P; and a Mo tube was used for the trace elements, Rb, Sr, Ba, Y, Zr, Nb, Ni, Zn, Pb, U and Th. For a discussion on the methods employed and error involved, see Appendix E. The individual analyses are given in Appendix F.

MAJOR ELEMENTS

CHEMICAL VARIATION

Table V illustrates the range and variation in the major and minor elements within the stratigraphic sequence of early Tertiary volcanic rocks in the Okanagan Lake region.

The Upper basalts are the lowest in silica, and the basal rhyolites are the highest. The other rocks are in between, with the mafic phonolites of the Yellow Lake Member being undersaturated with respect to silica, while the Park Rill andesites and Marama dacites and rhyodacites are oversaturated. The trachytes and trachyandesites range from just undersaturated to just oversaturated. The range in SiO_2 reflects the modal and normative quartz content.

The Al_2O_3/SiO_2 ratios are highest in the mafic phonolites, lowest in the calc-alkali rocks, and intermediate in the trachytes and trachyandesites.

Total iron, as well as magnesium and calcium, show no unusual variations. They are high in the basaltic rocks and mafic phonolites, and lower in the dacites and rhyolites. These refractory elements reflect the modal and normative plagioclase and ferro magnesium minerals in the rock.

The alkalies, on the other hand, show a somewhat different variation. They are enriched in the mafic phonolites

TABLE V CHEMICAL VARIATIONS (WT %) OF MAJOR ROCK UNITS

	Shingle Crk. Porph.	Trepanier Member	Trepanier ash flow	Yellow Lake Member	Kitley Lake Member	Kearns Crk. Member
Number of analyses	1	1	2	4	4	1
SiO_2	73.06	76.26	69.30-76.40	53.50-55.76	58.32-60.67	55.38
TiO_2	0.33	0.29	0.34	0.83-0.96	0.67-0.84	0.98
Al_2O_3	14.45	12.38	15.44-15.77	16.06-19.25	17.52-19.80	14.16
Fe_2O_3	1.27	1.22	1.31-1.61	3.74-5.12	3.04-4.45	3.88
FeO	0.47	0.45	0.34-0.85	1.26-2.97	0.61-1.95	2.95
MnO	0.04	0.03	0.03-0.04	0.10-0.13	0.06-0.18	0.27
Mgo	0.82	0.50	0.54-0.73	2.86-4.39	0.71-2.63	6.13
CaO	1.85	1.20	0.65-1.17	4.54-6.11	2.32-5.17	6.90
Na_2O	2.74	3.38	0.58-5.29	3.85-5.44	3.44-5.39	3.33
K_2O	4.87	4.19	3.60-5.51	4.73-5.89	4.96-7.09	5.34
P_2O_5	0.10	0.10	0.09-0.11	0.68-1.04	0.30-0.51	0.78

TABLE V (CONTINUED)

	Nimpit Lake Member	Nimpit Lake ash flow	Park Rill Member	Marama Formation	Upper Basalts
Number of analyses	4	1	2	2	4
SiO_2	58.13-59.10	57.12	62.05-62.40	66.95-71.10	47.14-48.63
TiO_2	0.89-1.01	0.99	0.71-0.83	0.38-0.59	1.82-2.68
Al_2O_3	16.38-18.73	16.13	14.89-15.44	15.18-15.92	13.97-14.68
Fe_2O_3	3.02-5.12	3.39	3.75-4.02	1.79-2.37	3.54-9.64
FeO	0.56-2.00	2.53	1.06-1.86	0.30-2.40	3.12-9.37
MnO	0.05-0.09	0.04	0.06-0.68	0.04-0.07	0.17-0.21
MgO	1.97-2.73	2.80	2.43-3.79	0.67-1.80	6.73-9.28
CaO	3.54-5.24	4.04	4.19-4.84	2.52-4.62	7.34-9.41
Na_2O	3.94-5.25	5.36	3.50-6.43	3.91-4.50	3.01-4.53
K_2O	5.57-6.74	6.98	2.85-3.55	1.20-3.41	0.89-1.87
P_2O_5	0.39-0.54	0.55	0.28-0.49	0.12-0.16	0.33-0.86

and, to a lesser extent, in the trachytes and trachyandesites. They are low in the more mafic members of the calc-alkali rocks present. The dacites, rhycdacites and rhyolites contain higher amounts of alkalies than their basic end members. The alkalies reflect the amount of modal alkali feldspar present and normative alkali minerals. The high content of alkalies in the Kearns Creek basaltic andesite accounts for the presence of alkali feldspar in the rock.

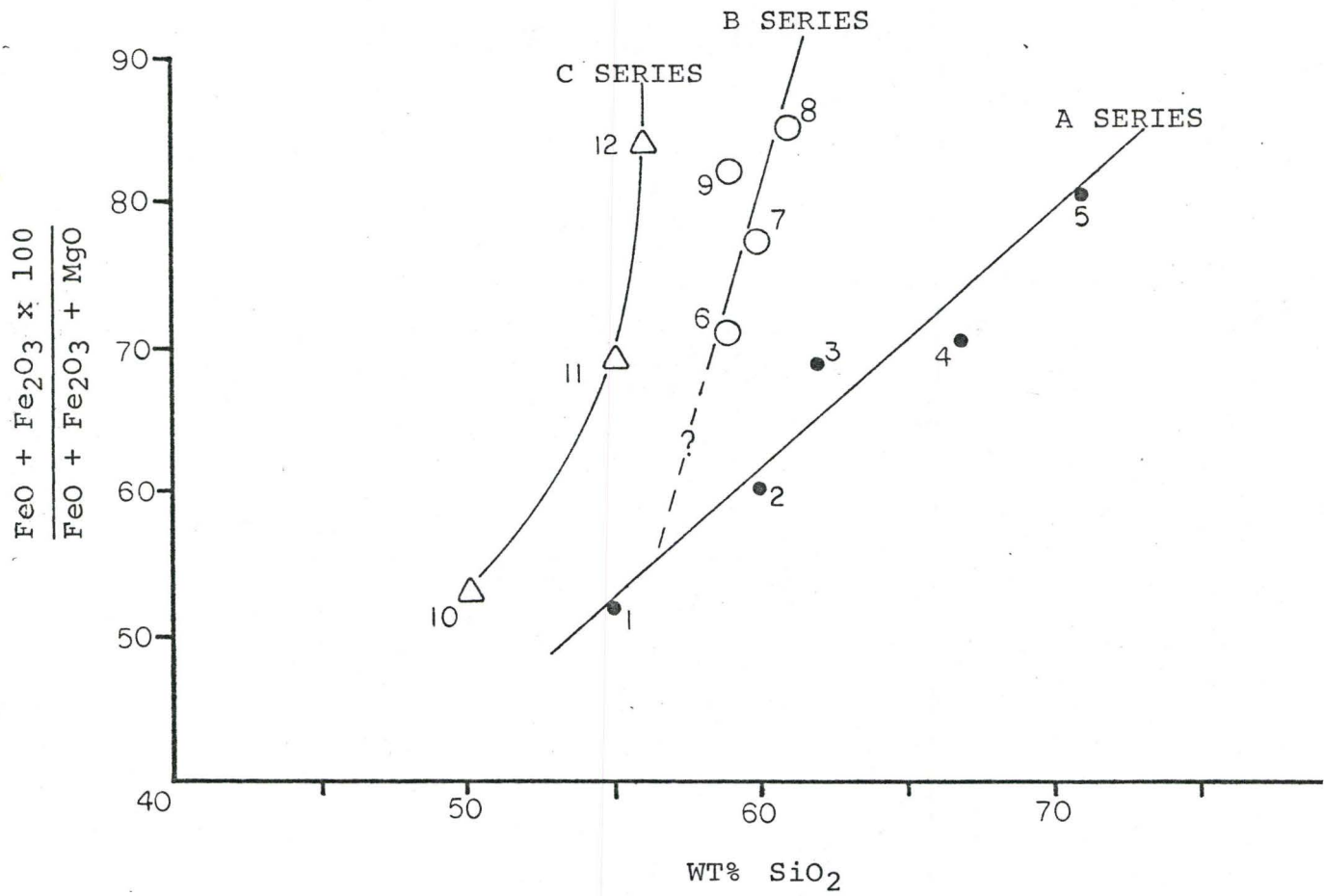
Phosphorus is very high in the mafic phonolites, low in the andesites, dacites and rhyolites; and intermediate in the trachytes and trachyandesites. The amount of phosphorus in the rocks reflects the amount of modal and normative apatite.

Titanium content is high in the basic rocks, and becomes progressively lower in the acid rocks. It is an indicator of the modal and normative ferro magnesium minerals present, especially titaniferous augite.

Chemical differences in the igneous rock groups of the study area are demonstrated with a $FeO + Fe_2O_3 \times 100/FeO + Fe_2O_3 + MgO$ versus SiO_2 diagram (Fig. 26). It can be seen that the rocks are divisible on a chemical basis into 3 main magmatic series. The andesite-dacite-rhyodacite rocks, designated "A" series, show the least iron enrichment and the most silica enrichment. The mafic phonolites, designated "C" series, show the most iron enrichment and least silica enrichment. The trachytes and trachyandesites, designated "B" series, are intermediate to the "A" and "C" series.

Fig's 27, 28 and 29 show the main chemical variations in each series. Triangles represent data from Church (1973, Table 3-1). The solid circles represent data from this study. In these, the amount of a given oxide is plotted against the Modified Larsen Index (1/3 Si+K) - (Ca+Mg). Iron is not added because it would not be possible to show iron enrichment in a series satisfactorily. The Modified Larsen Index is conventionally taken as an index of magmatic evolution (Carmichael et al, 1974, 71), and is a measure of the basicity or acidity of the rock.

Fig. 26 MAGMATIC TREND DIAGRAM



(From Yoder and Tilley, 1962)

1 CLM-45 and #8 (average)
2 HWY-BC and #4,5,6,7 (average)
3 CLM-47 and #10 (average)
4 KNA-131
5 HWY-DM
6 SUM-1,F1-4,ROK-161,HWY-MV,HWY-YL,KNA-338,KNA-145, and #13,11 (average)
7 CLM-73
8 KNA-315
9 #12
10 #16
11 ROK-86,ROK-245,CLM-92,and #15 (average)
12 #14

#4,5,6,7,8,10,11,12,13,14,15,16 are analysis from Church (1973, Table 3-1)

Fig. 27 "A" SERIES VARIATION DIAGRAM

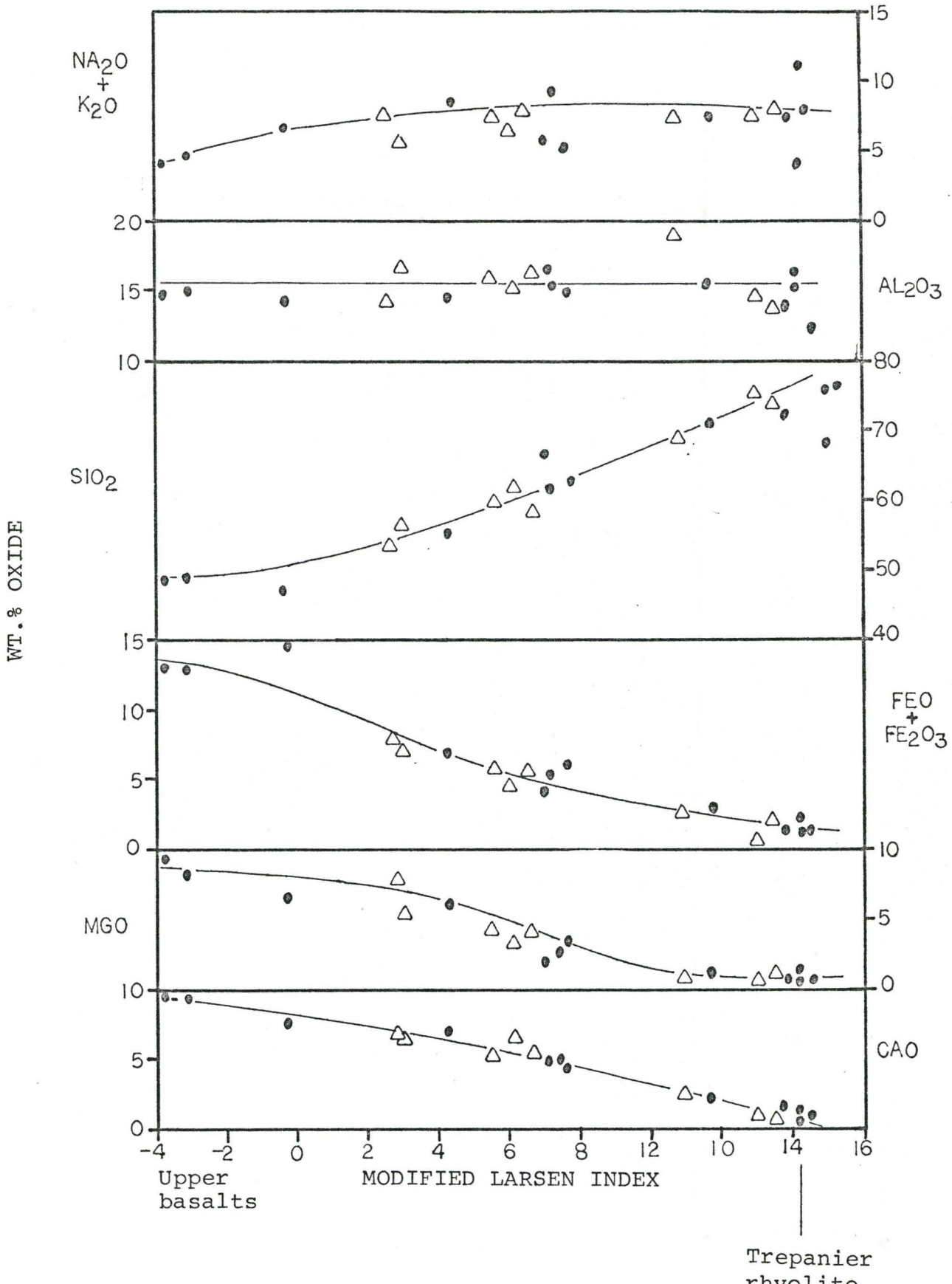


Fig. 28 "B" SERIES VARIATION DIAGRAM

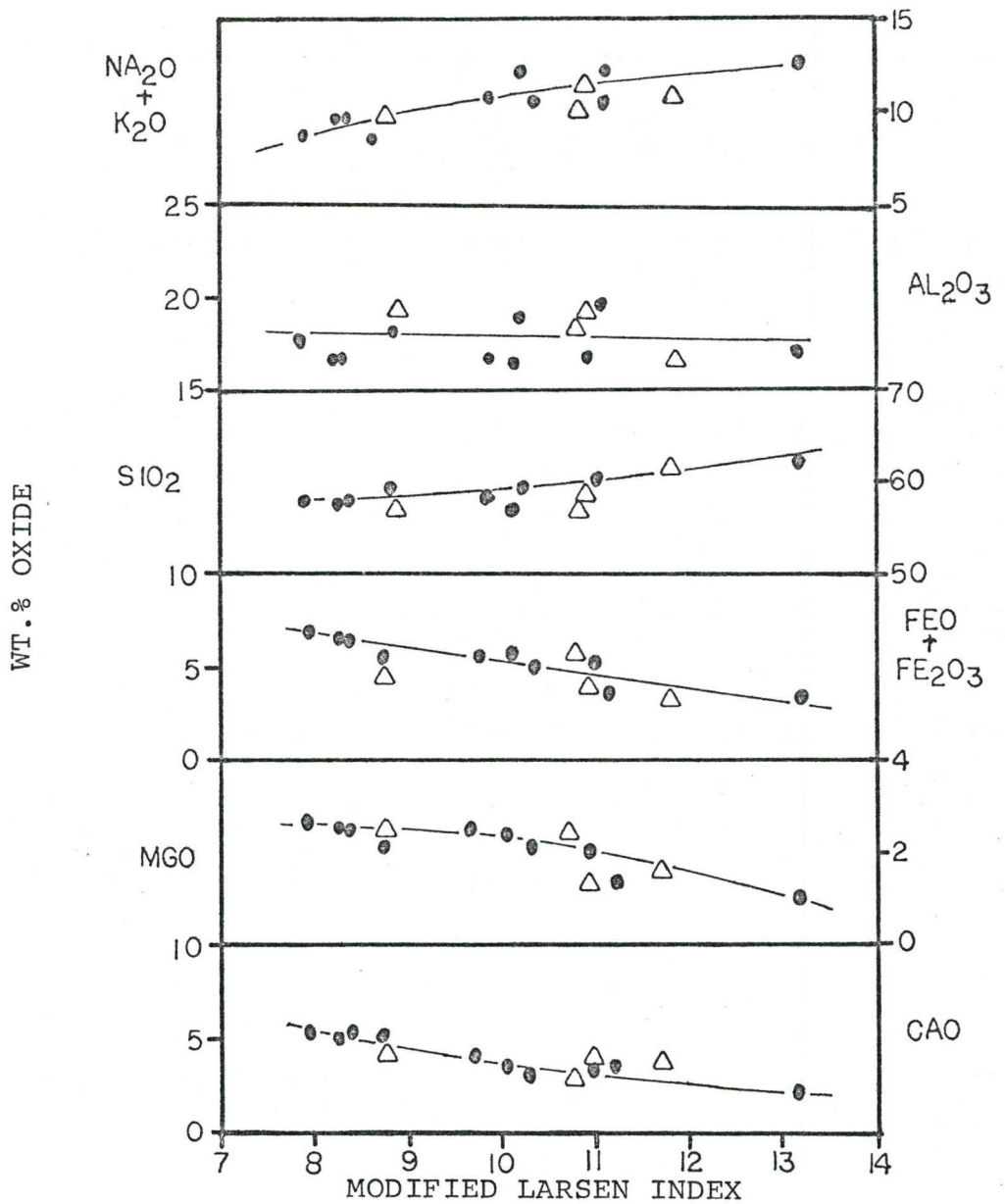


Fig. 29 "C" SERIES VARIATION DIAGRAM

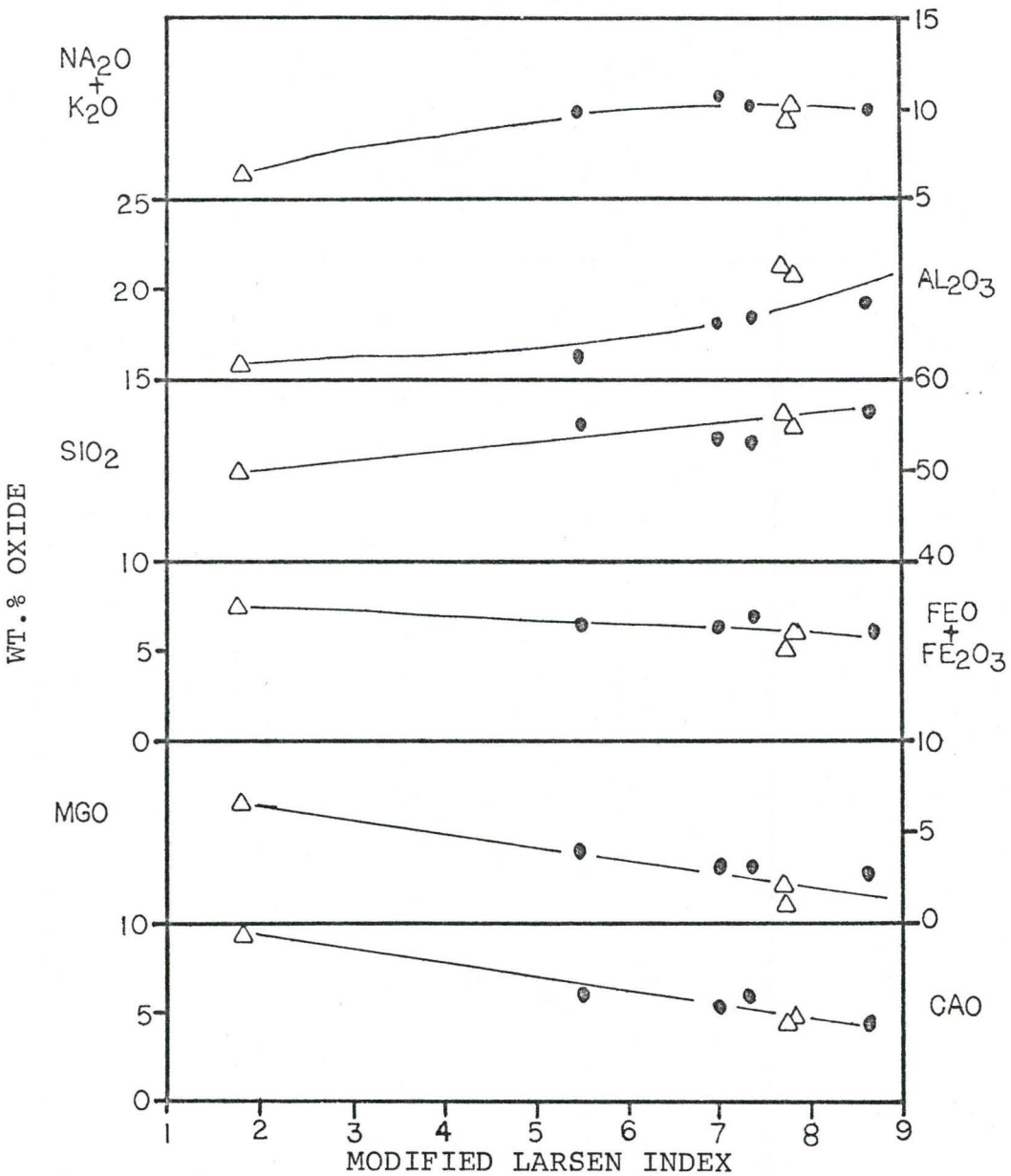


Fig. 27 is the "A" series variation diagram. This series represents a calc-akaline trend, and the important characteristics are as follows:

1) Silica increases, with increasing (1/3 Si+K) - (Ca+Mg).

2) The alkalies show only a slight increase with acidity.

3) Al_2O_3 is scattered showing no variation from the basic to the acid end.

4) Total iron CaO and MgO show similar decreasing trends with acidity.

The chemical variations observed in the "A" series rocks of south-central British Columbia are very similar to those observed for the basalt-andesite-rhyolite association of the San Juan Volcanic Province of Colorado (Turner and Verhoogan, 1960, 273-277); the Cascades Range, N.W. U.S.A. (Williams, 1942; Turner and Verhoogen, 1960, 277-279; Nockolds and Allen, 1952); and the Aleutian Islands, Alaska (Coats, 1952).

Fig. 28 is the "B" series variation diagram. These rocks are trachytes and trachyandesites, and the following trends are observed:

1) A slight increase in SiO_2 with acidity.

2) A slight scattered increase in alkalies with acidity.

3) Al_2O_3 is scattered and shows no chemical variation.

4) The refractory elements, Fe, Mg and Ca, show a decrease with acidity along an almost linear trend.

Similar trends to those in the "B" series rocks are also found in the igneous rocks of Eastern Otago in New Zealand (Benson, 1942), who states also that similar rocks can be found in Utah.

Fig. 29 is the "C" series variation diagram. These rocks are mildly alkaline in nature and show the following chemical trends:

1) SiO_2 increases linearly and slightly towards the acid end.

2) The alkalies increase slightly with acidity.

3) Al_2O_3 increases slowly and then rapidly with acidity

reflecting the high Al_2O_3 content of the mafic phonolite acid end members.

4) The refractory elements decrease with acidity, with iron decreasing to a lesser degree than the others.

Similar trends to those observed for the "C" series rocks of the Okanagan Valley are also observed in the mildly alkaline lavas of the Crater Highlands and the Rungwe area in Tanganyia (Sutherland, 1960). The basic potassic lavas of the Highwood Mountains in central Montana also resemble the mafic phonolites of south central B.C. in chemistry, as well as mineralogy (Hurlbut and Griggs, 1939; Larsen, 1940; Larsen et al, 1941).

TRACE ELEMENTS

CHEMICAL VARIATION

Variations in the abundance of trace elements are of great importance in evaluating the evolution of igneous rocks. Trace elements tend to be good indicators of differentiation in magmatic processes because variations in their abundance tend to be more regular, generally, than those of the major elements, and the partition co-efficients of many of them are generally smaller (Schnetzler and Philpotts, 1968).

Table VI shows the ranges and variations in trace elements within the volcanic sequence. Appendix F contains the results of the analyses for each sample.

Rubidium shows a wide variety of chemical variation. A plot of K/100 vs Rb (Fig. 30) gives a linear trend with the equation of the line being K = 300 Rb + 6000. This indicates that Rb enrichment parallels K enrichment, and that the K/Rb value is 300, which is in the range of K/Rb ratios for acidic rocks and potash rich lavas, and is only slightly above the value for average crustal rocks (Erlank, 1968).

The potassium enriched rocks are the basal rhyolites, the mafic phonolites, and the trachytes and trachyandesites. These rocks, being enriched in Rb relative to the others, contain varying amounts of alkali feldspar and potassic mica. Rb substitutes for potassium and prefers the mica structure over

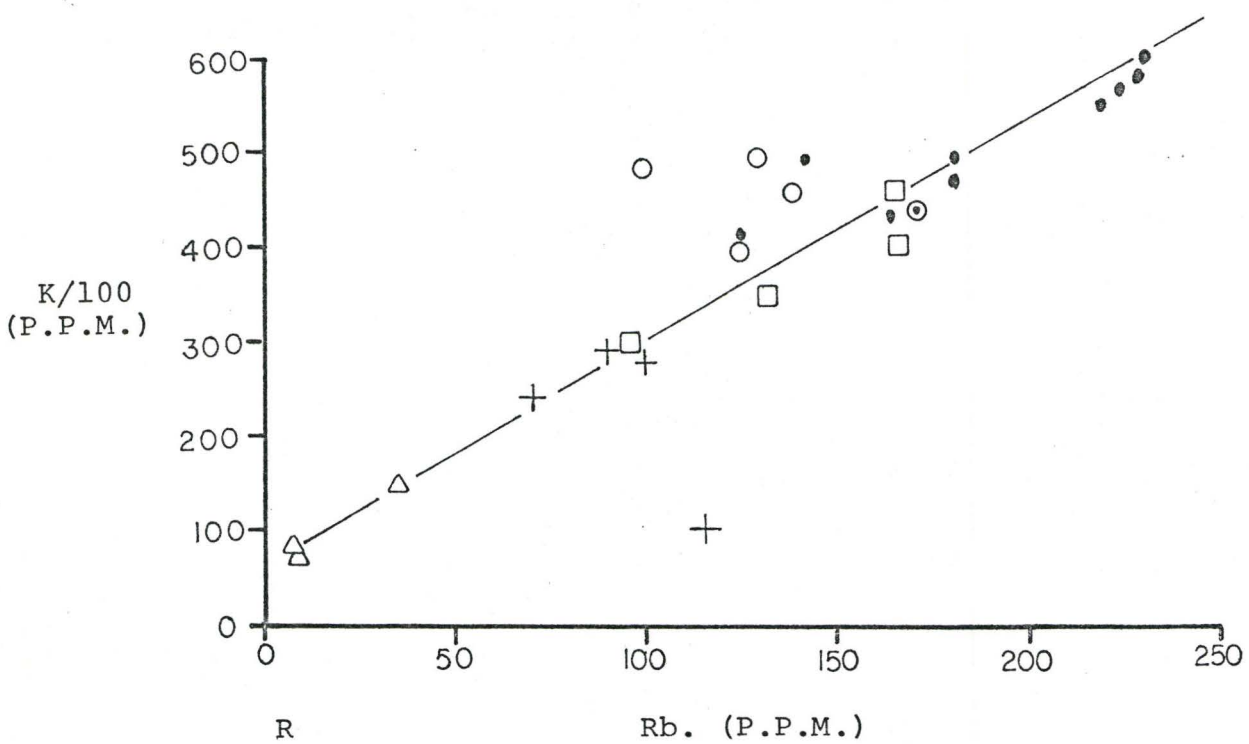
TABLE VI TRACE ELEMENT VARIATIONS (P.P.M.) OF MAJOR ROCK UNITS

	Shingle Crk. Porph.	Trepanier Member	Trepanier ash flow	Yellow Lake Member	Kitley Lake Member	Kearns Crk. Member
Number of analyses	1	1	2	4	4	1
Rb	166.0	131.8	96.1-165.4	97.0-140.7	126.5-230.1	169.5
Sr	1154	904	522-976	3000-4474	1690-1806	1144
Ba	2368	1505	1793-1970	3126-3899	2588-2827	2432
Y	39	41	13-14	24-25	18-29	21
Zr	206	609	186-189	321-329	256-355	209
Nb	15	60	18-20	65-89	36-81	37
Ni	16	17	17-19	27-51	14-20	102
Zn	43	44	39-49	92-115	58-105	91
Pb	38	40	32-35	30-42	30-41	39
U	7.3	3.2	5.2-7.6	8.4-13.0	6.5-8.3	3.4
Th	36	37	28-40	49-53	20-52	13
K/Rb	243.5	263.9	276.5-310.9	314.1-504.0	255.8-353.9	261.5
Rb/Sr	0.14	0.15	0.20	0.02-0.04	0.07-0.13	0.15

TABLE VI (CONTINUED)

	Nimpit Lake Member	Nimpit Lake ash flow	Park Rill Member	Marama Formation	Upper Basalts
Number of analyses	4	1	2	2	4
Rb	179.8-225.6	233.9	67.8-87.8	100.7-116.9	9.6-34.8
Sr	1128-1560	958	842-1164	400-570	494-510
Ba	1868-2642	1497	1231-1708	1315-1368	227-497
Y	16-43	19	20-23	11-15	21-31
Zr	220-267	260	176-224	143-167	119-305
Nb	27-38	33	16-29	12-14	22-61
Ni	26-43	49	22-34	19-21	117-166
Zn	67-79	78	75-82	70-74	103-107
Pb	33-42	41	24-32	29-32	0-9
U	1.9-5.2	2.8	3.8-4.0	4.8-5.7	0-2.0
Th	15-24	21	7-14	9-10	0
K/Rb	248.0-267.1	247.7	335.6-349.0	85.2-281.1	446.0-812.7
Rb/Sr	0.12-0.16	0.24	0.08	o.21-0.25	o.o2-o.18

Fig. 30 POTASSIUM VS. RUBIDIUM DIAGRAM



△ Basalts
□ Rhyolites
+ Andesites-Rhyodacites
⊙ Basaltic Andesites
• Trachyandesites-Trachytes
○ Phonolites

all others, but because the abundance of potassic feldspar is much higher in these rocks, a greater percentage of the Rb will be contained in the feldspar (Erlank, 1968).

Strontium and Ba are highly enriched in the phonolites, lesser enriched in the trachytes, trachyandesites, and rhyolites; and are low in the basalts, andesites and dacites. These two elements are taken up largely by potassic feldspar. Sr shows no affinity for potassic mica, whereas Ba does (Goldschmidt, 1954, 246), but modal mica is fairly low in the rocks compared to modal K-feldspar.

Sr substitutes for Ca in calcium minerals, such as apatite and plagioclase (Goldschmidt, 1954, 244), but no distinct trends are observed indicating Sr enrichment in plagioclase, except possibly in the trachytes and trachyandesites. There may be some enrichment of Sr in apatite in the mafic phonolites, and, to a lesser extent, in the trachytes and trachyandesites. Because of the differences in the ionic radii between Ca^{2+} and Ba^{2+}, Ba rarely enters the lattices of Ca minerals (Goldschmidt, 1954, 250). In conclusion, it seems that the high concentrations of Sr and Ba in the mafic phonolites, trachytes and trachyandesites and basal rhyolites can be accounted for by the abundance of potash feldspar in these rocks.

Yttrium, Zr and Nb show very similar chemical variation as well. The basal rhyolites contain the greatest abundance of all these elements, with the phonolites, trachytes and trachyandesites containing lesser amounts, and the basalts, andesites and dacites containing the least. These elements are known to concentrate in later stage "residual" magmas in rock series which are considered to be developed by fractional crystallization, particularly in those magmas characterized by higher concentrations of alkali minerals (Butler and Smith, 1962; Goldschmidt, 1954, 314, 504).

Yttrium, zirconium and niobium are all very low in the basal rhyolite ash flow, compared to the concentrations in the lava flow. Weaver and Scean, (1972) attribute this phenomenon

to the preferential partitioning of the elements to a volatile phase which was lost during or shortly after eruption.

Nickel and zinc are concentrated in the more mafic rocks, and in particular, Ni is very abundant in the basalts. Both these elements occur in higher concentrations in mafic and ultramafic rocks in the ferromagnesium silicates, such as olivines and oxides, and to a lesser extent, pyroxenes (Goldschmidt, 1954, 262, 669-671). These minerals crystallize early; therefore, high nickel and zinc concentrations indicate an early stage of crystallization or magmatic differentiation.

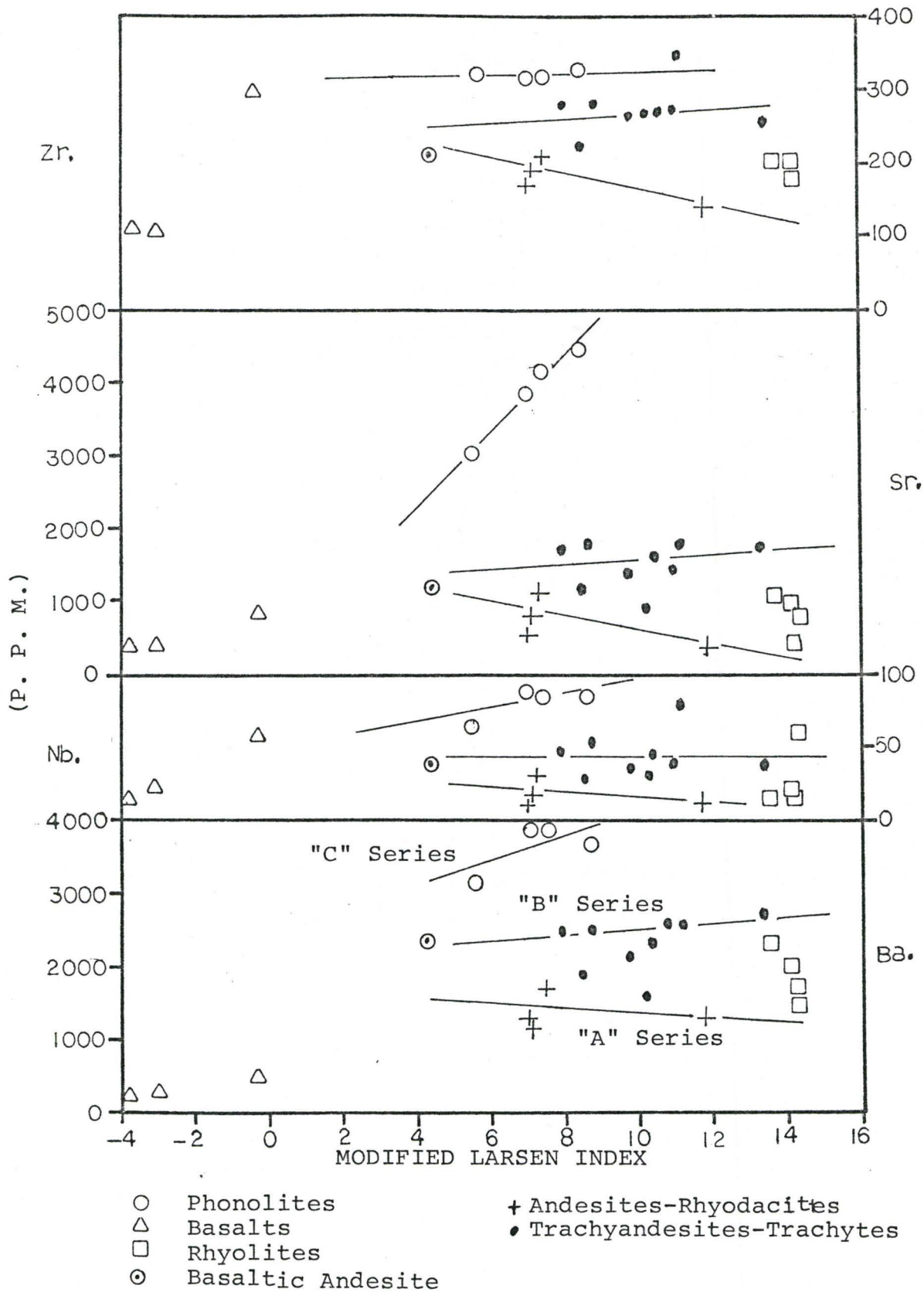
Lead shows no significant variation, except it is extremely low, near the sensitivity limit, in the basalts. It is generally captured in potassium minerals, especially the early crystallizers, and in magmatic calcium minerals, such as apatite, which has a great capacity for lead (Goldschmidt, 1954, 398).

Uranium and Th have higher concentrations in the phonolites. This may be related to the abundance of apatite in these rocks, since uranium is commonly captured by apatite. The data obtained is near the sensitivity limit of the analysis.

Fig. 31 is a plot of the trace element concentration versus the Modified Larsen Index to show chemical variations.

Strontium, Ba, Zr, and Nb proved to be the most useful, and all show similar trends. The mafic phonolites become highly enriched in each element as they become more acid, except for Zr, which shows only slight enrichment. The trachytes and trachyandesites become slightly enriched in each element, and the andesite-dacite-rhyodacite trend is one of element depletion. The lines in some cases were fitted with some speculation involved, and more data is needed to substantiate the trends. The enrichment of the "C" and "B" series rocks in these elements is a function of the high proportion of K-minerals in the rock, to which Sr and Ba will partition, and also shows that the rocks may be representative of residual magmas. The depletion of the calc-alkaline rocks in these elements is a function of the lack

Fig. 31 TRACE ELEMENT VARIATION DIAGRAM



of K-minerals crystallizing in the later stages of the liquid, and these elements would probably enter the lattices of minerals which crystallized earlier. For example, Sr substitutes for Ca in plagioclase, which crystallizes early; hence, as differentiation takes place, strontium becomes depleted. This evidence favours the previous line of thought, that there are three separate magmatic series present.

The Upper basalts and basal rhyolites occur in separate clusters, and do not appear to be related to any one trend. The basaltic andesite seems to be related to both the "A" series and the "B" series.

CHAPTER VI

PETROGENESIS

The origin of the volcanic rocks in south central B.C., as well as those in the rest of the eastern flank of the Cordillera, has been a topic of debate among petrologists for many years. Many hypotheses have been postulated, but no conclusive evidence has yet been obtained allowing petrologists to arrive at any one solution. One thing is almost certain, though, the origin of the volcanic rocks in this area is related to an orogenic event and intense tectonic activity.

Upon applying the evidence obtained in this study to some of the hypotheses postulated in the past, some speculative lines of thought emerge regarding the origin of the early Tertiary lavas.

Evidence from chemical variation and petrographic studies indicate that there are three main magmatic series:

1) "A" series - alkaline basaltic andesite?-andesite-dacite-rhyodacite.
2) "B" series - alkaline basaltic andesite?-trachyandesite-trachyte.
3) "C" series - mafic phonolites.

It is also clear at this point that the Trepanier Member and the Upper Basalts bear no genetic relationship to the main series lavas (Yellow Lake Member through to the Marama Formation). The basal rhyolites contain high concentrations of Y, Zr and Nb, indicating they are late differentiates from an earlier magmatic series. Lying at the base of the volcanic sequence and being a late differentiate makes it impossible for them to be related in any way to the main series volcanics.

The Upper basalts, on the other hand, are early differentiates of a magmatic series as evidenced by the high Ni and Zn content. Early magmatic differentiates lying at the top of a volcanic sequence cannot be related to that underlying volcanic sequence.

"A" SERIES (Andesite-Dacite-Rhyodacite)

The "A" series is represented by a limited spectrum

of calc-alkaline rocks.

The factors which must be considered in the discussion on the genesis of these lavas are:

1) The uniform distribution of phenocrysts.
2) Presence of resorbed biotite and hornblende.
3) Two generations of plagioclase feldspar.
4) Abundant glass in the matrix.
5) Depletion of trace elements with increasing acidity.
6) Slight increase in the FeO/MgO ratio and SiO_2, and a general decrease in the refractory elements.

Many of these features are common to andesitic provinces (Turner and Verhoogen, 1962, 276), and therefore have some genetic significance. Osborn (1957) notes that some of these chemical variations are typical for rocks which differentiated as a result of fractional crystallization from a "wet" magma under constant oxygen pressure. Some of the features express a tendency for mutual association of minerals belonging to different stages of magmatic evolution. This concept is better understood if we assume that the magmas are thoroughly mixed, partially crystalline, and were derived from some parent. The presence of uniformly distributed phenocrysts of similar composition in the series proves that the magma at extrusion was partially crystalline and thoroughly mixed.

The presence of both hornblende and biotite in the andesite, in particular, shows that the magma was "wet". Resorption of the hornblende and biotite to give partial pseudomorphous aggregates of magnetite, involves the oxidation of iron to the ferric state (Turner and Verhoogen, 1960, 277). Resorption of these minerals in volcanic rocks is a response to a decrease in Ph_2O at or near the time of extrusion (Turner and Verhoogen, 1960, 138-139). Under conditions of high water pressure the biotite crystallizes readily. On ascending from depth at which the phenocryst assemblages formed, the water escapes as a volatile phase, and the Ph_2O is lowered. This, in turn, shrinks the biotite stability field, resulting in magmatic corrosion of the biotite (Carmichael, 1967). Hornblende behaves in a similar manner.

The andesites and dacites typically contain what might

be two generations of plagioclase feldspar. The first is in the form of stubby, compositionally zoned crystals; and the second is in the form of slender, rectangular, unzoned laths.

The first generation feldspars may be a result of early crystallization in the magma chamber under conditions of high PH_2O, which effectively lowers the crystallization temperature of the minerals, raises the feldspar solvus, and reduces the extent of ternary solid solution (Carmichael et al, 1974, 220-227). These feldspars show a well-developed sequence of oscillatory zonations in many cases, as well. This is most likely due to the crystallizing feldspar moving in and out of equilibrium with the liquid, due to changes in some of the dependant parameters, such as pressure, temperature, water pressure, oxygen pressure, etc. The second generation feldspars probably started to crystallize shortly before the magma was extruded, or during a time when the liquid remained compositionally constant, which could have been only for a short time.

The rocks of the "A" series contain a considerable quantity of glass compared to the rocks of the "B" and "C" series. This is a function of the water content which plays a significant role at the eruptive stage (Kennedy, 1955). A dry magma has a higher liquidus temperature than a wet magma. If the magma reaches the surface as the liquidus temperature is reached, there should be plenty of glass and some phenocrysts. The dacites and rhyodacites are characterized by relatively high proportions of glass, compared to the andesites and basaltic andesites. It is also the dacites and rhyodacites, which contain abundant feldspars with "swallow tails" in the ground mass, indicating rapid quenching (Fig. 20).

The FeO/MgO ratio shows a slight increase with silica content (Fig. 26). Fenner (1929) studied the crystallization of basalts and discovered that magnesium concentrated in the ferro-magnesium minerals, such as pyroxene and olivine, in greater proportions than iron. This resulted in the residual liquid becoming iron enriched, along with silica.

Rocks of the "A" series are also characterized by a

decreasing Sr, Ba, Nb and Zr trend. This behaviour is most likely correlated with the removal of these elements by early crystallizing minerals.

The evidence given thus far is strongly in favour of the "A" series lavas being derived as a result of fractional crystallization of a parent magma. Although no field evidence exists which may give some clue as to what the parent magma may have been, several possibilities exist.

Kennedy (1933) suggested that a probable parent of the calc-alkaline series of rocks is a tholeitic magma type. The possibility exists that the calc-alkaline series observed in south sentral B.C. is the result of differentiation of a primary magma similar in composition to the Miocene basalts in the area. Field evidence is lacking to support this suggestion. Experimental work carried out by Green and Ringwood (1968) supports a possible model for the origin of calc-alkaline rocks based on a two-stage magmatic process. The first stage involves the fractional melting of a pyrolite mantle to produce an under-saturated basaltic magma which rises to higher levels. Ringwood and Green (1966) state that this is a likely process in contin-ental margins. Water enters the pile, resulting in amphibolite forming in the lower parts. Subsequent heating due to orogenic episodes leads to partial melting at pressures up to 10Kb (basal crust), giving rise to calc-alkaline members. Field evidence for such a process is lacking, as basalt rocks should start off the sequence.

Variation diagrams are often good indicators of parent magma composition (Turner and Verhoogen, 1960; Nockolds and Allen, 1953). If a well-established trend is obtained, then the area on the diagram where most scatter begins is represen-tative of the composition of the parent magma. In order for this to be of any value, a great number of data points must be plotted. One would expect the parent magma to be located near the basic end of the spectrum, but Turner and Verhoogen (1960) point out that in some calc-alkaline series diagrams, the parent magmas correlate with an oversaturated magma of basaltic andesite

composition (53-54% SiO_2). The basaltic andesite of the Kearns Creek Member examined in this study (55.4% SiO_2), is alkaline in nature, and unless differentiation of the magma took place along an unusual path, it would not represent the parent magma.

Church (1973) has shown by the use of fractionation diagrams that if a crystal cumulate of pyroxene, hornblende and plagioclase was removed from a magma of andesite composition (Park Rill Member), then the "A" series rocks could be generated.

In summary, a model for the genesis of the calc-alkaline rocks in south central B.C. is as follows:

A parent magma of composition close to that of andesite existed at depth with a high PH_2O and high fO_2. Plagioclase, pyroxene, olivine, hornblende and biotite crystallized out of the magma, taking with them large amounts of Ca, Mg, Sr, Ba, Ni and Zn, and lesser amounts of Fe. The crystal cumulate, along with large amounts of liquid,with which they were still in equilibrium, began to rise to the surface. With lower load pressures, the PH_2O and fO_2 decreased as a result of volatile escape. This resulted in resorption of the biotite and hornblende as their stability fields shrank, and raising of the liquidus temperature. Therefore, crystallization slowly came to an end, and the magma extruded on surface was andesitic in composition, with some glass in the ground mass. The residual liquid left behind was higher in SiO_2 and FeO/MgO, but lower in Ca, Mg, and the trace elements. Further fractionation after very short periods of time under dryer conditions gave rise to the formation of the dacites and rhyodacites with abundant ground mass and glass.

"B" SERIES (Trachyandesite-trachyte)

In discussing the origin of the "B" series lavas, factors which must be considered areas follows:

1) The presence of two feldspars and alkali feldspar mantling plagioclase feldspar.

2) Resorbed biotite.

3) Large increase in the FeO/MgO ratio.

4) Slight increase in trace element concentrations.

5) Presence of abundant microlites of feldspar in the ground mass.

6) Presence of large glomerophenocrysts of plagioclase feldspar and clinopyroxene.

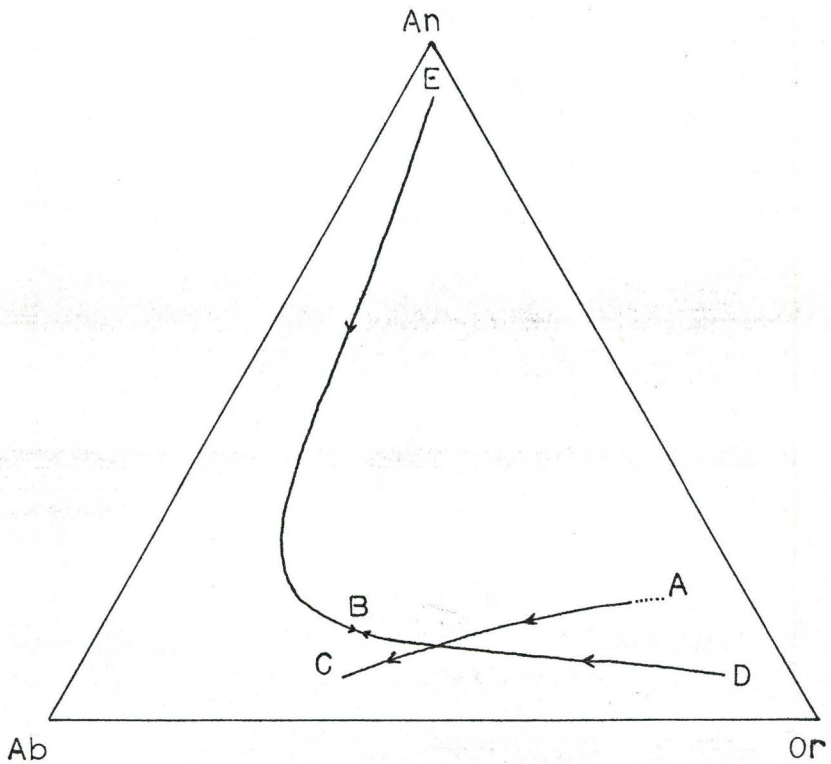
The origin of the alkali feldspar jackets on plagioclase is a key factor in the genesis of the "B" series lavas, and the ternary system Ca Al_2 Si_2O8 - Na Al Si_3O8 - K Al Si_3O8 must be considered.

The appearance of two feldspars during crystallization in trachytic magmas depends to a large extent upon the amount of solid solution between the feldspars and on the temperature of crystallization (Tuttle and Bowen, 1958). The temperature of crystallization of feldspars is highest in trachytes, which are deficient in both silica and nepheline. At high T's, the maximum ternary solid solution exists, but decreases at lower temperatures. Fig. 32 depicts the system anorthite-albite-orthoclase. While two feldspars co-exist in equilibrium, the liquid in terms of the feldspathic components will be confined to a boundary curve, A-C. At the temperature at which both feldspars attain the same composition, C, the boundary curve will terminate (Carmichael, 1965; Tuttle and Bowen, 1958). Evidence from volcanic rocks suggests that this boundary curve terminates very close to the alkali feldspar sideline (Tuttle and Bowen, 1958). This close approach is indicated by the co-existence of plagioclase and potash feldspar in the lavas.

The effect of water in the system is to reduce the extent of ternary solid solution, and the effect of pressure is to raise the feldspar solvus.

At moderately high temperatures, pressures and PH_2O, there would be considerable amounts of plagioclase feldspar crystallizing. If the magma began to rise, water would escape as a volatile phase as the pressure and temperature decreased. The boundary curve A-C (Fig. 32) would move into the potash feldspar region, resulting in enrichment of normative potash

Fig. 32

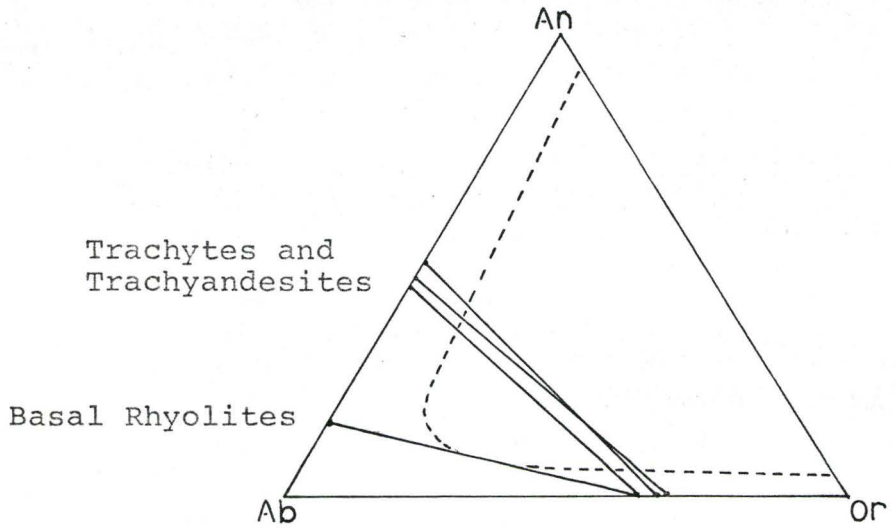


Ternary diagram of the system $NaAlSi_3O_8$-$KAlSi_3O_8$-$CaAl_2Si_2O_8$.
The approximate limit of solid solution under conditions expected in trachytic magmas is given by the curve D-B-A. Feldspars having compositions along the curves DB and EB are in equilibrium with liquids having compositions along A-C. At the temperature of B a single feldspar is in equilibrium with the liquid at C. The temperatures represented by this diagram are relatively high and are comparable to those existing in trachytic lavas. Arrows indicate directions of falling temperature.
(From Tuttle and Bowen, 1958, Figs. 64 and 65).

feldspar and crystallization of the mineral (Carmichael et al, 1974; Rahman and Mackenzie, 1969; Tuttle and Bowen, 1958). The result then could be earlier crystallized plagioclase feldspar with later crystallized alkali feldspar mantling them, since the plagioclase crystals could act as growing nuclei. Some of the plagioclase crystals have corroded margins. This indicates that the boundary curve was nearing its termination where it becomes a resorption, rather than a co-precipitation curve (Tuttle and Bowen, 1958).

Church (1963; 1973) has shown that the orientation of the tie lines joining the compositions of the co-existing feldspars in the ternary system is very important. The feldspar compositions in the trachytes and trachyandesites were joined by steeply-dipping tie lines, and the feldspar compositions in the basal rhyolites were joined by shallow-dipping tie lines (Fig. 33). According to Yoder Stewart and Smith (1956-1957), steeply-dipping tie lines indicate low pressure-high temperature conditions, and tie lines of gentle slope suggest high pressures and lower temperatures. This further substantiates the conclusion stated earlier, that the basal rhyolites bore no close genetic relationship to the overlying rocks.

Fig. 33



Ternary relations of the co-existing feldspars as shown by the tie lines.
------- solid solution boundary.
(From Church, 1963).

Plagioclase feldspar as well as clinopyroxene are found in large clusters, suggesting they may have been derived from loose crystal accumulates in a magma chamber (Church, 1973). This further supports the early crystallization of plagioclase and clinopyroxene.

The slight increase in Ba, Sr, Zr and Nb content, with increasing acidity, is a function of these elements being contained in the later crystallizing potash feldspar, and residual liquid.

As crystallization proceeded with clinopyroxenes, olivine and other mafic minerals, the residual magma became enriched in iron as well as alkali feldspar. As crystallization advanced towards its close, the increasing concentration of potash in the residual magma was expressed in two ways:

1) microlites of feldspar,
2) mantles about the plagioclase.

These characteristics were also observed by Benson (1942; 1944) in his study of the igneous rocks of Eastern Otago in New Zealand. Kennedy (1955) stated that water tends to diffuse toward the cooler marginal and upper portions of a melt. Morey and Hesselgesser (1952) demonstrated by a series of experiments in the H_2O-Na_2O-SiO_2 system, that alkalic silicates are extremely soluble in superheated water vapor at high pressures. Water migrating toward the upper portions of the magma column will carry dissolved alkalies with it, thus enriching the upper portion of the magma chamber in alkalies, and decreasing it in silica. If this process was allowed to continue for a long period of time, there would be significant enrichment of alkalies in the top of the column. Lower in the column, plagioclase feldspar would be crystallizing, and being "light", would float up into the alkali rich portion. During the rise of the magma up the vent, pressure and temperature would decrease, volatiles would escape, and the solubility of the alkaline feldspars would decrease, resulting in the crystallization of the alkali feldspar. This mechanism also accounts for the mantling of

plagioclase feldspar by alkali feldspar, and may even account for the formation of the Kitley Lake Member as a result of fractionation from an alkaline basaltic parent. Some remaining portion of the residual magma, still rich in alkalics and mafic constituents, may have erupted, giving rise to the Kearn's Creek alkaline basaltic andesite, shortly after the first eruption. The residual magma may have undergone alkali separation again by the same process as discussed earlier, and further eruption would give rise to the Nimpit Lake Member. It was mentioned earlier that the alkaline basaltic andesite may be related to both the "A" and the "B" series. If this is the case, then the final residual magma must have been depleted in alkalies and fractionated further to give rise to the calc-alkaline rocks of the "A" series. Church (1963) discovered that plagioclase feldspar in latites of the "A" series had the same composition as the plagioclase in the trachyandesites of the "B" series. This may indicate that the "A" and "B" series were derived from the same parent magma by a complicated process similar to the one described above. The parent magma may have had a composition similar to that of the Kearns Creek basaltic andesite.

In summary, the origin of the tracyandesites and trachytes may have been very similar to the origin of the "A" series rocks, with the exception that the parent magma was enriched in alkali elements, and ternary solid solution of the feldspars played a major role in the genesis of the "B" series rocks. It is also possible that the "B" and "A" series rocks were derived from a similar parent magma by a complicated series of fractionations.

"C" SERIES (Mafic Phonolites)

In discussing the genesis of the mafic phonolites, the following factors must be kept in mind:

1) Presence of primary analcite with microvugs and inclusions of feldspar.

2) Large increase in FeO:MgO ratio, and the high

Al_2O_3/SiO_2 ratio.

3) Abundant potash feldspar.

4) Euhedral phenocrysts of clinopyroxene and potash feldspar.

5) Enrichment of trace elements.

A theory postulated in the past to account for alkaline rocks is one of lime assimilation of a primary basaltic andesite (Daly, 1912; Church, 1963). This theory accounts for the high alkalinity and low silica and if assimilation of clayey sediments has occurred as well, then the high concentrations of trace elements, such as Ba and Sr can be accounted for (Coats, 1952). Although pre Tertiary limestones and clayey sediments exist in south central B.C., it seems difficult to account for the large thicknesses of mafic phonolites observed. Field evidence for this mechanism is also lacking.

As was mentioned earlier, mafic phonolites of similar mineralogy and chemistry to the Yellow Lake phonolites comprise part of the Tertiary volcanic sequence of central Montana. Petrographic and chemical variation within the region is explained in terms of magmatic differentiation of an alkaline olivine basalt modified possibly by assimilative reactions.

With separation and removal of calcic plagioclase and orthopyroxene at depths, an Fe rich and Mg poor, but increasingly alkaline magma would result, giving rise to the mafic phonolites (Currie, 1976).

The occurrence of primary analcite in the mafic phonolites is an indicator of crystallization at depths under conditions of high PH_2O (Kim and Burley, 1971; Burley, Personal Communication, 1978). This depth corresponds to a pressure of about 7½ kb, below which the analcite becomes unstable and the nepheline, albite and water field become stable. The microvugs and feldspar inclusions may be accounted for by the analcite becoming unstable upon rising to the surface.

The alkalinity of the mafic phonolites can be accounted for by a long period of differentiation of a primary magma,

such as an alkaline olivine basalt at great depths under conditions of high water pressure. Because of the slow differentiation process, euhedral phenocrysts would be able to form. The enrichment in trace elements, especially Ba and Sr, are a direct result of the enrichment of the magma in potash feldspar.

Another mechanism for the origin of the mafic phonolites was demonstrated by Church (1973). If a crystal cumulate composed dominantly of clinopyroxene and biotite, with small amounts of potash, was subtracted from a rock of tephrite[1] composition, a rock with composition similar to the mafic phonolites would result. Still, the primary analcite must be accounted for, and if this mechanism took place, one would expect to find the tephrite stratigraphically lower in the sequence, not higher.

One last theory proposed by Church (1973) is certainly worth mentioning. If magma of the "A" series was allowed to mix with "C" series magma, then a magma of "B" series composition could result. Evidence for this is as follows:

1) Alkali feldspars of"C" series mixing with plagioclase feldspars of "A" series would give two feldspars of "B" series.

2) Low apatite trace element and alkalies content plus low FeO/MgO and Al_2O_3/SiO_2 ratios of "A" series, mixed with high values of these components in "C" series, would result in intermediate values for the "B" series.

These features are observed in the volcanic rocks of south central B.C., but if this did occur, the presence of the alkaline basaltic andesite in the series would be difficult to explain, and one would expect to find inclusions of "A" or "C" series rocks in the "B" series rocks.

In conclusion, the various flows found in the early Tertiary volcanic sequence of south central B.C. can be accounted for by fractional crystallization of different magma types.

(1) Tephrite is a plagioclase, feldspathoid basic lava, and is found in the Skaha Formation of south-central B.C.

The calc-alkaline rocks from a basaltic andesite or andesite parent, the trachytes and trachyandesites from an alkaline basaltic andesite or basalt, and the phonolites from an alkaline olivine basalt over a long period of time.

CHAPTER VII

SUMMARY AND CONCLUSIONS

The volcanic rocks of the Okanagan Lake region of south-central B.C. are characterized by a very diverse sequence of early Tertiary lava flows and pyroclastic flows.

The lavas range from basic to semi-basic to acid composition with intermediate types, andesites, trachyandesites and trachytes predominating.

Evidence from mineralogical and chemical variation indicates that the rocks can be divided into three series, namely, the "A", "B" and "C" series.

"A" series is a silica-enrichment calc-alkali series, showing regular chemical and mineral progression from andesites to dacites to rhyolites. The more basic rocks contain plagioclase feldspar, augite, magnetite, and/or hornblende, and olivine with traces of biotite. The more acid rocks contain less ferro-magnesium minerals, and more glass in the groundmass.

The "B" series is characterized by two feldspar lavas, trachyandesite and trachyte. Alkali feldspar in these commonly forms jackets around the plagioclase feldspar, which varies in composition from An20 - An40. The ferro-magnesium minerals include augite, olivine, and biotite and magnetite are usually accessory. The "B" series shows less silica-enrichment and more iron-enrichment than the "A" series.

"C" series are silica-undersaturated phonolite lavas, which occur near the base of the stratigraphic sequence. They are rich in analcite and potash feldspar, as well as augite, olivine and magnetite, with lesser amounts of biotite. Chemically, the mafic phonolites are distinguished by low silica-enrichment and high iron-enrichment, as well as marked increases in Sr, Ba and Rb, compared to the "A" and "B" series.

The "A", "B" and "C" series are believed to be genetically unrelated, but the "A" and "B" series may be linked by a common parent magma.

The most probable origin of the "A" series lavas is magmatic differentiation of a basaltic andesite or andesite parent under initial conditions of high PH_2O and high fO_2. The origin of the "B" series lavas is envisaged as being a result of magmatic differentiation of an alkaline basaltic andesite under conditions of high PH_2O and high fO_2. It is quite possible, however, that the "A" and "B" series are linked by a common alkaline basaltic andesite parent. If this is the case, then the differentiation process was complicated by the segregation of alkalies in the water-rich upper portions of the magma column. Eruption of this portion of the column would give rise to "B" series lavas and leave the residual magma depleted in alkalies. The "A" series lavas could then be generated.

The most probable origin of the "C" series lavas is magmatic differentiation of an alkaline olivine basalt, with the removal of calcic plagioclase and orthopyroxene at depth. Lime assimilation may have modified the process.

The "B" series lavas are intermediate to the "A" and "C" series lavas, both mineralogically and chemically, and it is possible that mixing of the "A" and "C" series magmas, to give rise to the "B" series lavas, occurred.

A P P E N D I X

APPENDIX A, PETROGRAPHIC DESCRIPTIONS OF MEMBERS NOT INCLUDED IN MAIN TEXT

SHINGLE CREEK RHYOLITE PORPHYRY (S.C.P.)

This sample was collected from the Skaha Lake region about six miles south-east of Penticton.

From known exposures, the Shingle Creek Porphyry intrusion is about 4 miles long and 1.5 miles wide (Bostock, 1966). It is believed to be a feeder dike to the Trepanier rhyolite and ash flow.

The porphyry is granitic and contains abundant euhedral sanidine phenocrysts measuring between a couple of mm. and 10 cm. in length. Large phenocrysts displaying Carlsbad twins are common, as are untwinned ones (Fig. A-1). White plagioclase phenocrysts and rounded and embayed quartz phenocrysts measuring up to 1.5 cm. are common. These are set in a buff to pink aphanitic matrix.

Examination of the rock in thin section reveals that it is composed of phenocrysts of sanidine, plagioclase, quartz, and biotite set in a fine grained matrix of dust, feldspars, quartz, oxides and glass.

Sanidine phenocrysts have a considerable variation in size, from less than 0.5 mm. in thin section, to 10 cm. in hand specimen. They are commonly euhedral and display Carlsbad twins.

Plagioclase feldspar ranges from less than 0.5 mm. in thin section to 1.5 cm. in hand specimen. They are usually stubby and rectangular, with slightly corroded edges. A composition based on extinction angles is An26.

Quartz phenocrysts occupy the same size range as the plagioclase feldspar. They are commonly rounded and embayed, indicating resorption at lower pressures and temperatures.

Some slightly corroded brown pleochroic biotite flakes of rectangular habit, varying from 0.3 to 0.6 mm. in length, occur as free floating phenocrysts, showing a tendency to become aligned in a parallel fashion around the larger phenocrysts.

Magnetite does not occur as phenocrysts, but is scattered randomly and scarcely throughout the groundmass. The rest of the groundmass consists of a very fine grained mixture of feldspar, quartz, dust and minor glass.

Sanidine and plagioclase feldspar phenocrysts are commonly replaced partially by a mixture of sericite, carbonate and clay minerals.

TREPANIER RHYOLITE ASH FLOW (KNA-43, IR-267)

This portion of the Trepanier Member is characterized by non-welded crystalline pyroclastic flows containing a large proportion of devitrified glass.

Crystals present include plagioclase feldspar, potash feldspar, quartz and minor biotite.

The plagioclase feldspar occurs as randomly oriented rectangular laths, ranging from less than 0.2 mm. to about 4.0 mm. Corners are commonly rounded.

Less abundant than plagioclase are corroded, rounded crystals of potash feldspar which occupy about the same size range as the plagioclase. Fractures in the larger crystals are occupied by fine granular quartz and glass.

Quartz grains ranging up to 2.0 mm. in diameter are rounded, embayed and contain inclusions of glass. These features indicate resorption at lower temperatures and pressures.

Rectangular, corroded, brown pleochroic biotite flakes are scattered randomly throughout the section. They range from less than 0.1 mm. to 3.0 mm. in length.

The matrix consists almost entirely of devitrified glass, reflecting rapid cooling of the flow. Spherulites consisting of intergrowths of trydimite or cristobalite and alkali feldspar reach up to 2.5 mm. in diameter (Fig. A-2). These large spherulites commonly radiate outward from a nucleus of feldspar or magnetite. Other small spherulites with extinction crosses are common (Fig.9). Axiolites measuring several mm. in length are also present (Fig. A-3). Crystallites are scattered randomly throughout.

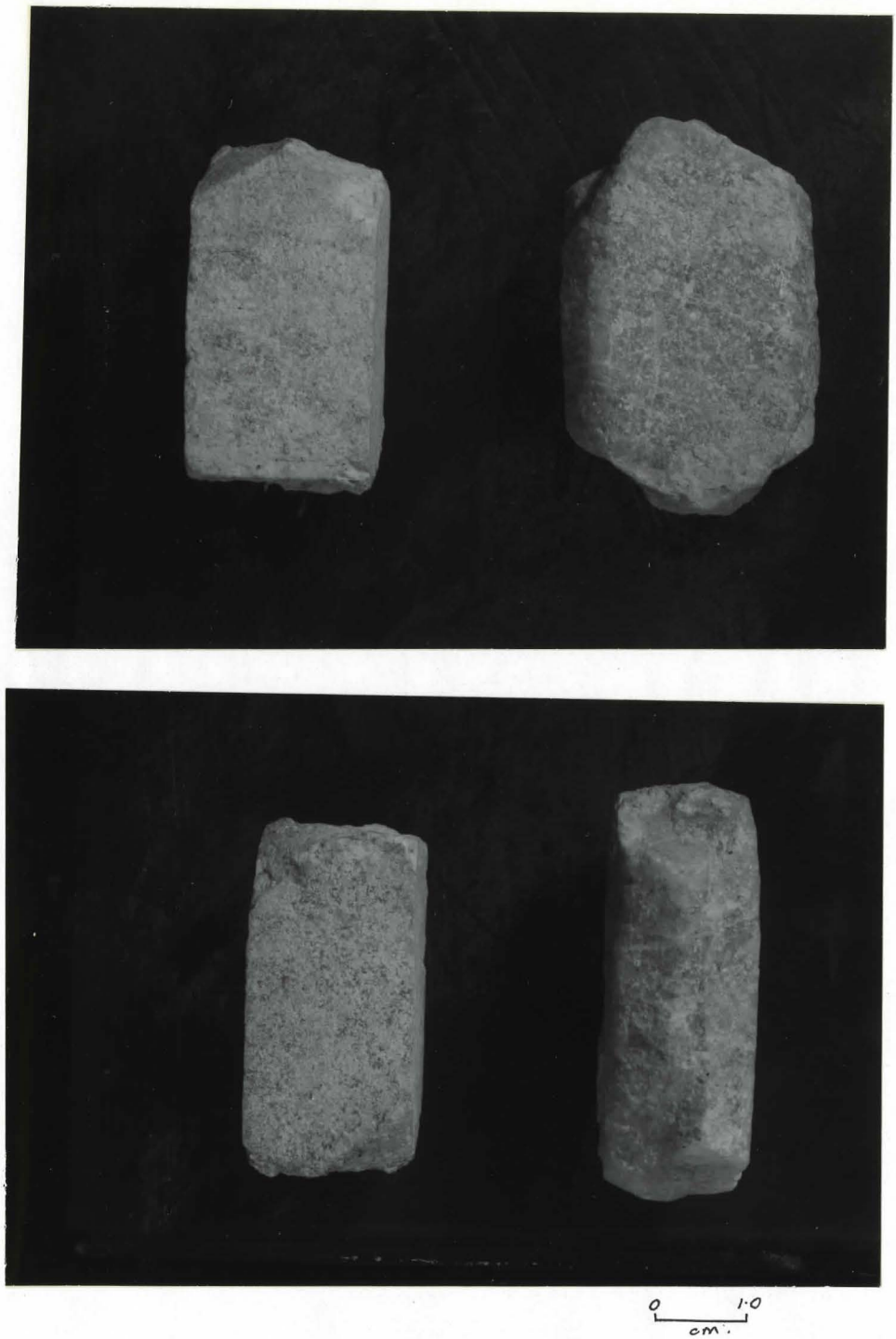


Fig. A-1 Sanidine phenocrysts of the Shingle Creek Porphyry (Both twinned and untwinned varieties).

The ash flow is fairly well sorted, with both lithic and pumice fragments being absent. The pumice fragments are commonly abraded to dust and preserved in the matrix, or escape in the cloud which rises above the active flow (Walker, 1972).

Both the plagioclase and potash feldspar are highly altered to clay and carbonate minerals.

MODAL ANALYSIS (500 points)

Devitrified glass	-	70%
Plagioclase feldspar	-	17%
Biotite	-	6%
Potash feldspar	-	5%
Magnetite	-	2%

TRACHYTIC ASH FLOW (Sum-1)

This ash flow, representing part of the Nimpit Lake Member, was sampled in the Summerland region.

It is a non-welded, poorly sorted pyroclastic flow consisting of lithic fragments, pumice fragments and crystals set in a dusty to glassy matrix.

Lithic fragments are largely composed of microlites of feldspar in a glassy matrix. They are rounded and measure up to 3.0 mm. in maximum dimension. Other lithic fragments are fine grained and banded (Fig. A-4), possibly representing fragments from flow banded rhyolites which are present about 35 miles north of Kelowna in the Lumby area.

Dark brown, rounded pumice fragments measuring up to 2.0 mm. in diameter are also present (Fig. A-5). Vesicles in the pumice are not flattened, indicating that the flow has not undergone much lithification. Calcite fills the vesicles in many instances (Fig. A-6). Larger pumice fragments are absent, and most of them are less than 1.0 mm. in diameter. This is because the fragments have a low mechanical strength and are easily fragmented by a process of internal vesiculation, or by transport (Walker, 1971). The dark brown colour of the pumice may reflect the conservation of heat from the source and slow cooling in the flow with resulting oxidation of the iron (Walker, 1971).

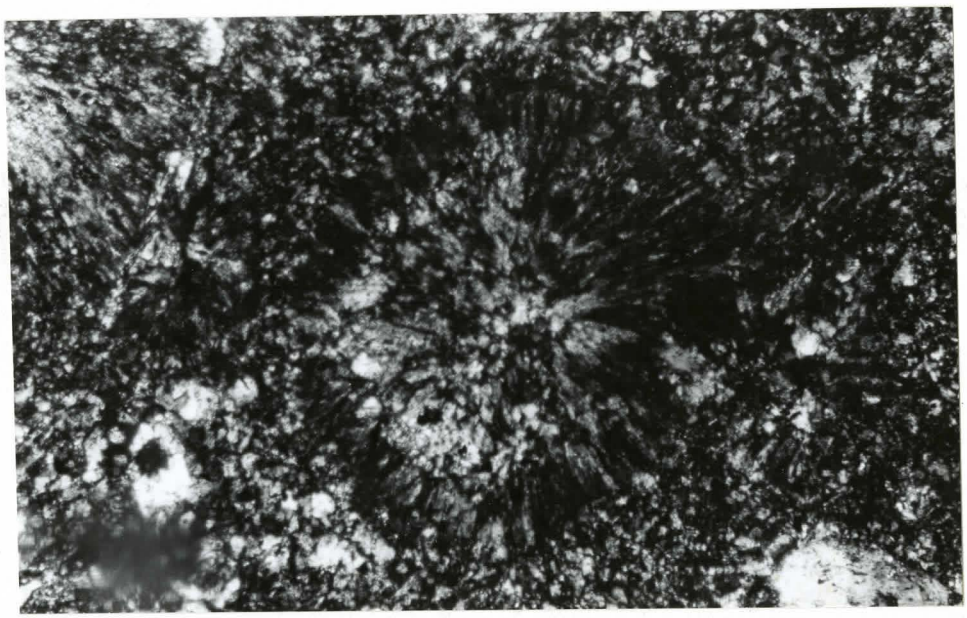


Fig. A-2 Spherulite in the Trepanier rhyolite ash flow (Crossed Nicols). Magnification is 40 X (see also Fig.9)

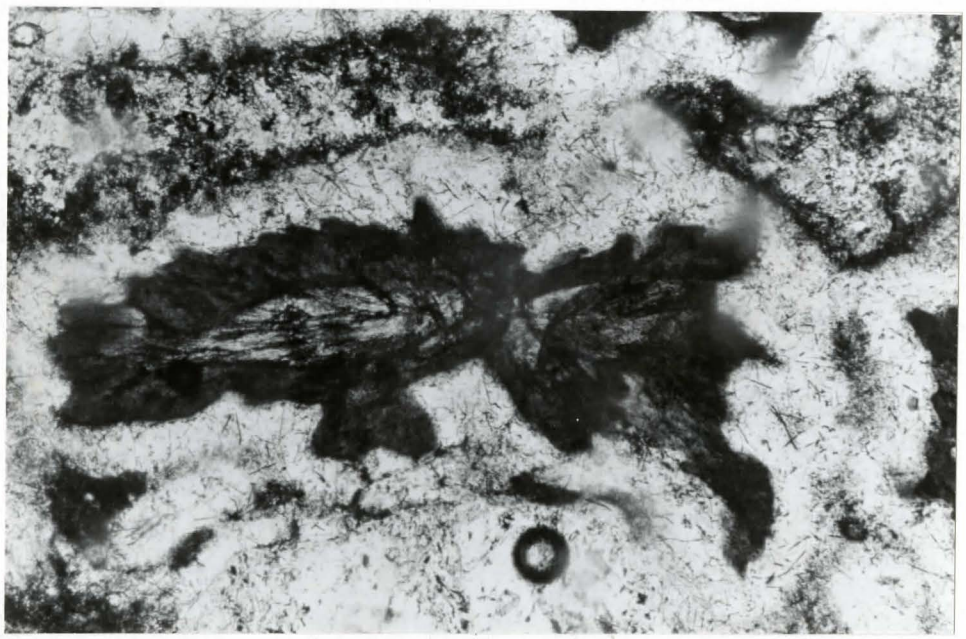


Fig. A-3 Axiolite in Trepanier rhyolite ash flow. Note also the abundant crystallites (Crossed Nicols). Magnification is 40 X.

Crystals include angular fragments of augite which show simple and polysynthetic twins. Plagioclase feldspar and granular magnetite are also present. The crystals are not usually larger than 3.0 mm.

Dark glass and volcanic dust constitute the matrix.

The feldspar is often replaced partially or entirely by sericite and carbonate.

MODAL ANALYSIS (500 points)

Lithic fragments	-	28%
Crystals	-	16%
Pumice fragments	-	13%
Groundmass	-	43%

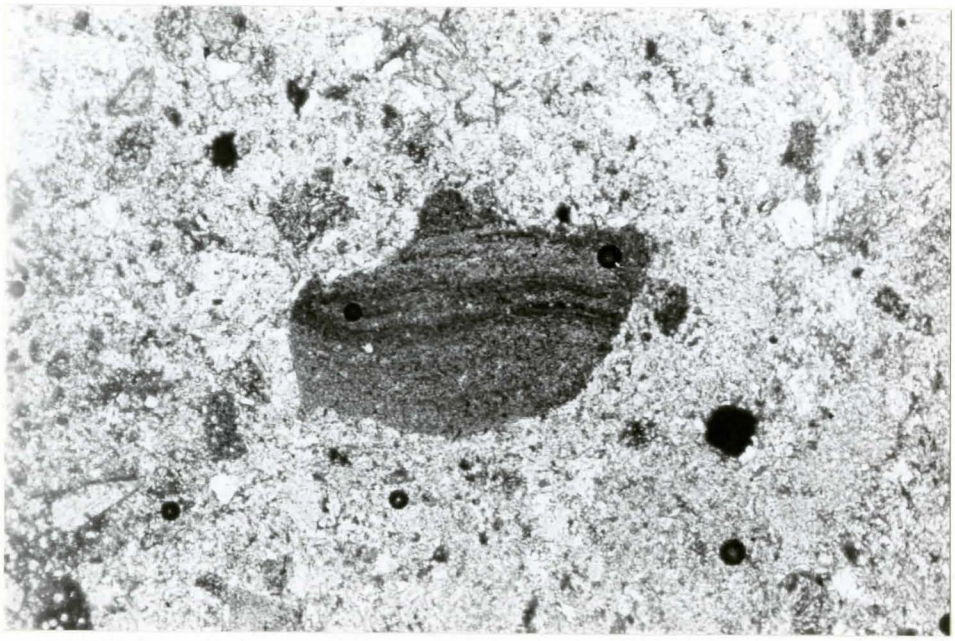


Fig. A-4 Lithic fragment in the Nimpit Lake trachytic ash flow, showing flow banding. (Plain Light). Magnification is 40 X.

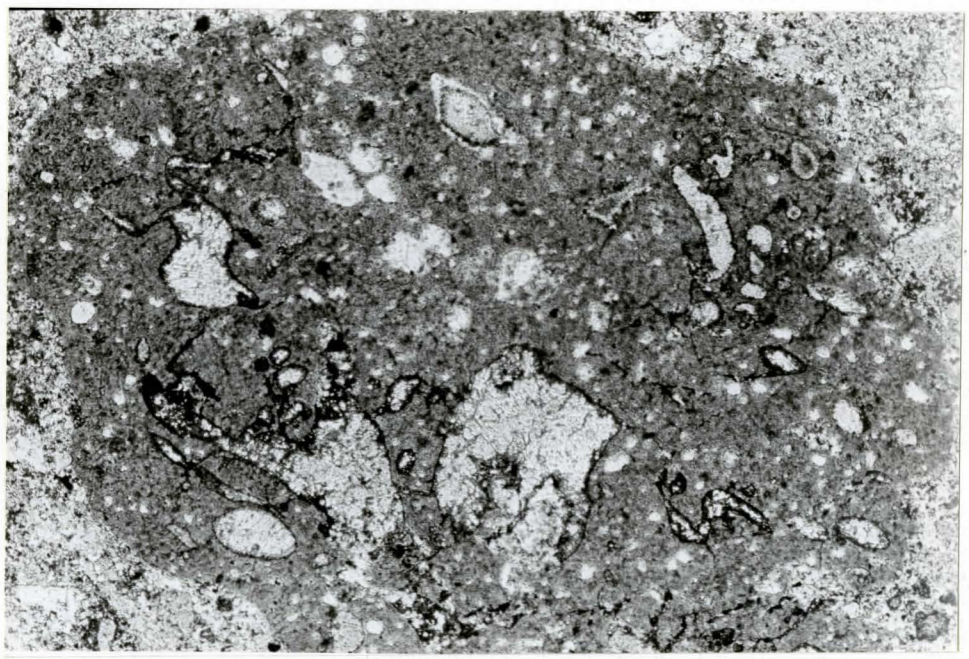


Fig. A-5 Pumice fragment in the Nimpit Lake trachytic ash flow. (Plain Light). Magnification is 40 X.

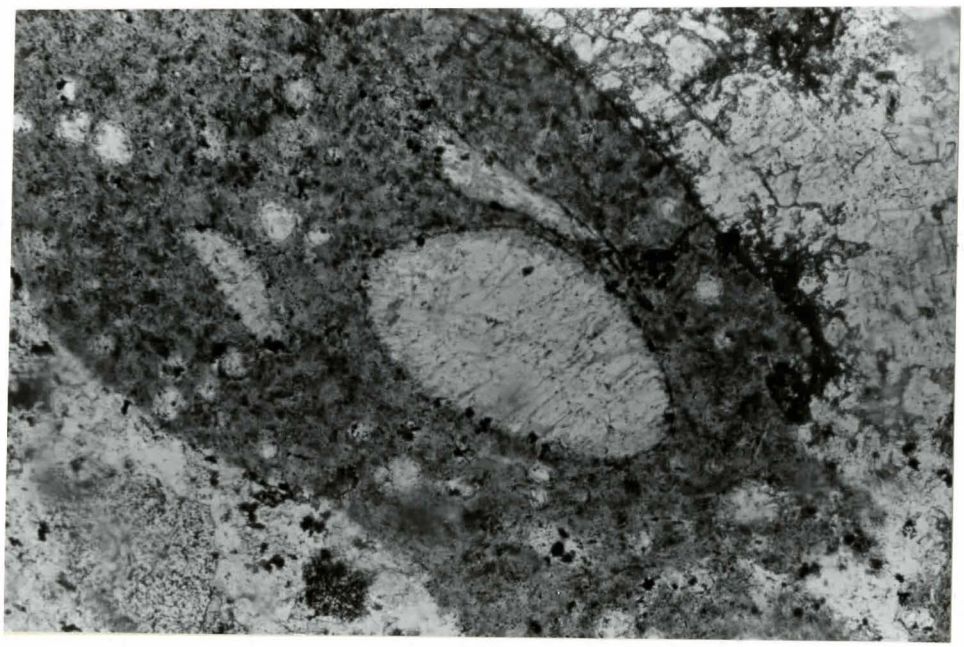


Fig. A-6 Calcite filled vesicle in the pumice fragment shown in Fig. A-5. Note that vesicles are not flattened, indicating that lithification has not taken place to a high degree. (Plain Light.) Magnification is 100 X.

APPENDIX B, LIST OF ROCK SAMPLES

	ROCK TYPE	LOCATION
TREPANIER MEMBER		
Shingle Crk. Porph.	Rhyolite Porphyry	Skaha Lake
KNA-348	Rhyolite	Kelowna
KNA-43	Rhyolite ash flow	Kelowna
IR-267	Rhyolite ash flow	Skaha Lake
YELLOW LAKE MEMBER		
ROK-245	Analcitic mafic phonolite	Rock Creek
CLM-92	Analcitic mafic phonolite	Skaha Lake
RID-50	Rhomb porphyry mafic phonolite	Summerland
ROK-86	Mafic phonolite	Rock Creek
KITLEY LAKE MEMBER		
ROK-161	Trachyandesite	Rock Creek
HWY-YL	Trachyandesite	Skaha Lake
CLM-73	Trachyte	Skaha Lake
KNA-315	Trachyte	Kelowna
KEARNS CREEK MEMBER		
CLM-45	Basaltic Andesite	Skaha Lake
NIMPIT LAKE MEMBER		
SUM-1	Trachytic ash flow	Summerland
KNA-145	Trachyandesite	Kelowna
FI-4	Trachyte	Rock Creek
HWY-MV	Trachyte	Skaha Lake
KNA-338	Trachyte	Kelowna
PARK RILL MEMBER		
HWY-BC	Andesite	Rock Creek
CLM-47	Andesite	Skaha Lake
MARAMA FORMATION		
KNA-131	Dacite	Kelowna
HWY-DM	Rhyodacite	Skaha Lake
CARROT MOUNTAIN BASALT		
KNA-4	Andesitic basalt	Kelowna
KNA-250	Basalt	Kelowna
LAMBLY CREEK BASALT		
KNA-343	Olivine basalt	Kelowna
KNA-279	(Sphene) basalt	Kelowna

TABLE C-1

APPENDIX C, MODAL ANALYSES (percent)

Sample	Plagioclase Feldspar	Alkali Feldspar	Clino-pyroxene	Biotite	Magne-tite	Olivine	Others	Ground Mass
S.C.P.	1.5	29.6	--	3.0	0.5	--	7.8(Q)	57.7
KNA-348	10.4	7.0	--	1.6	1.0	--	20.0(Q)	60.6
ROK-245	--	40.0	8.0	0.5	8.5	--	6.3(A)	38.6
CLM-92	--	63.7	11.6	0.4	5.7	3.2	4.5(A)	10.9
RID-50	--	23.2	10.0	1.2	1.8	--	--	67.0
ROK-86	--	64.9	8.6	1.0	7.1	2.9	--	15.5
ROK-161	23.5	7.4	4.0	2.0	2.0	3.0	--	59.2
HWY-YL	24.0	8.0	4.4	3.0	2.0	1.4	0.7(H)	57.8
CLM-73	24.6	13.6	1.4	0.8	1.4	--	--	58.2
KNA-315	14.3	3.5	1.0	1.0	Tr.	--	--	80.2
CLM-45	9.2	2.2	14.2	--	0.9	7.6	--	65.9
KNA-145	1.7	--	3.5	--	0.2	2.3	--	92.3
FI-4	8.4	0.7	2.0	--	0.3	4.0	--	85.0
HWY-MV	8.6	2.2	4.0	--	2.2	--	--	83.0
KNA-338	11.7	1.0	1.3	1.1	Tr.	--	--	84.8
HWY-BC	26.9	--	8.9	2.9	2.7	--	Tr.(H)	58.7
CLM-47	32.5	--	1.3	0.6	2.8	2.3	13.1(H)	47.4
KNA-131	7.0	--	3.0	1.0	--	--	--	89.0
KNA-DM	2.0	--	--	--	--	--	--	98.0
KNA-250	31.0	--	2.4	Tr.	16.3	--	--	50.3
KNA-343	46.5	--	28.6	--	10.5	13.6	--	--
KNA-279	50.0	--	22.5	--	21.5	--	6.0(S)	--
KNA-4	34.0	--	4.0	3.0	5.0	--	--	54.0

Tr. = Trace

(Q) = Quartz

(A) = Analcite

(H) = Hornblende

(S) = Sphene

Olivine is not usually present, but serpentine or bowlingite often form perfect pseudomorphs after it (Fig's 14 and 16).

APPENDIX D, ROCK CLASSIFICATION BASED ON DISCRIMINATORY FUNCTIONS

D1 = Discriminatory Function 1
D2 = Discriminatory Function 2
D3 = Discriminatory Function 3
D4 = Discriminatory Function 4

For alkalies - silica diagram (Irvine and Baragar, 1971, Fig.3)
+D1= subalkaline, -D1 = alkaline.
For AFM Plot (Irvine and Baragar, Fig.2) +D2 = tholeitic,
-D2 = calc-alkaline if rock is subalkaline and norm-An L.T. 40.
For Ne-Qtz-ol Plot (Irvine and Baragar, Fig.4) +D3 = alkaline,
-D3 = subalkaline.
For Al_2O_3 - An Plot (Irvine and Baragar, Fig.6) +D4 = calc-alkaline,
-D4 = tholeitic so long as norm-An G.T. 40.

Using the above discriminatory functions eliminates the necessity of plotting the data on the diagrams since the discriminatory functions are based on the positions of the boundary lines on the diagrams. If a value for a discriminatory function is 0, then that sample would plot right on the boundary between the two divisions.

In some cases, there are discrepancies involved. If the sample plots very close to the boundary, then one function may place it on one side of the boundary, while another function may place it on the other side. In these cases it is necessary to compare the results of that sample with results of other samples from the same rock unit in order to satisfactorily classify it. It is best to use the largest discriminatory number value for each sample, if discrepancies exist.

TABLE D-1 DISCRIMINATORY FUNCTIONS

SAMPLE	D1	D2	D3	D4
S.C.P.	14.3	-22.9	-53.2	0.4
KNA-348	17.7	-17.2	-50.8	0.8
KNA-43	-19.6	-18.6	-16.3	3.1
IR-267	27.7	-11.1	-92.4	1.1
ROK-245	-27.6	-17.6	21.5	4.2
CLM-92	-37.6	-20.2	30.3	4.9
RID-50	-20.1	-24.7	17.7	3.0
ROK-86	-18.2	-20.1	3.6	4.5
ROK-161	-6.7	-17.3	-7.6	2.9
HWY-YL	-4.7	-15.1	-14.5	2.7
CLM-73	-24.0	-14.1	0.8	5.6
KNA-315	-62.8	-9.4	13.9	5.8
CLM-45	-9.0	-21.3	3.5	0.5
SUM-1	-63.2	-21.8	29.4	4.1
KNA-145	-13.4	-15.0	-0.5	2.6
FI-4	-30.0	-22.6	8.2	3.2
HWY-MV	-54.0	-18.2	19.0	4.4
KNA-338	-20.4	-17.8	0.5	4.6
HWY-BC	5.6	-20.8	-28.5	0.3
CLM-47	-7.2	-23.3	2.2	2.8
KNA-131	14.0	-16.5	-30.9	1.3
HWY-DM	13.5	-12.2	-39.8	1.2
KNA-250	-7.7	-2.6	11.6	0.2
KNA-343	0.6	3.0	-4.7	-1.6
KNA-279	-0.1	1.0	-4.6	-0.8
KNA-4	2.7	-17.8	-27.9	1.8

SEE APPENDIX B FOR ROCK NAMES.

APPENDIX E, ANALYTICAL METHODS

1) SAMPLE PREPARATION

To prepare samples for analysis, the weathered surfaces were removed. The samples were then crushed to -200 mesh, using a Spex Industries shatter box with tungsten carbide rings.

For whole rock analysis, fused discs were used. They were made by fusing 3.00 g of a lithium tetraborate and lithium metaborate mixture (flux) with 0.5 g of the rock powder in Pt/Au crucibles for 3 - 5 minutes at 1200° C. Pressed powder discs in Al casings were used for trace element analysis.

ACCURACY OF X.R.F. DETERMINATIONS

(A) MAJOR OXIDE ANALYSIS

The accuracy of the X.R.F. analysis for major oxides was checked by running standards as unknowns and comparing them to recommended values (Abbey, 1975). The standards used were B-1, B-2, B-3, W-1, JG-1, BCR-1, GSP-1, NIM-N and NIM-G. The following are the results for running standards BCR-1 and GSP-1:

	BCR-1 (Recommended)	BCR-1 (Unknown)	GSP-1 (Recommended)	GSP-1 (Unknown)
SiO_2	54.85	54.92	67.31	67.73
TiO_2	2.22	2.28	0.66	0.66
Al_2O_3	13.68	13.38	15.19	15.39
Fe_2O_3(T)	13.52	13.71	4.33	4.31
MnO	0.19	0.18	0.04	0.04
MgO	3.49	3.57	0.96	0.98
CaO	6.98	6.94	2.02	2.04
Na_2O	3.29	2.97	2.80	2.91
K_2O	1.68	1.71	5.53	5.65
P_2O_5	0.33	0.34	0.28	0.28

Errors are negligible (Similar results were obtained for the other standards).

(B) TRACE ELEMENT ANALYSIS

As for the major oxides, the accuracy of the trace

element analyses was checked by running standards as unknowns, and comparing them to recommended values (Abbey, 1975). For Rb and Sr, NBS70A, G-2, GSP-1, AGV-1, W-1 and BCR-1 were used as standards. The following are the results for running standards GSP-1 and W-1 (P.P.M.):

	GSP-1 (Recommended)	GSP-1 (Unknown)	W-1 (Recommended)	W-1 (Unknown)
Rb	250	250.7	21	22.4
Sr	230	230.0	190	191.6

The error is negligible (Similar results were obtained for the other samples).

For Ba, standards W-1, NIM-N, NIM-P, GH, PCC-1, BR, JB-1, GSP-1, BCR-1, SY-1, NIM-G and NIM-S were used. The following are the results for running standards W-1 and BR (P.P.M.)

	W-1 (Recommended)	W-1 (Unknown)	BR (Recommended)	BR (Unknown)
Ba	160	151.7	1050	99.55

The error is negligible (Similar results were obtained using the other standards).

For Y, Zr and Nb, standards SY-1, SY-3 and NIM-G were used. The following are the results for running standards SY-1 and NIM-G (P.P.M.):

	SY-1 (Recommended)	SY-1 (Unknown)	NIM-G (Recommended)	NIM-G (Unknown)
Y	441	398	100	148
Zr	3030	2371	300	266
Nb	150	136	50	41

In this case, the error is significant, but would not change the interpretations.

For Pb, Zn, and Ni, standards W-1, SY-2 and NIM-L were used. The following are the results for running these (P.P.M.):

	W-1 (Recommended)	W-1 (Unknown)	SY-2 (Recommdned)	SY-2 (Unknown)	NIM-L (Recommended)	NIM-L (Unknown)
Pb	8.0	6.2	129.3	106.3	45.0	42.4
Zn	86.0	85.4	--	--	280.0	280.0
Ni	78.0	78.0	?	14.9	--	--

The errors are negligible (Pb is questionable). For U and Th, standards SY-3, SY-2, NIM-L, GSP-1, NIM-G, JG-1, G-2 and W-1 were used. The following are the results for running standards NIM-G and NIM-L (P.P.M.):

	NIM-G (Recommended)	NIM-G (Unknown)	NIM-L (Recommended)	NIM-L (Unknown)
U	14	9.0	12	14.2
Th	57	67	70	54

The errors are not negligible and the values obtained in some instances are within the sensitivity limits of the analysis.

2) FeO ANALYSIS

Individual determinations of FeO were obtained by dissolving 1.000 g of rock powder in a mixture of HF and H_2SO_4 and titrating the solution with standard dichromate titrant (R-15, P-15) until the end point is reached as indicated by the Zeromatic. When the end point is reached, all the Fe^{2+} has been complexed.

ACCURACY OF ANALYSIS

To check the accuracy of the method, standards were analyzed as unknowns and the results were compared to the accepted values. Standards used were BR and ON-64 (McMaster University standard). The results are as follows (%):

	BR (Recommended	BR (Unknown)	ON-64 (Recommended)	ON-64 (Unknown)
FeO	6.60	6.79	6.77	6.67
			6.77	6.50
			6.77	6.57
			6.77	6.70

ON-64 was analyzed several times to ensure that the analyses were running smoothly. The resulting error was very small.

3) FELDSPAR STAINING

Each slab from which the thin sections were cut were stained for the presence of alkali feldspar, using a solution of sodium cobaltinitrate.

APPENDIX F

TABLE F-1

WHOLE ROCK ANALYSES (NORMALIZED TO 100%)

Sample	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5
S.C.P.	73.06	0.33	14.45	1.27	0.47	0.04	0.82	1.85	2.74	4.87	0.10
KNA-348	76.26	0.29	12.38	1.22	0.45	0.03	0.50	1.20	3.38	4.19	0.10
KNA-43	69.33	0.34	15.44	1.31	0.83	0.04	0.73	1.17	5.29	5.51	0.11
IR-267	76.40	0.34	15.77	1.66	0.34	0.03	0.54	0.65	0.58	3.60	0.09
ROK-245	53.50	0.96	18.1	5.12	2.09	0.13	3.06	5.72	4.41	5.88	1.04
CLM-92	53.52	0.92	18.13	3.74	2.97	0.12	3.17	5.53	5.44	5.48	0.97
RID-50	55.06	0.95	16.06	4.65	1.86	0.10	4.39	6.11	5.11	4.73	0.98
ROK-86	55.76	0.83	19.25	4.96	1.26	0.12	2.86	4.54	3.85	5.89	0.68
ROK-161	58.32	0.84	17.52	4.27	1.95	0.12	2.63	5.17	3.81	4.96	0.51
HWY-YL	59.39	0.81	17.57	4.45	1.35	0.12	2.14	5.14	3.44	5.19	0.51
CLM-73	59.74	0.67	19.80	3.40	0.61	0.18	1.18	3.57	4.53	5.94	0.38
KNA-315	60.67	0.78	18.60	3.04	1.03	0.06	0.71	2.32	5.39	7.09	0.30
CLM-45	55.38	0.98	14.16	3.88	2.95	0.27	6.13	6.90	3.33	5.34	0.78
SUM-1	57.12	0.99	16.13	3.39	2.53	0.10	2.80	4.04	5.36	6.98	0.55
KNA-145	58.13	1.00	16.40	5.08	1.60	0.09	2.49	5.24	3.94	5.57	0.46
FI-4	58.38	0.94	16.38	4.29	1.30	0.09	2.73	4.59	4.13	6.63	0.54
HWY-MV	58.55	1.01	16.79	4.92	0.56	0.05	2.08	3.54	5.25	6.74	0.51
KNA-338	59.10	0.89	18.73	3.02	2.00	0.09	1.97	3.64	4.33	5.85	0.39
HWY-BC	62.4	0.83	14.89	4.02	1.86	0.68	3.79	4.19	3.50	3.55	0.49
CLM-47	62.05	0.71	15.44	3.75	1.06	0.06	2.43	4.84	6.43	2.85	0.28
KNA-131	66.95	0.59	15.92	1.79	2.40	0.07	1.80	4.62	4.50	1.20	0.16
HWY-DM	71.10	0.38	15.18	2.37	0.30	0.04	0.67	2.52	3.91	3.41	0.12
KNA-4	63.60	0.70	16.65	2.36	2.32	0.09	1.94	3.96	3.34	4.75	0.30
KNA-250	47.14	2.68	14.10	7.24	7.30	0.21	6.73	7.34	4.53	1.87	0.86
KNA-343	48.48	1.82	13.97	3.54	9.37	0.17	9.28	9.15	3.01	0.89	0.33
KNA-279	48.63	1.85	14.68	9.64	3.12	0.18	7.92	9.41	3.26	0.94	0.35

APPENDIX F

TABLE F-2

TRACE ELEMENT ANALYSES (P.P.M.)

Sample	Rb	Sr	Ba	Y	Zr	Nb	Ni	Zn	Pb	U	Th	K/Rb	Rb/Sr
S.C.P.	1660	1154	2368	39	206	15	16	43	38	7.3	36	243.5	0.14
KNA-348	131.8	904	1505	41	609	60	17	44	40	3.2	37	263.9	0.15
KNA-43	165.4	976	1970	13	199	20	19	49	32	7.6	40	276.5	0.17
IR-267	96.1	522	1793	14	186	18	17	39	35	5.2	28	310.9	0.18
ROK-245	128.9	4054	3899	24	324	85	29	107	42	8.8	51	378.6	0.03
CLM-92	140.7	3860	3885	25	321	89	27	95	41	13	49	323.3	0.04
RID-50	125.0	3000	3126	24	326	65	51	115	42	8.4	52	314.1	0.04
ROK-86	97.0	4474	3602	24	329	85	28	92	30	9.8	53	504.0	0.02
ROK-161	126.5	1690	2588	29	281	48	18	71	34	8.3	26	325.4	0.07
HWY-YL	165.4	1728	2594	27	287	51	19	95	41	8.3	35	260.4	0.10
CLM-73	139.3	1806	2649	29	355	81	14	105	30	6.6	52	353.9	0.08
KNA-315	230.1	1722	2827	18	256	36	20	58	32	6.5	20	255.8	0.13
CLM-45	169.5	1144	2432	21	209	37	102	91	39	3.4	13	261.5	0.15
SUM-1	233.9	958	1497	19	260	33	49	78	41	2.8	21	247.7	0.24
KNA-145	179.8	1128	1868	35	220	27	29	70	33	3.9	15	257.1	0.16
F1-4	217.3	1318	2178	21	261	31	43	67	42	5.2	24	253.2	0.16
HWY-MV	225.6	1472	2642	16	267	38	36	79	42	4.2	23	248.0	0.15
KNA-338	181.8	1560	2423	43	256	37	26	67	42	6.0	24	267.1	0.12
HWY-BC	87.8	1164	1708	20	224	29	34	82	32	3.8	14	335.6	0.08
CLM-47	67.8	842	1231	23	176	16	22	75	24	4.0	7	349.0	0.08
KNA-131	116.9	570	1315	15	167	14	21	74	32	4.8	9	85.2	0.21
HWY-DM	100.7	400	1368	11	143	12	19	70	29	5.7	10	281.1	0.25
KNA-4	158.2	860	2050	23	224	30	16	71	32	5.2	28	236.3	0.18
KNA-250	34.8	910	497	31	305	61	117	104	0	1.6	0	446.0	0.04
KNA-343	10.0	496	232	21	124	24	157	107	2	0.0	0	738.7	0.02
KNA-279	9.6	494	227	22	119	22	166	103	9	1.9	1	812.7	0.02

KEY FOR APPENDIX G

Qz = Quartz
Co = Corundum
Or = Orthoclase
Ab = Albite
An = Anorthite
Ne = Nepheline
Di = Diopside
He = Hedenburgite
En = Enstatite
Fs = Ferrosilite
Fo = Forsterite
Fa = Fayalite
Mt = Magnetite
Il = Ilmenite
Hm = Hematite
Ap = Apatite
Ag = Augite
Hy = Hypersthene
Ol = Olivine
Pl = Plagioclase feldspar

TABLE G-1

APPENDIX G

EQUIVALENT CATION NORMS

	S.C.P.	KNA-348	KNA-43	IR-267	ROK-245	CLM-92	RID-50	ROK-86	ROK-161	HWY-YL	CLM-73	KNA-315	CLM-45
Qz	31.52	35.28	13.58	55.05	--	--	--	--	4.60	7.28	2.14	--	--
Co	1.72	0.38	--	11.27	--	--	--	--	--	--	0.37	--	--
Or	29.15	25.12	32.17	22.06	34.44	31.78	27.50	34.58	29.25	30.73	34.74	41.23	31.28
Ab	24.93	30.79	46.94	5.40	27.23	26.39	34.85	34.35	34.15	30.96	40.26	42.99	29.65
An	8.64	5.38	2.10	2.73	12.13	8.71	6.81	17.75	16.04	17.23	15.07	5.54	7.86
Ne	--	--	--	--	7.22	12.93	6.18	--	--	--	--	2.79	--
Di	--	--	2.34	--	7.40	8.69	13.36	0.17	4.99	3.99	--	3.08	15.95
He	--	--	--	--	--	0.89	--	--	--	--	--	--	0.87
En	2.29	1.40	0.82	1.55	--	--	--	3.37	4.75	3.93	3.23	--	1.64
Fs	--	--	--	--	--	--	--	--	--	--	--	--	0.09
Fo	--	--	--	--	3.51	3.18	3.94	3.29	--	--	--	0.29	5.38
Fa	--	--	--	--	--	0.33	--	--	--	--	--	--	0.29
Mt	0.50	0.52	1.34	0.16	3.13	3.84	2.53	1.47	3.05	1.73	0.44	0.89	4.02
Il	0.47	0.41	0.47	0.49	1.33	1.26	1.30	1.15	1.17	1.13	0.92	1.07	1.35
Hm	0.56	0.52	0.01	1.10	1.45	--	1.50	2.46	0.94	1.95	2.05	1.49	--
Ap	0.21	0.21	0.23	0.20	2.16	1.99	2.02	1.41	1.07	1.07	0.79	0.62	1.62
Ag	--	--	2.34	--	7.40	9.59	13.36	0.17	4.99	3.99	--	3.08	16.82
Hy	2.29	1.40	0.82	1.55	--	--	--	3.37	4.75	3.93	3.23	--	1.73
Ol	--	--	--	--	3.51	3.51	3.94	3.29	--	--	--	0.29	5.67
Pl	33.57	36.17	49.04	8.13	39.37	35.10	41.67	52.10	50.19	48.18	55.33	48.53	37.51

APPENDIX G (Cont'd.) EQUIVALENT CATION NORMS

	SUM-1*	KNA-145	Fl-4	HWY-MV**	KNA-338	HWY-BC	CLM-47***	KNA-131	HWY-DM	KNA-250	KNA-343	KNA-279	KNA-4
Qz	--	2.72	--	--	1.96	14.77	3.91	21.91	27.32	--	--	--	14.09
Co	--	--	--	--	--	--	--	--	0.84	--	--	--	--
Or	40.51	32.92	38.90	39.29	34.26	21.04	16.57	7.11	20.31	11.12	5.26	5.60	28.19
Ab	27.67	35.39	36.83	36.94	38.55	31.53	56.82	40.54	35.40	32.81	27.06	29.52	30.13
An	--	10.63	6.54	2.32	14.28	14.49	4.78	19.77	11.81	12.70	22.01	22.85	16.50
Ne	11.00	--	--	5.74	--	--	--	--	--	4.87	--	--	--
Di	12.00	9.90	10.05	9.37	0.87	2.52	13.21	1.29	--	12.67	12.32	17.54	0.84
He	0.92	--	--	--	--	--	--	0.45	--	1.95	4.70	--	0.17
En	--	1.93	0.04	--	4.96	9.24	--	4.34	1.87	--	4.39	12.50	4.96
Fs	--	--	--	--	--	--	--	1.54	--	--	1.67	--	1.03
Fo	1.20	--	1.81	0.74	--	--	--	--	--	9.27	11.33	0.59	--
Fa	0.09	--	--	--	--	--	--	--	--	1.43	4.32	--	--
Mt	3.10	1.84	1.26	--	2.97	4.20	1.10	1.88	--	7.62	3.70	3.84	2.48
Il	1.35	1.39	1.30	0.93	1.23	1.16	0.97	0.82	0.53	3.76	2.54	2.60	0.98
Hm	--	2.31	2.13	3.38	0.10	0.01	1.84	--	1.67	--	--	4.22	--
Ap	1.13	0.96	1.12	1.05	0.81	1.03	0.58	0.34	0.25	1.81	0.69	0.74	0.63
Ag	12.92	9.90	10.05	9.37	0.87	2.52	13.21	1.74	--	14.62	17.02	17.54	1.01
Hy	--	1.93	0.04	--	4.96	9.24	--	5.88	1.87	--	6.06	12.50	5.99
Ol	1.29	--	1.81	0.74	--	--	--	--	--	10.70	15.65	0.59	--
Pl	27.67	46.02	43.37	39.26	52.83	46.02	61.61	60.32	47.21	45.51	49.07	52.37	46.62

* 1.03 acmite
** 0.23 rutile
*** 0.22 wollastonite

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