Geology of the White Lake Basin

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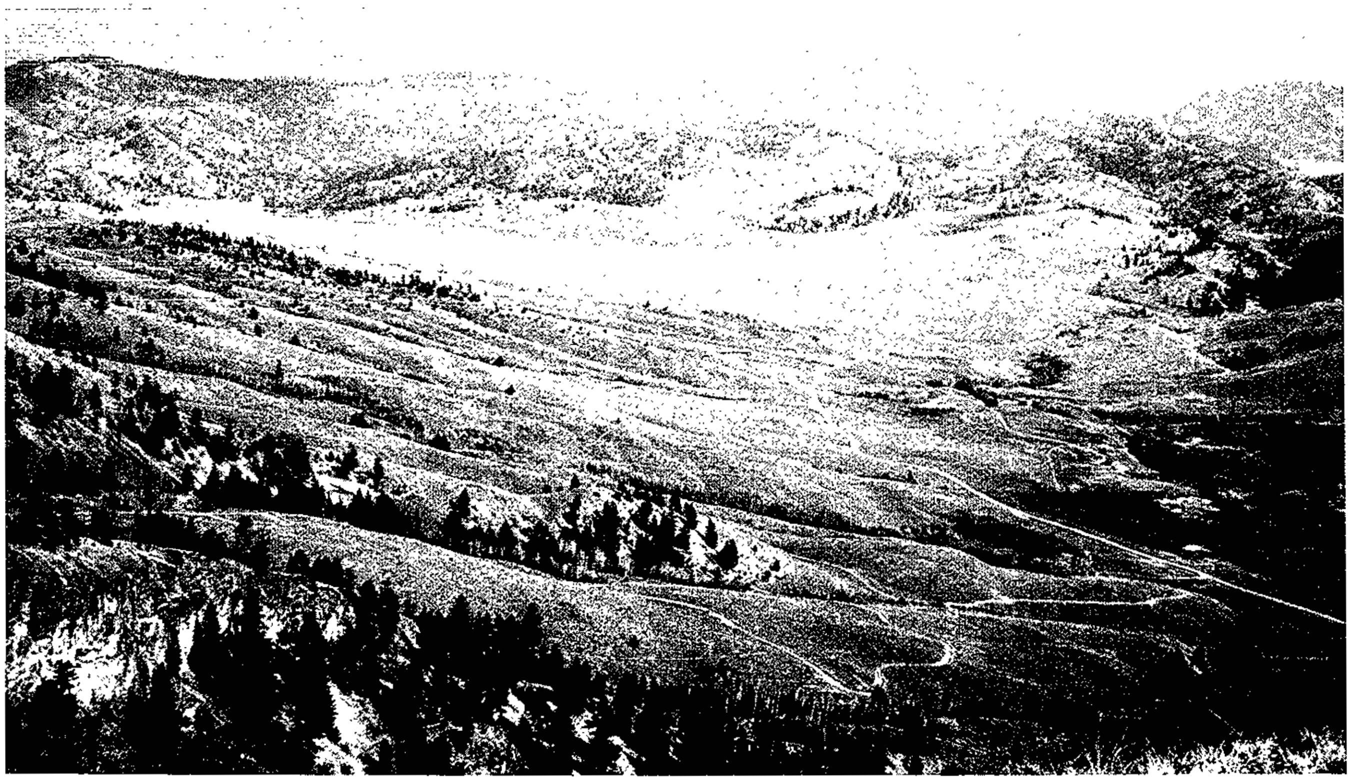

The White Lake basin looking southeast to White Lake and beyond.

GEOLOGY OF THE WHITE LAKE BASIN

SUMMARY

The object of this study was to establish the stratigraphy, structure, and petrology of Early Tertiary rocks in the White Lake area near Penticton, British Columbia. This was achieved by field mapping and laboratory work performed mainly as a thesis study for the Department of Geology, University of British Columbia.

Early Tertiary rocks of the White Lake area consist of five main stratigraphic subdivisions which are from the base as follows:

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

The maximum aggregate thickness of the sequence is about 12,000 feet, and it is all believed to be of Eocene age. Each subdivision rests with some angular or erosional unconformity on older rock. The preservation of the sequence from erosion is partially explained by regional downfaulting. The greatest downward movement is near the Okanagan Valley where it is estimated that basal beds locally exceed depths of 5,000 feet below mean sea level. In general, beds are tilted easterly as if rotated downward forming a trap-door-like structure. Locally, folds are developed but these are without regional pattern and may be the result of simple flexures in the basement rocks.

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

'A' series — mainly plagioclase porphyries; lavas of rhyodacite and andesite composition.

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

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

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

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

The Dusty Mac gold-silver prospect is the main mineral deposit in the area. A detailed investigation shows that mineralization of the White Lake Formation near Okanagan Falls accompanied a pulse of silicification prior to a period of movement and brecciation on faults and shear zones.

Study of the volcanic rocks of the White Lake Basin leads to consideration of general problems of classification of volcanic rocks, particularly fine-grained rocks, and hence a new classification is presented in Appendix B.

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INTRODUCTION

SCOPE AND CONTENT

The object of this study was to establish the stratigraphic succession, structural history, and petrology of Early Tertiary volcanic rocks in a typical, well-exposed, and accessible area of southern British Columbia. The work was very largely performed in partial fulfillment of the requirements for a Ph.D. at the University of British Columbia. Subsequently, while on the staff of the Department of Mines and Petroleum Resources, the writer mapped an additional area in which the Dusty Mac gold-silver prospect occurred. Further chemical work was performed in the Departmental laboratories and a K-Ar age determination carried out by Geochron Laboratories Ltd. for the Department.

LOCATION AND ACCESS

The White Lake map-area is in south-central British Columbia, approximately 150 miles due east of Vancouver and 8 miles south of Penticton in the southern Okanagan region. It covers about 70 square miles lying roughly between latitude 49 degrees 17 minutes and 49 degrees 23 minutes north and longitude 119 degrees 34 minutes and 119 degrees 48 minutes west.

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

The village of Okanagan Falls, on the Okanagan branch line of the Canadian Pacific Railway in the east part of the map-area, provides local essential services.

NATURE OF THE MAP-AREA

The White Lake map-area is characterized mainly by a low mountainous terrain bounded on the east by the Okanagan and tributary valleys (local base level about 1,100 feet above

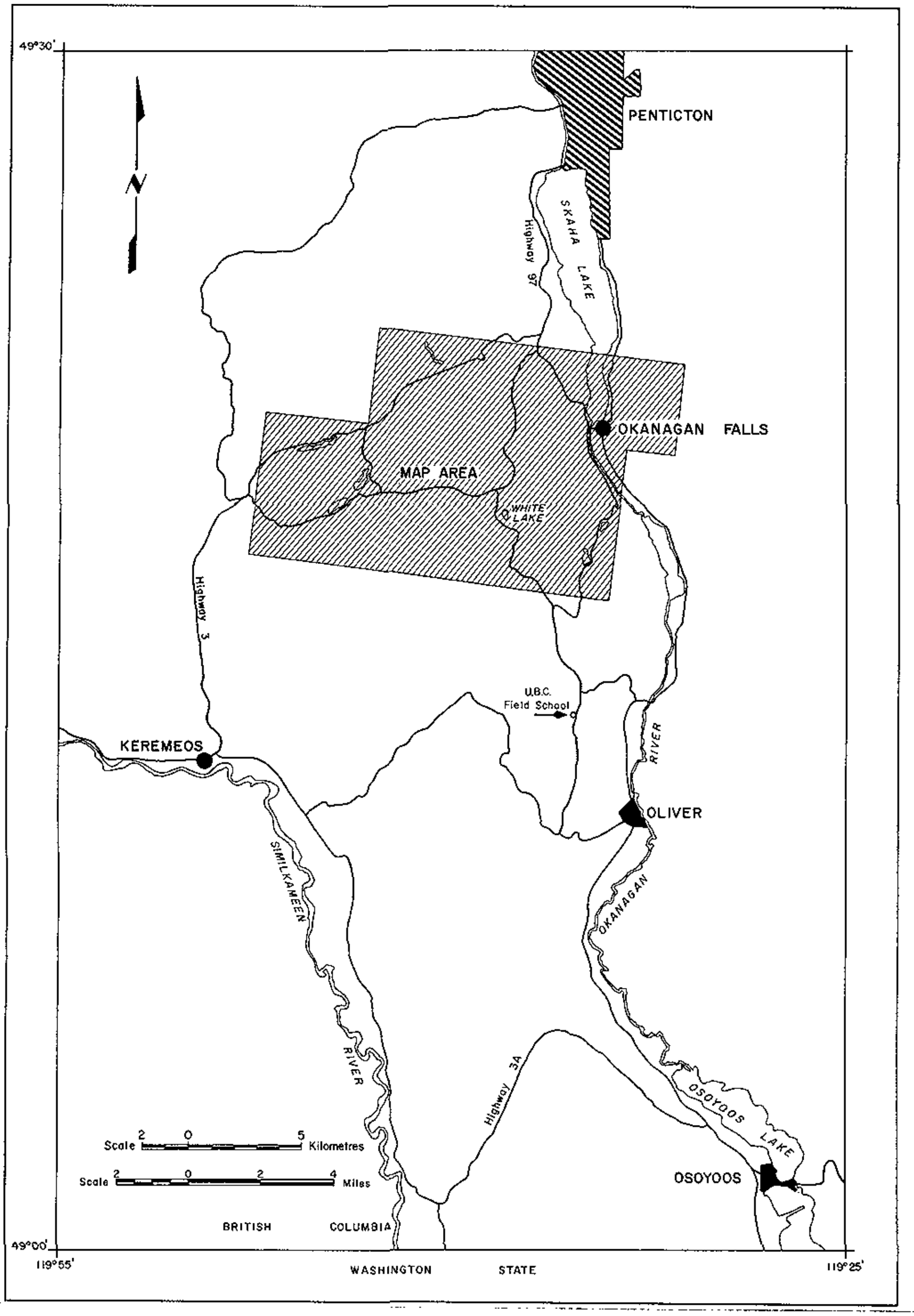

Figure 1.1. Location of the map-area.

mean sea level), and on the west by valleys tributary to the Similkameen drainage system (local base level about 1,800 feet above mean sea level). Shales, eroded from a basin-like geological structure, underlie a dish-shaped topographic depression in the east-central part of the map-area. Slopes rise gently from White Lake, a small ephemeral body of water near the centre of the depression (about 1,750 feet above mean sea level), to an almost complete ring of hills. Concordant summits northwest and southwest of White Lake underlie a remnant of a once continuous upland surface, about 4,500 feet above mean sea level, known as the Thompson Plateau (Holland, 1964). To the east the depression is separated from the Okanagan Valley by numerous small knobs and ridges and by Mount Hawthorne which rises to 2,750 feet. The basin rim is breached by several valleys containing small intermittent streams.

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

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

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

Animal life is abundant and markedly varied. Bear, deer, and grouse are hunted by local sportsmen. Poisonous spotted prairie rattlesnakes inhabit talus slopes and rocky ledges and are considered hazardous by the local ranchers. Brown mud turtles live in Mahoney and Green Lakes in the southeast part of the map-area and are a tourist attraction.

GLACIAL HISTORY

According to the Glacial Map of Canada (1958), the Wisconsin ice sheet moved southerly from an ice divide north of Kamloops and attained a maximum elevation in excess of 7,000 feet in the southern Okanagan.

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

East of White Lake, where the rocks were examined in detail, 16 of a total of 18 striae measurements trend southerly, 2 trend easterly. The presence of large blocks of granite breccia in gravel deposits west of Mahoney Lake establishes a southerly sense for the most recent ice advance, since the source of these blocks is about 1.5 miles to the north (Fig. 1.2).

A series of small closed depressions (site of ephemeral ponds) southeast of White Lake were probably formed by 'eddies' set up in southerly flowing ice in response to local topographic features (Fig. 1.3). These depressions are mostly located on the south sides of knolls and bluffs where the thickest ice would accumulate an erode in a manner analogous to the formation of tarns and paternoster depressions such as commonly found in glaciated rugged terrain.

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

At a later stage, meltwaters flowed south and east through the White Lake basin to the Okanagan Valley via Kearns Creek. Significant outwash deposits were formed at this time in the vicinity of Marron Lake and White Lake. Unable to pass directly south across the White Lake basin, the meltwaters flowed southeast of the Dominion Astrophysical Observatory site because of probable ice damming. Still later, when the Okanagan ice lobe retreated north of Okanagan Falls, the Kearns Creek course was abandoned and meltwaters flowed eastward to glacial Lake Penticton following the present course of Marron Creek. A considerable volume of white silt (delta deposit) was laid down by this stream west of Okanagan Falls.

PREVIOUS WORK

The presence of Tertiary rocks in the White Lake area was reported by Dawson (1879) during a reconnaissance survey of southern British Columbia. No geological information on this area was published until local gold-mining activity created a market for cheap blacksmithing coal.

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

> "In general the structure of the White Lake coal area is that of a synclinal basin, the strike of which is east and west. In detail, however, there are often wide variations from this direction, especially on the eastern side of the area where apparently there has been considerable disturbance since the deposition of the coal-bearing beds. The dips range 0° to 50° and average about 20°. Some faulting has taken place, especially in the disturbed region on the east.
>
> "The rocks of the coal-bearing formation (White Lake Formation) appear to have been laid down in a gradually subsiding basin on the western edge of a region in which volcanism was active at intervals throughout the whole period of their deposition. The eruptions at this focus were of the explosive type and great volumes of tuff were blown out and deposited in the basin. In parts of the basin these tuffs were water worn to form true sandstones; but in other parts they have not been so worn and they retain the same angularity of the grain when first ejected.
>
> "Overlying the coal-bearing rocks on the east is a series of volcanic breccias and tuffs and some flows of an andesite or more acid nature. In places the overlying volcanic rocks succeed the coal-bearing rocks conformably; but in other places there is a marked angular unconformity between them. It is probable, however, that this unconformity does not indicate any great time interval between the two series. The upper volcanic rocks occupy an

exceedingly irregular and broken country to the east of the coal basin, which no doubt is the source from which tuffs were derived. This broken country is apparently the locus of an ancient Tertiary volcano which was active at intervals during and after the deposition of the coal-bearing rocks. It has all the characteristics of an ancient, denuded volcanic crater about a mile in diameter, the bottom and sides of which have slumped in leaving a series of steep-sided hills and deep sinkholes now often filled with water."

Camsell's description of the coal-bearing beds will be given in Chapter 2 of this report.

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

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

Cairnes (1937) presented an account of the mineral deposits of the Kettle River area, west half; map 538A (Geological Survey of Canada) by Cairnes (1940) shows Bostock's geology of the White Lake area unmodified.

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

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

The distribution of Tertiary bedded rocks of central and southern British Columbia and northwestern Washington State is shown on Figure 1.4. Geological information on this region is provided by many authors. Dawson (1896) gave a detailed description of Tertiary rocks in the Kamloops area. This work was reviewed and brought up to date by Cockfield (1948). The most recent description of the Tertiary succession at Princeton was given by Hills (1960). Daly (1912) first described the Kettle River sedimentary rocks and Midway volcanic rocks near the village of Midway. Recently, Little and Monger (1966) revised and added to this work. Tertiary rocks, similar to those near Midway, occur in the Beaverdell area and were described by Reinecke (1915). Drysdale (1915) reported on Kettle River type sedimentary rocks and Midway type volcanic rocks at Franklin camp. Also, in Washington State, similar rocks occurring near the town of Republic were mapped and described by Parker and Calkins (1964), and Staaz (1964).

Other works applicable to the Tertiary rocks of the region are referred to in following sections.

FIELD WORK AND ACKNOWLEDGMENTS

Field work was done mainly between 1963 and 1965 with a total of seven and one-half months required to complete the mapping programme. Reconnaissance mapping was

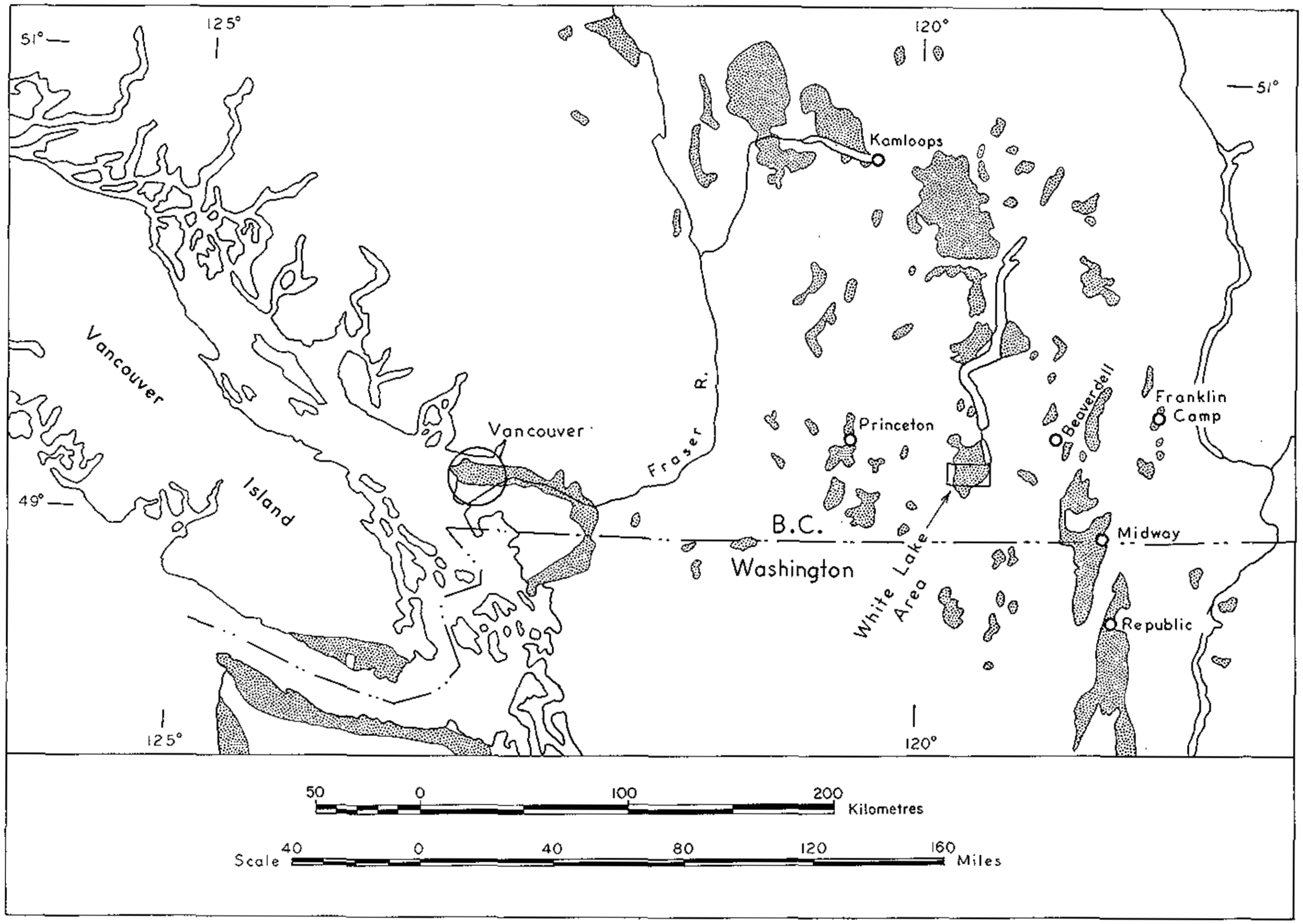

Figure 1.4. Location of Early Tertiary bedded rocks.

completed on the scale of approximately 3,000 feet to 1 inch, boundaries of geological units being interpolated between points of intersection on traverses with the aid of lineaments visible on airphotos (Fig. 1.2). Also, a detail outcrop map, covering about 8 square miles on the scale of 1 inch to 500 feet, was prepared for part of the geologically complex area east of White Lake (Fig. 1.3). Geographic positions were transferred from photographs to topographic maps using altimeter readings and radial-line plots. Additional field work was done in 1970 east of the Okanagan Valley in an area that included the Dusty Mac prospect.

Sincere thanks are extended to Professor W. H. Mathews who initiated the study and to Professors K. C. McTaggart and Howell Williams who were able to visit the field area with the writer.

GEOLOGICAL SETTING

The distribution of Early Tertiary bedded deposits of southwestern British Columbia and northern Washington State is shown on Figure 1.4. These deposits occur as scattered erosional remnants of what was probably a once continuous belt composed mainly of volcanic rocks extending from at least central Washington through the Interior to central British Columbia.

Precise dates of these strata are relatively few. Ten K-Ar age determinations on rocks from south-central British Columbia range from 45 to 53 million years (Mathews, 1964). Within 110 miles of the White Lake basin, the following ages were determined: near Kamloops, 45 to 47 m.y., near Princeton, 48 m.y., near Midway 48 to 49 m.y. The age of a vertebrate fossil found in the Princeton area, determined by Russell (1935), agrees well with the above K-Ar determinations. One specific determination on rocks of the White Lake basin gave an age of 51.6±1.8 million years (Church, 1970).

Basal Tertiary rocks are typically coarse breccias and conglomerates. In many places these are overlain by volcanic beds with local interdigitated fluvial and lacustrine sedimentary rocks. In the Princeton and Kamloops areas, Early Tertiary volcanic rocks are commonly dark coloured, probably of andesitic or basaltic composition, whereas, in the southern Okanagan area and near Midway these rocks are generally light coloured having varied composition of acid or intermediate character. Detailed data are scarce but regional studies show that these strata are rarely more than a few thousand feet thick. In contrast to the younger Tertiary units which are almost everywhere flat lying, the older Tertiary strata are commonly tilted and, in places, folded. Mathews (1964) gives ages 10, 12, and 13 million years for some of these younger rocks northwest of Kamloops.

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

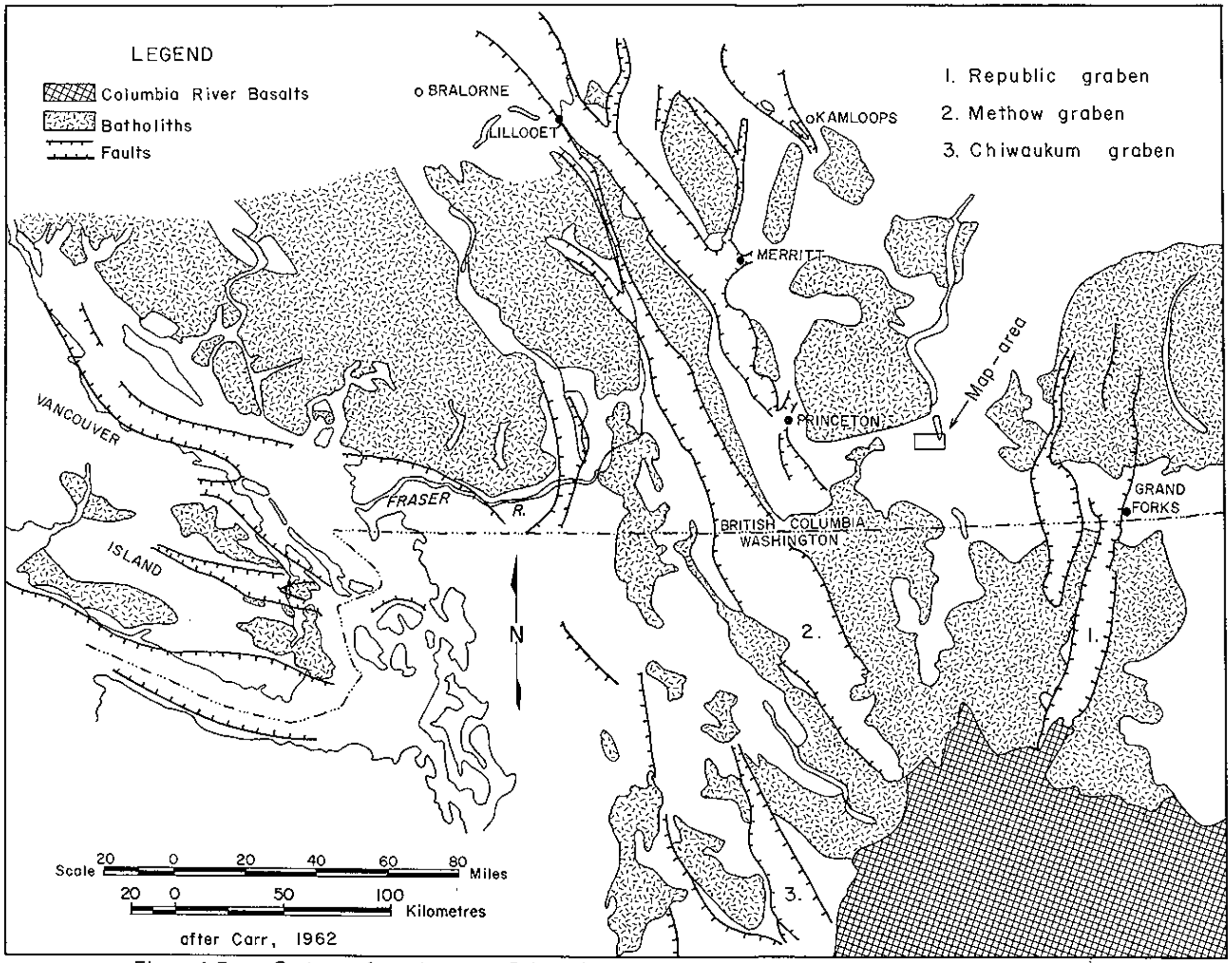

Figure 1.5. Grabens of southwestern British Columbia and northern Washington State, after Carr, 1962.

According to Bally, *et al.*, (1966) in the Rocky Mountain area of southeastern British Columbia and adjacent parts of Alberta, tensional conditions and uplift prevailed after Laramide thrusting and molasse-type deposition ceased during Paleocene times. Uplift was accompanied by large-scale 'listric normal' fault movement which was instrumental in formation of many longitudinally oriented valleys of interior British Columbia. These valleys became important drainage routes to the Pacific Ocean and favourable sites for Early Tertiary deposition.

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2

GENERAL GEOLOGY AND STRUCTURE

The following discussion deals principally with the distribution, thickness, lithology, local and regional structural relations and correlation of the main Tertiary rock units; only brief reference is made to pre-Tertiary rocks.

PRE-TERTIARY ROCKS

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

The Shoemaker Formation, mainly dark grey chert, and Old Tom Formation, mainly greenstone, are interlayered units well exposed in area about a mile west of Yellow Lake and south along Highway 3A, and in the area south of Dorfler Ranch. Old Tom rocks are also exposed on the west wall of Okanagan Valley about 1 mile north of Green Lake. A small window of Shoemaker Formation, showing through Tertiary rocks, is located about three-quarters of a mile northwest of Mahoney Lake.

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

TERTIARY ROCKS

The present study leads to several important modifications of Bostock's (1941) seven-fold division of Tertiary rocks (Map 627A, *Geol. Surv., Canada*). Bostock's scheme from the top downward is as follows:

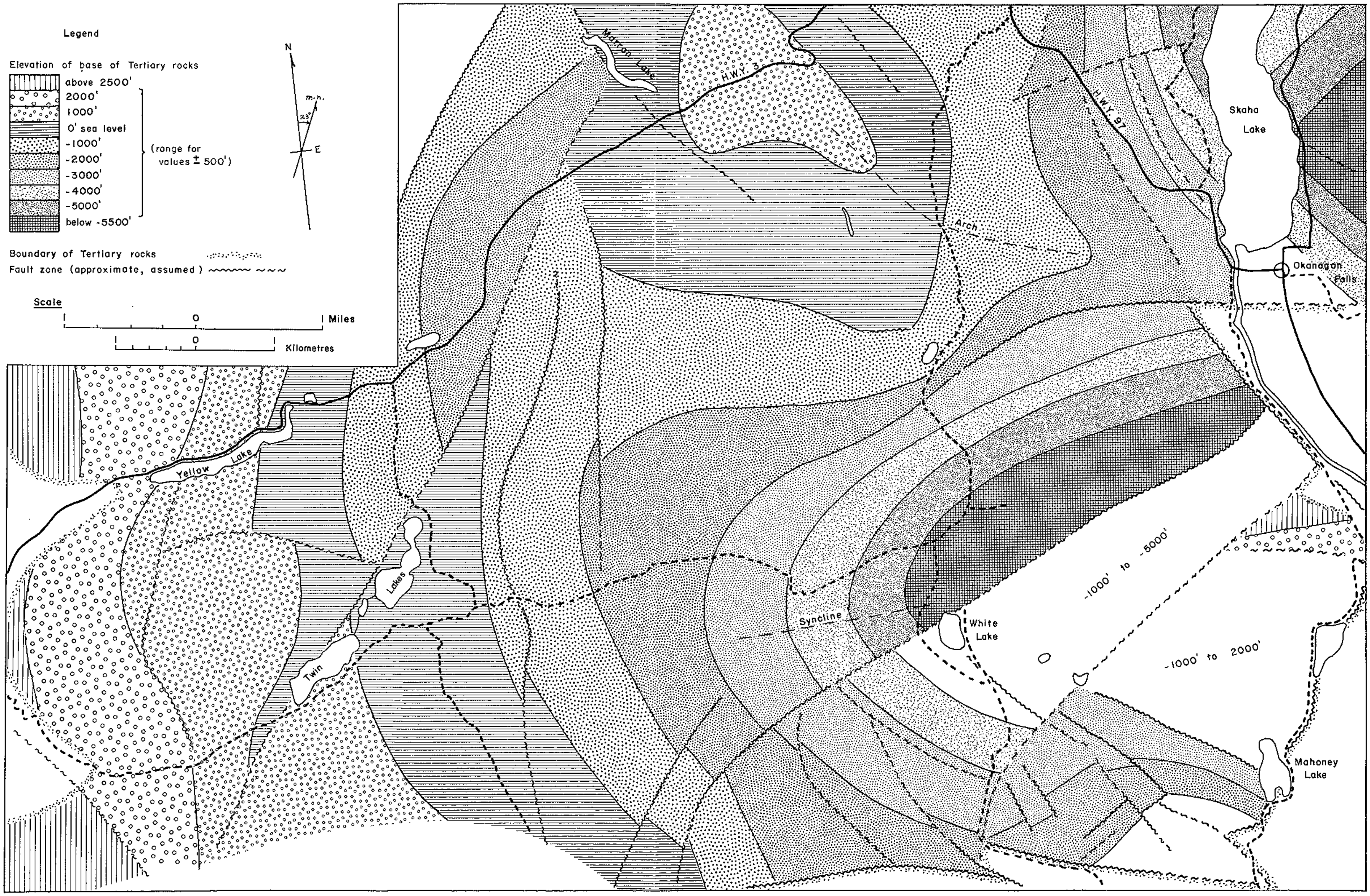
7 – Unnamed conglomerate.

6 – Unnamed agglomerate, conglomerate.

TABLE 2.1. TERTIARY FORMATIONS

	Thickness Range in Feet
SKAHA FORMATION	
UPPER MEMBER — Essentially a fanglomerate with large boulders and blocks of Tertiary and pre-Tertiary rock.	0 to 600
LOWER MEMBER — Mainly slide breccia with some intercalated conglomerate and tephrite (augite porphyry).	0 to 300
WHITE LAKE FORMATION	
UPPER MEMBER — Mainly light-coloured pyroclastic rocks, volcanic breccia (Indian Head breccia) with some sedimentary rocks and tephrite (augite porphyry).	0 to 300
MIDDLE AND LOWER MEMBERS — Interdigitated sedimentary and volcanic rocks; White Lake sedimentary rocks consist of volcanic sandstone and conglomerate with some coal; White Lake volcanic rocks consist of feldspar porphyry lavas, lahars, and pyroclastic rocks.	0 to 3,500
MARAMA FORMATION	
NOT SUBDIVIDED — Predominantly rhyolite and rhyodacite lava with some pyroclastic rocks and local basal conglomerate.	0 to 1,000
MARRON FORMATION	
PARK RILL MEMBER — Mainly merocrystalline and glassy andesite lava.	200 to 1,500
NIMPIT LAKE MEMBER — Mainly trachyte and trachyandesite lava.	400 to 1,000
KEARNS CREEK MEMBER — Mainly pyroxene-rich vesicular basaltic andesite lava.	0 to 400
KITLEY LAKE MEMBER — Mainly trachyte and trachyandesite lava.	1,000
YELLOW LAKE MEMBER — Mainly anorthoclase lava, augite porphyry lavas (phonolites), and pyroclastic rocks.	500 to 1,800
SPRINGBROOK FORMATION	
NOT SUBDIVIDED — Mainly boulder conglomerate overlying valley talus with fragments of underlying pre-Tertiary rocks.	0 to 700

Figure 2.1 Inferred configuration of basal Tertiary surface



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

Table 2.1 shows a revised scheme based on a five-fold division of the rocks (Fig. 1.2). Bostock's Springbrook Formation '1' and White Lake Formation '4' are retained with only minor changes in description. Unit '2' is not observed in the map-area and, therefore, is dropped from the Table of Formations. The name Marama Formation is newly applied to rocks, mainly rhyodacite and rhyolite, equivalent to the upper part of Bostock's Marron Formation '3' but found to be unconformable on the older succession. The Marron Formation, as now defined, consists of five conformable volcanic members bounded below by the Springbrook Formation and above by the Marama Formation. The name Skaha Formation is newly applied to conglomerate and volcanic rocks, units '6' and '7' of Bostock's scheme, and interbedded slide breccia not recognized by Bostock.

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

The surface is generally tilted in an easterly direction. Its regularity is broken by an east-trending syncline in the east-central part, and a southeast-trending anticline in the north part of the map-area. Also, near the east and southeast margins of the map-area, the surface is truncated abruptly by gravity faults of the Okanagan system which generally show westerly or northerly downthrow. Where faults pass subparallel to structure contours, the general slope of the surface is locally increased or decreased depending on the direction of downthrow.

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

DETAILED DESCRIPTION OF FORMATIONS

SPRINGBROOK FORMATION: The Springbrook Formation was named and described by Bostock (1940, 1941) in marginal notes appended to Geological Survey of Canada Maps 627A, 628A, and 341A. The following description is on Map 627A:

TABLE 2.2. SUMMARY OF LITHOLOGY OF SPRINGBROOK FORMATION AND LOWER MARRON FORMATION

(Location – 2 miles west of Green Ranch)

ELEVATION IN FEET (m.s.l.)		DESCRIPTION		FORMATIONS
3,720	base of bluff and top of section	analcite porphyry; anorthoclase augite porphyry; some columnar jointing	mainly lava	lower part of Marron
3,200	contact			
		augite porphyry breccia; hoodoo structures	mainly coarse pyroclastic rocks	
2,850	contact			minor angular unconformity
		well-bedded conglomerate; dips range from zero to 22 degrees east		Springbrook
2,550		possible fault	poor exposure	
2,390		chert breccia		
2,150	contact			great unconformity
1,980	base of exposure	massive black chert	poor exposure	Shoemaker

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

DISTRIBUTION AND THICKNESS: The Springbrook Formation is exposed only on the western extremity of the map-area and immediately north of Mahoney Lake in the southeast corner of the map-area (Fig. 1.2).

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

LITHOLOGY: A summary of data from the stratigraphic section of lowest Tertiary beds of the west boundary of the map-area is given in Table 2.2.

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

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

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

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

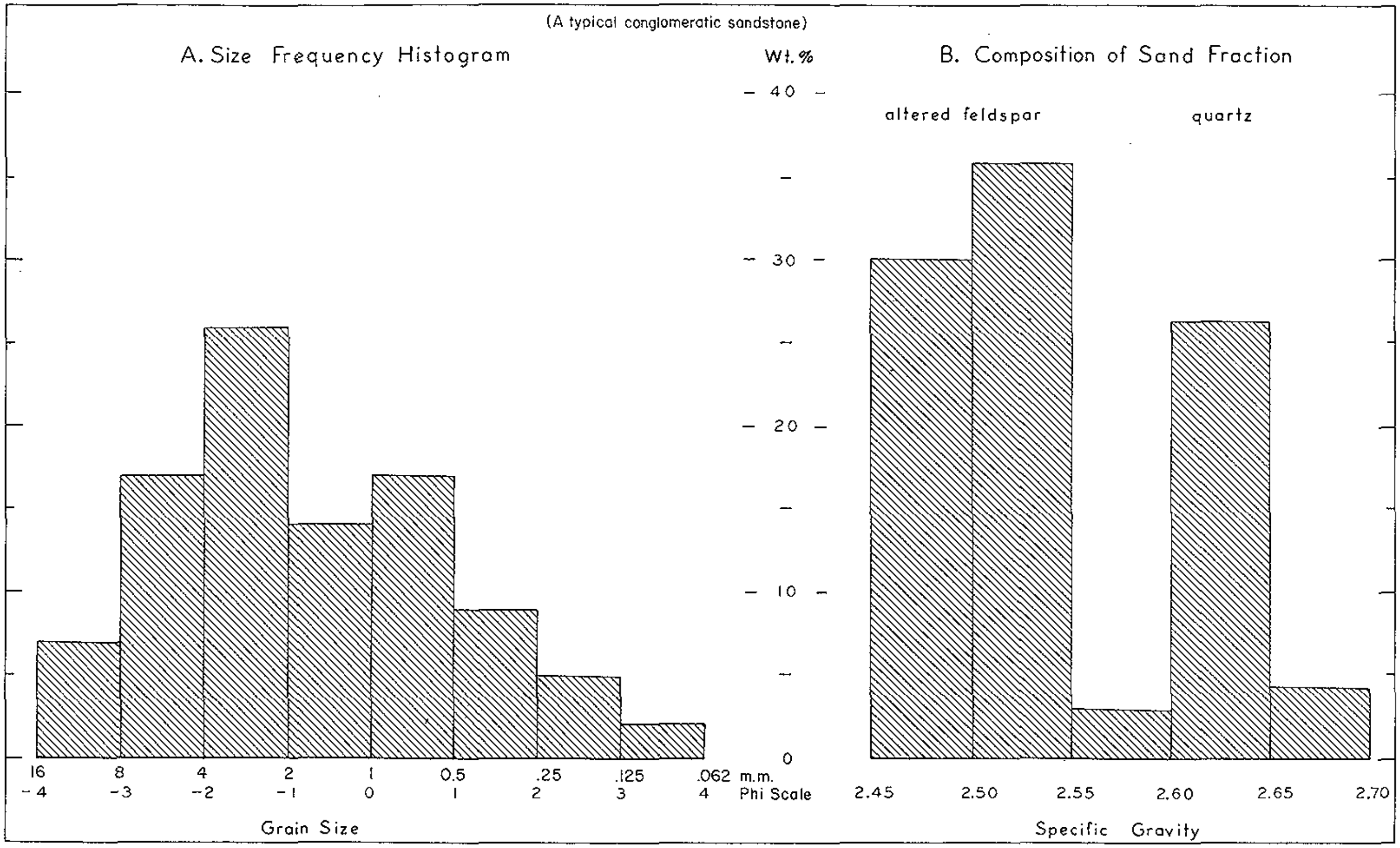


Figure 2.2. Grain analyses of Springbrook sedimentary rock.

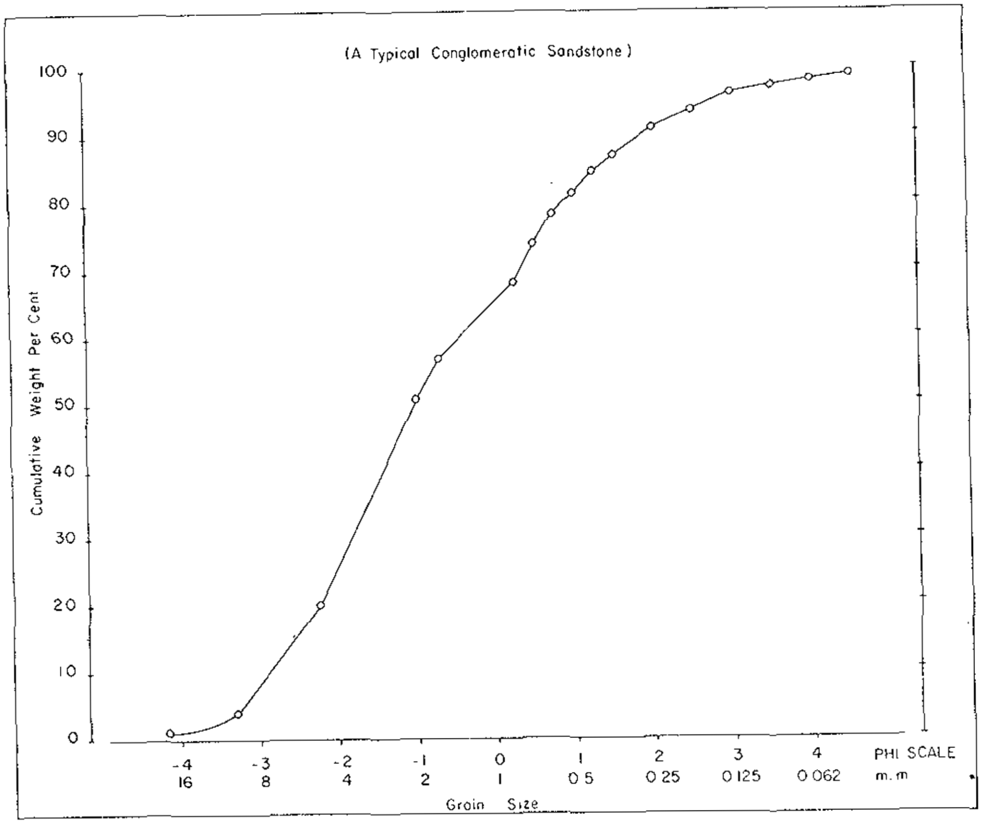


Figure 2.3. Size frequency cumulative curve of Springbrook sedimentary rocks.

STRUCTURE: In the western part of the map-area Springbrook beds dipping 10 to 15 degrees east are overlain with some angular unconformity by Marron volcanic rocks dipping up to 5 degrees east. However, it is probable that this unconformity represents only a short time interval because the contact between the two formations is generally smooth.

AGE: Bostock published conflicting information on the age of the Springbrook Formation. On map 628A (*Geol. Surv., Canada*), he indicates that the upper beds "contain plants of early Tertiary, perhaps Paleocene age"; on map 341A (*Geol. Surv., Canada*) he states that "these beds contain plants of presumably late Eocene age." Since map 628A was published in 1941, one year after 341A, the description on 628A is considered to be Bostock's most recent interpretation. Until a more comprehensive study is made, however, the present author tentatively assigns Middle Eocene age to the Springbrook Formation in keeping with K-Ar dates obtained on similar rocks in southern British Columbia (Mathews, 1964).

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

Kettle River Formation (Daly, 1912; Midway area).
Curry Creek Formation (Reinecke, 1915; Beaverdell area).
Coldwater Formation (Dawson, 1879; Kamloops area).
Allenby Formation (Shaw, 1952; Princeton area).
O'Brien Creek Formation (Muessig, 1962; Republic area).

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

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

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

MARRON FORMATION: The name Marron Formation was applied by Bostock (1941) to the Early Tertiary volcanic rocks underlying a large area in the central part of combined 15-minute quadrangle maps, Olalla, British Columbia (*Geol. Surv., Canada,* Map 628A) and Okanagan Falls, British Columbia (*Geol. Surv., Canada,* Map 627A). His brief description of these rocks on map 627A is as follows:

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

Mapping by the writer provides the basis for a six-fold subdivision of these rocks. The name Marron Formation is amended in this study, and refers only to the lowest five members, a succession of conformable or nearly conformable beds.

The type-section of the Marron Formation is located near Yellow Lake, parallel to structure cross-section A-B (Fig. 1.2 and Table 2.1). At the base of this section, 0.8 mile west of Yellow Lake at an elevation of 3,000 feet, the lowermost member of the Marron

Formation rests with slight angular unconformity on Springbrook conglomeratic beds. At the top of the section, 0.7 mile west of 'B' at 3,700 feet, lavas of the uppermost member of the Marron Formation are overlain unconformably by younger volcanic rocks. (In the type-section, Marron rocks dip 5 to 25 degrees easterly. The aggregate thickness of the strata is about 5,000 feet.)

In the type-section the lowermost Marron unit, here termed the 'Yellow Lake Member,' is well exposed near 'A' (Fig. 1.2). At 0.8 mile west of Yellow Lake and elevation 3,000 feet, these rocks rest on the Springbrook Formation; at elevation 4,400 feet in the same area, the Yellow Lake Member is overlain by the 'Kitley Lake Member' (Plate IIA). The Kitley Lake rocks are exposed in the type-section between 'A,' at an elevation of 4,600 feet, and at a point 2.5 miles west of 'B' at elevation 2,700 feet. The 'Kearns Creek Member' is a relatively thin unit near the middle of the Marron succession and is exposed about a half mile east of Yellow Lake midway between points 'A' and 'B.' Younger rocks, here termed the 'Nimpit Lake Member,' are present near Trout Lake cropping out in the area 0.5 to 1.8 miles east of Yellow Lake in cross-section A-B. The 'Park Rill Member,' the uppermost unit of the Marron Formation overlies the Nimpit Lake rocks 1 mile west of 'B' at an elevation of 3,300 feet and is overlain by a younger volcanic formation 0.7 mile west of 'B' at elevation 3,700 feet.

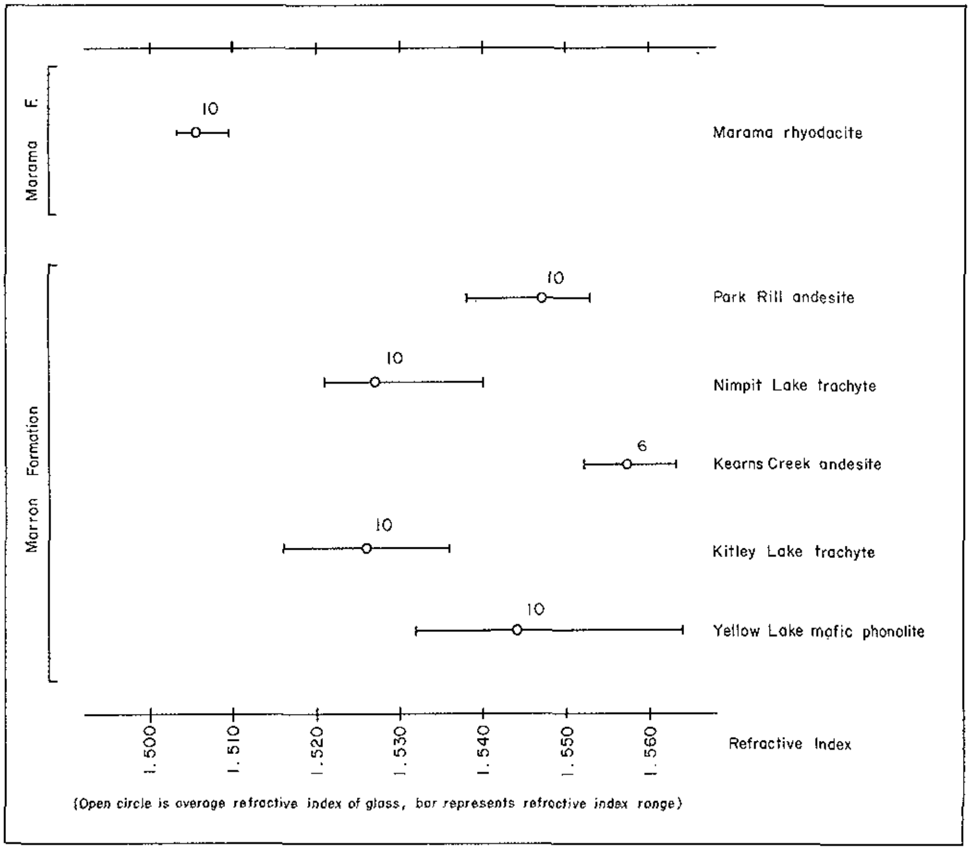


Figure 2.4. Glass bead refractive indices of Marron and Marama lavas.

The refractive index of glass prepared from powdered rock samples is helpful in distinguishing lavas characteristic of various Marron members. These data are shown on Figure 2.4. Complete chemical analyses of these rocks, including some data on minor elements, are tabulated in the chapter on Igneous Petrology, and detailed petrographic descriptions are given in Appendix A.

YELLOW LAKE MEMBER: The name Yellow Lake Member is applied to alkali-rich volcanic rocks that form the lowermost unit of the Marron Formation. The petrography of these rocks is briefly described by Church (1963) and more fully by Bird (1965).

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

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

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

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

This distinction is also evident where large anorthoclase and augite-bearing porphyry lavas are observed east of Marron Lake, and small rhomb lavas are present in the vicinity of the switchback on Highway 3A and areas immediately south. However near Yellow Lake the rocks are not easily divisible into large and small porphyry units. Rhomb porphyries are poorly developed and the lavas are lighter coloured and more amygdaloidal than those found at other localities. On bluffs 2 miles west of Green Ranch near the west boundary of the map-area, the rocks consist of about 350 feet of volcanic breccia overlain by about 600 feet of lavas. In places these rocks are cut by columnar jointed rhomb porphyry dykes.

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

KITLEY LAKE MEMBER: The Kitley Lake Member consists of feldspar porphyry lavas with minor pyroclastic rocks composed mainly of trachytic and trachyandesitic clasts. The Kitley Lake Member conformably overlies the Yellow Lake Member (Plate IIA).

Distribution and Thickness: The Kitley Lake rocks are extensively exposed in the western part of the map-area, particularly on mountain tops and ridge crests. Smaller areas of exposure are to be seen at the north end of Marron Lake, near the junction of Highways 3A and 97 and to the south, and on the hillside west of Kitley Lake and the low hills and valleys to the southeast. Other exposures of this unit are found west and northwest of Mahoney Lake (Fig. 1.2).

The Kitley Lake Member has a relatively uniform thickness of about 1,000 feet and underlies approximately three-quarters of the map-area rocks at some depth, although less than 15 per cent comprises exposed rocks of this unit.

Lithology: The Kitley Lake rocks form conspicuous, thick trachyte flows in the lower part of the Marron Formation. In the western part of the map-area, where best exposed, the unit is characterized by vertical slab-like pillars which locally form cliffs more than 100 feet high.

Lavas are commonly non-vesicular and cream coloured where fresh, but where badly weathered, surfaces are mottled with brownish red hues or dark grey with bleached white feldspar phenocrysts.

The most widely distributed phase of this member has discrete tabular crystals and polygonal clusters and clots of feldspar phenocrysts measuring 3 to 6 millimetres in diameter, some small pyroxene grains, and few biotite flakes embedded in a fine crystalline matrix. Plagioclase is the dominant feldspar but sanidine is abundant, occurring as discrete glassy laths or mantles on plagioclase.

West of Mahoney Lake, the upper part of the formation is a 'clot-lath porphyry' about 400 feet thick. This rock contains both laths and anhedral clots of feldspar 2 to 6 millimetres in diameter set in a buff coloured, micro-crystalline matrix. Ferromagnesian minerals are virtually absent. Also, at this locality, the lower part of the formation consists of a thin zone of porphyry characterized by a high content of small, equant crystals and clusters of feldspar phenocrysts, 2 to 4 millimetres in diameter, embedded in a fine-grained matrix.

Fractures in these rocks are commonly filled with calcite, less commonly laumontite-leonhardite, and rarely heulandite..

KEARNS CREEK MEMBER: The Kearns Creek Member, a distinctive basaltic andesite unit occurs with apparent conformity, near the middle part of the Marron succession, overlying the Kitley Lake Member.

Distribution and Thickness: Although widely distributed, the Kearns Creek rocks are poorly exposed; outcrops cover less than 2 per cent of the total map-area. The largest area of exposure is found on valley slopes south of the T. L. Ranch; small exposures may be seen east of Yellow Lake and near Mahoney Lake (Fig. 1.2).

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

Lithology: The unit consists of dark brown, markedly vesicular, basaltic andesite lava and flow breccia. Typically these rocks have abundant pyroxene phenocrysts and a few scattered laths of plagioclase. Areas underlain by this unit are generally low lying and covered with a brown, granular regolith, the rocks being readily weathered and eroded.

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

NIMPIT LAKE MEMBER: The Nimpit Lake rocks are chemically similar to the Kitley Lake trachyte and trachyandesite lavas but differ in texture and stratigraphic position. The Nimpit Lake Member forms the upper middle part of the Marron Formation overlying the Kearns Creek basaltic andesites with apparent conformity.

Distribution and Thickness: The Nimpit Lake Member is exposed continuously for several miles on slopes southeast and north of the T. L. Ranch, between points 0.5 and 3.5 miles east of Yellow Lake on Highway 3A and adjacent slopes, and on northeast-facing slopes located south of Highway 3A in line between Marron Lake and Prather Lake. The member underlies roughly half of the map-area, although less than 15 per cent of this is bedrock exposure.

The unit is about 1,000 feet thick where best exposed on the bluffs north of Twin Lakes. In a few places west of Mahoney Lake the unit appears to be less than 200 feet thick.

Lithology: The Nimpit Lake lavas have been eroded forming a distinctive bluff and bench topography in the central part of the map-area where the thickest deposits are observed. Bluffs vary in height from 50 to more than 200 feet, each corresponding approximately to the thickness of one or more lava flows.

The flows are trachytes that are commonly yellowish or cream coloured where fresh, non-vesicular, and contain scattered small phenocrysts of pyroxene and radiating plagioclase glomerophenocrysts set in a fine crystalline matrix. Some flows contain accessory biotite and sanidine. Most of the rocks are homogeneous and constituent minerals vary only slightly in composition and abundance.

Pyroclastic deposits within the member are generally thin and discontinuous, however, near Prather Lake the unit contains abundant agglomerate and some tuff. In places west of Mahoney Lake, rosette porphyry trachyte lavas are intermixed with light-coloured, aphanitic volcanic breccias.

PARK RILL MEMBER: The Park Rill Member is the uppermost unit of the Marron Formation and rests conformably on the Nimpit Lake trachytes (Plate IIB).

Distribution and Thickness: Park Rill rocks are exposed chiefly in the central and southern parts of the map-area. Thick deposits are to be seen on slopes west and south of Stewart Ranch and west and east of Dorfler Ranch near Park Rill. A relatively thin but continuous deposit crops out high on the north flank of the hill between Prather Lake and T. L. Ranch. Other important exposures are present near Mahoney Lake, on the ridge east of Prather Lake, and southwest of Marron Lake (Fig. 1.2).

The lateral extent of the Park Rill andesite comprises about 30 per cent of the map-area, but less than half of this area is actual bedrock exposure.

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

Lithology: The Park Rill volcanic rocks are mostly dark brown, non-vesicular andesite lavas. The unit is generally massive, and individual flows are distinguished only with difficulty. The rock is typically merocrystalline, containing about equal parts glass and crystals measuring about 1 millimetre in diameter. A phase of this unit cropping out on the ridge east of Prather Lake is especially glassy; some specimens having less than 5 per cent crystals.

STRUCTURE: Marron strata show important variations in attitude throughout the map-area. Near the west boundary the rocks are almost horizontal or dip gently east; in the central and southeastern parts, they underlie younger beds of the White Lake syncline; in the north-central part, they are arched over a broad southeast-trending anticlinal axis that forms a local structural high adjacent to the White Lake syncline.

The dip of the Marron beds in the map-area rarely exceeds 30 degrees except in areas of severe fault disturbance such as west of Mahoney Lake where some beds are almost vertical.

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

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

TABLE 2.3. CORRELATION OF MARRON FORMATION AND MIDWAY GROUP

Marron Members		Thickness Range (in feet)	Divisions of Midway Group		Thickness Range (in feet)
Park Rill Member	andesite	200 - 1,500	Upper Division	andesite	800
Nimpit Lake Member	trachyte	400 - 1,000			
			Middle Division	trachyandesite andesite	200 - 1,000
Kearns Creek Member	andesite	0 - 400			
Kitley Lake Member	trachyandesite	1,000			
Yellow Lake Member	phonolite	500 - 1,000	Lower Division	phonolite	300 - 1,000

CORRELATION AND AGE: Marron beds are comparable with the Midway Group. Recent studies by Little and Monger (1966) of the Tertiary rocks near Midway, British Columbia, reveal much about the internal structure of the Midway Group. Three divisions composed mainly of porphyritic lava are recognized: a basal division consisting of 300 to 1,000 feet of rhomb porphyry and related alkali-rich rocks; a middle division, 200 to 1,000 feet thick, with two parts – a lower discontinuous unit composed mainly of andesite and an upper, widespread unit composed of trachyte and trachyandesite; an upper division, at least 800 feet thick, composed of andesite. This Midway succession bears a marked resemblance to the Marron Formation as shown in Table 2.3. No major stratigraphic division of the Midway Group is without a Marron equivalent; however, apparently there is no counterpart of the Kitley Lake Member in the Midway section.

Mathews (1946) gives two K-Ar ages for Midway rocks: 'pulaskite porphyry' 48 million years and Rock Creek ash 49 million years (Middle Eocene). Description of rocks and sample locations suggest that pulaskite porphyry corresponds to Midway trachyandesite lava (equivalent to the Nimpit Lake Member of Marron Formation); Rock Creek ash immediately underlies the trachyandesite lava. A sample of biotite from a trachyte lava flow in the Kitley Lake sequence immediately east of Yellow Lake was recently collected by the writer and dated by Geochron Laboratories Ltd. giving an age of 51.6±1.8 million years.

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

MARAMA FORMATION: The Marama Formation is the name proposed in this study for a unit characteristically composed of rhyolitic and rhyodacitic rocks that unconformably overlies the Marron Formation and underlies the White Lake Formation. The *type-section of the Marama Formation lies near the crest of the mountain south of* Marama Creek, near point 'B' in structure sections A-B and B-C (Fig. 1.2). At the base of type-section, 0.7 mile west of 'B' at elevation 3,700 feet, Marama pyroclastic rocks unconformably overlie Park Rill andesite lavas. At the top of the type-section, 1.4 miles southeast of 'B' at elevation 2,700 feet, Marama lavas and flow breccias are overlain unconformably by younger sedimentary rocks. (In the line of section, the Marama rocks dip 10 to 25 degrees southeast and reach a thickness, mainly lavas, of 700 feet.)

DISTRIBUTION AND THICKNESS: The Marama Formation is most widely distributed in the central and northern parts of the map-area where it forms precipitous bluffs several hundred feet high (Plate IV). The thickest deposits cap the ridge northwest of Marama Creek, and cover the slopes north of Stewart Ranch and the ridge northeast of Prather Lake. Other important areas of exposure are on slopes immediately west of Green Ranch near Twin Lakes, west of Skaha Lake, and east of Okanagan Falls. A thin broken belt of rhyodacite breccia and pebble conglomerate extends for about a mile in an easterly direction from the main road near Dorfler Ranch. Also, small bodies of this rock crop out near the base of the White Lake Formation northeast of the Observatory Site (Fig. 1.2). Two small deposits of conglomerate and pyroclastic rocks, 1.5 miles northeast of Prather Lake, are tentatively assigned to this unit.

The Marama Formation probably underlies about 30 per cent of the map-area about half of which is covered by younger formations. The maximum observed thickness of the Marama Formation, on slopes northwest of Marama Creek, is about 1,000 feet. However, beds are generally discontinuous and, in places absent; for example, younger volcanic and sedimentary rocks about 1.5 miles southeast of White Lake rest directly on Marron strata.

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

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

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

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

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

In the central part of the map-area, north of Stewart Ranch, beds vary in dip from nearly horizontal at the top of the mountain to about 30 degrees southeast near the contact with younger sedimentary rocks. In this area, Marama and Marron rocks are cut by north-trending normal faults, some of which show a downthrow of several hundred feet to the west. Northwest of Highway 3A, between Trout Lake and Marron Lake, Marama rocks dip gently east and are downfaulted in the northeasterly trending Trout Lake graben (Fig. 2.5). Immediately east of Prather Lake, the Marama Formation is in contact with southeasterly dipping Marron rocks along an east-trending fault zone.

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

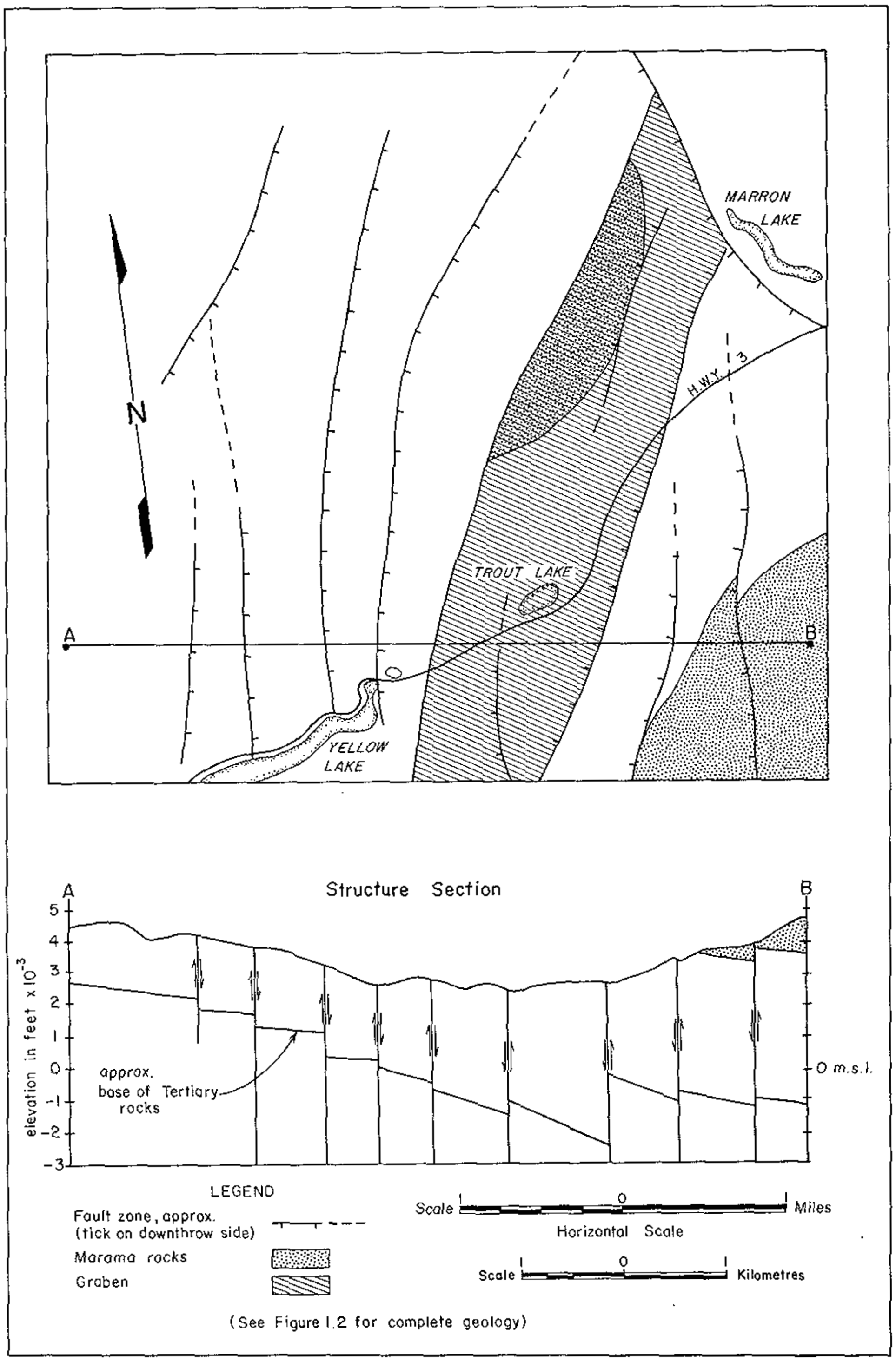


Figure 2.5. Trout Lake graben.

area.) The belt appears to be offset about one-half mile to the west along an east-trending fault near the north boundary of the map-area.

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

CORRELATION: Marama rocks are comparable to lavas cropping out on Mount Boucherie near Kelowna. The Boucherie lavas are cut by basalt dykes, thought to be feeders of Miocene 'Plateau' lavas, and they rest on conglomerate beds which in turn appear to rest on a surface deeply eroded in older lavas similar to the Kitley Lake rocks of the Marron Formation.

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

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

DISTRIBUTION AND THICKNESS: The White Lake Formation is located in the east-central and northeast parts underlying about 25 per cent of the map-area. Most of the sedimentary rocks lie west and north of White Lake, whereas the volcanic rocks are centred east and northeast of White Lake and near Okanagan Falls.

The thickest section of White Lake strata, about 3,500 feet thick, is to be seen near the Observatory Site. Between White Lake and Mahoney Lake the beds are thin and in places younger rocks rest directly on pre-Tertiary formations.

STRATIGRAPHY AND LITHOLOGY: White Lake beds exposed near White Lake are divisible into three members (Fig. 1.3). The lower and middle members contain interdigitated sedimentary and volcanic deposits; the upper member consists mainly of volcanic rocks with some intercalated sedimentary rocks.

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

(lower member)

> "A section along the valley of Prather creek [Kearns Creek] on the north side of the basin was measured which gave a thickness of about 2000 feet of beds. It is very likely, however, that this thickness is not uniform throughout the whole area, but, because of the conditions under which the beds were deposited, must vary greatly from one side of the area to the other. It is

possible also that the 2000 feet of thickness in the section represents more than the actual thickness of the beds, for while there is no apparent duplication of the beds by faulting it is very probable that there has been some slipping or faulting along the planes of bedding so as to give the section an apparent thickness greater than the actual.

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

(middle member)

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

Data compiled during the present study for section E-F (Fig. 2.6 and Fig. 1.2), located immediately east of Kearns Creek, coincide well with Camsell's description of the lower member; thick beds of fine-grained sedimentary rocks in the lower part of the section are overlain by equally thick deposits of coarse sedimentary rocks, possibly indicating large-scale infilling of Tertiary White Lake. However, the exposed section proves to be 2,400 feet thick – about 400 feet thicker than Camsell's estimate. Probably Camsell obtained his data from a section immediately west of Kearns Creek, on the side of the creek opposite E-F – here a bed of volcanic rock, thickening westward and occurring about 1,950 feet above the base of the formation, terminates the exposed section. This same volcanic bed can be traced to the south limb of White Lake syncline and serves as a good marker-zone for the top of the lower sedimentary member (Fig. 2.6).

Data compiled from a diamond-drill hole in the lower sedimentary member are summarized and illustrated on Figure 2.7. Selected samples of core were petrographically described by Ward (1964).

East of section E-F along strike, White Lake sedimentary rocks pass into a predominantly volcanic succession (Fig. 1.3 and section W-X). McEvoy (Dowling, 1915, p. 252) briefly describes the White Lake beds near the coal mine site about halfway between section E-F and W-X:

(lower member)

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

(middle member)

"In the upper part of the series, for a thickness of 1,000 feet, the shales and sandstones predominate. In the shales in this part 7 seams of coal were uncovered, 4 of which did not contain more than one foot of clean coal."

Lithology of the White Lake sedimentary rocks is diverse. They are intercalated with many lenses and layers of pyroclastic rock. The tuffaceous layers are generally non-fissile

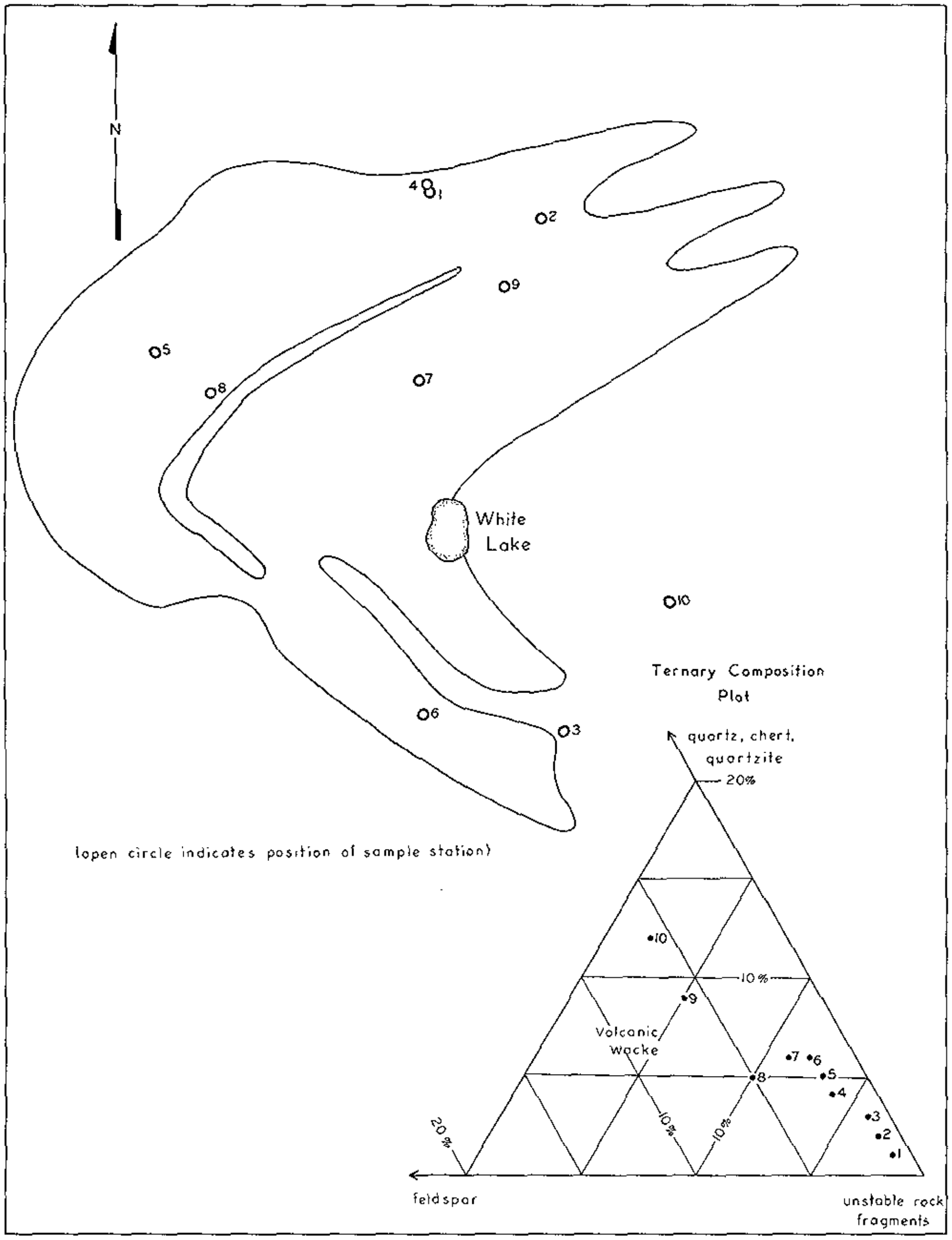


Figure 2.8. Composition of some White Lake sandstones.

and light coloured. Thinly bedded shales and mudstones are commonly folded and compressed below thick pyroclastic deposits probably owing to sudden deposition and loading.

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

The modal composition of ten White Lake sandstones is shown on Figure 2.8. These rocks contain a high percentage of volcanic fragments, with commonly more than 10 per cent argillaceous matrix, minor quartz, chert, quartzite, and feldspar. According to Gilbert's (Williams, Turner, and Gilbert, 1954) classification, the term 'volcanic wacke' best describes this type of rock.

Mudstones comprise much of the sedimentary facies of White Lake Formation but, because of their non-resistant nature, they are commonly poorly exposed. The rocks are thinly bedded and range in colour from light to dark grey — commonly dark colour indicates a high content of carbonaceous matter. Some mudstones are turbid and show little evidence of planar fabric; on the other hand, well-laminated zones and graded beds are not uncommon.

Small-scale infilling is observed in some places. A good example is near the 600-foot level of section G on the south limb of the White Lake syncline (Plate V and Figs. 2.6 and 1.2). A complete infill-cycle consists of about 55 feet of strata. Lithological change in the cycle can be roughly broken down as follows: at the base massive sandstone is abruptly overlain by 30 feet of thinly bedded mudstone, followed by 10 feet of flaggy sandstone with intercalated mudstone, overlain in turn by 15 feet of massive sandstone.

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

Volcanic Rocks: In the north limb of the White Lake syncline (Fig. 1.3 and accompanying W-X structure section) volcanic rocks have a total thickness of about 3,000 feet. The lowest member, about 1,500 feet thick, consists of thin feldspar porphyry lava flows and abundant lahar and pyroclastic deposits containing some accidental fragments of Marama rhyodacite. The middle member, about 1,200 feet thick, consists of a few feldspar porphyry lava flows and much lahar and agglomerate. Characteristically, the clastic rocks contain exotic fragments of Yellow Lake porphyry. The upper member, about 300 feet thick, consists mainly of brown augite porphyry lava and breccia containing small quartz xenoliths and a few blocks of granite.

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

In the area 0.5 to 2 miles southeast of White Lake the lower and middle members wedge out so that the upper member laps directly onto Yellow Lake porphyries (Fig. 1.3 and accompanying S-T structure section). Here the upper member consists of buff-coloured volcanic debris, the 'Indian Head breccia,' pyroclastic rocks, and some volcanic sandstone.

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

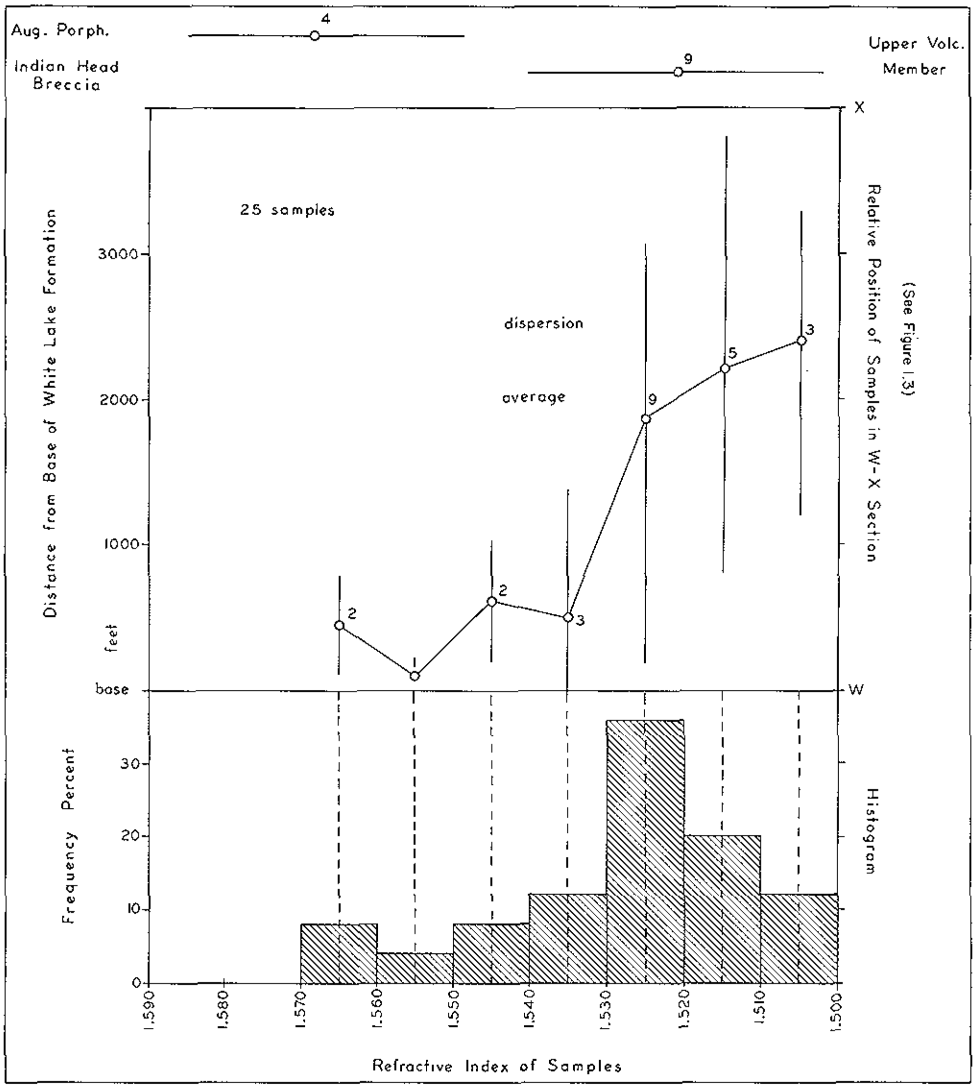


Figure 2.9. Refractive index variation of White Lake volcanic rocks.

Augite porphyry is very limited in distribution, occurring only in the upper member and, to some extent, in the overlying younger beds. In addition to the thin zone of this rock about a mile east of the Observatory Site (in W-X section) there are several small exposures about one-half mile southwest of The Hole (Fig. 1.3).

Detailed petrographic descriptions are given in Appendix A.

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

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

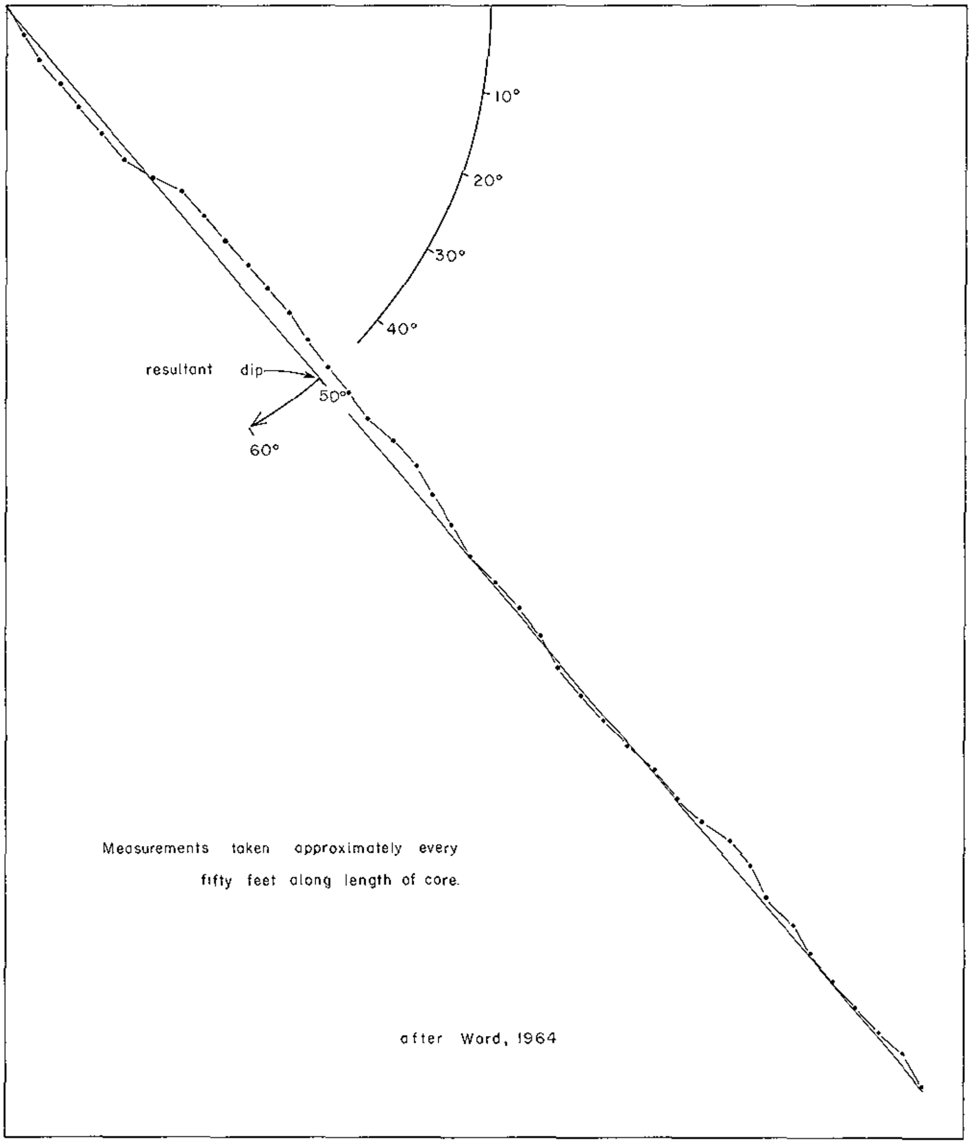


Figure 2.10. Resultant vector diagrams for dip of White Lake beds measured from diamond-drill core.

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

Reverse faulting is observed on the north limb of the syncline. About 1 mile northeast of the Observatory Site, for example, a body of Marama rhyodacite is thrust upward through several hundred feet of White Lake beds (Fig. 1.3). Evidence of important movement subparallel to bedding near the base of the White Lake Formation is also in diamond-drill core (Fig. 2.7).

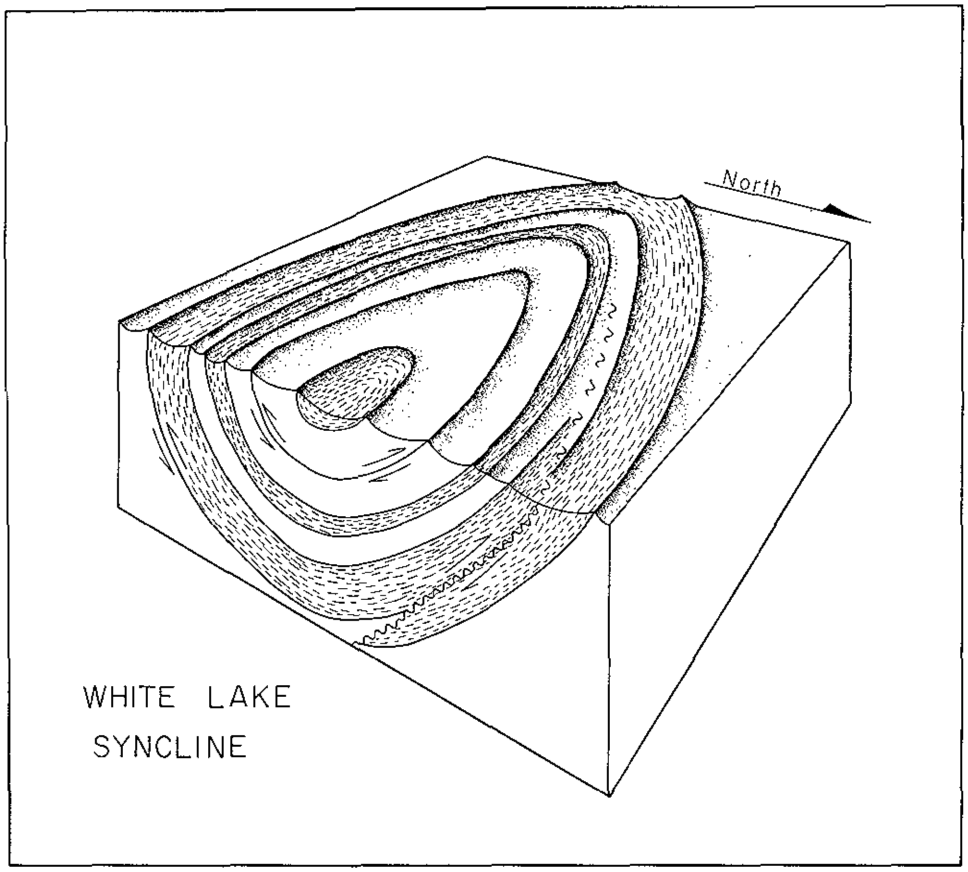


Figure 2.11. Diagrammatic structure section of the White Lake basin showing the results of concentric folding and related reverse faulting.

Figure 2.11 shows a hypothetical structure section through the White Lake basin showing the results of concentric folding and accompanying reverse fault movement.

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

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

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

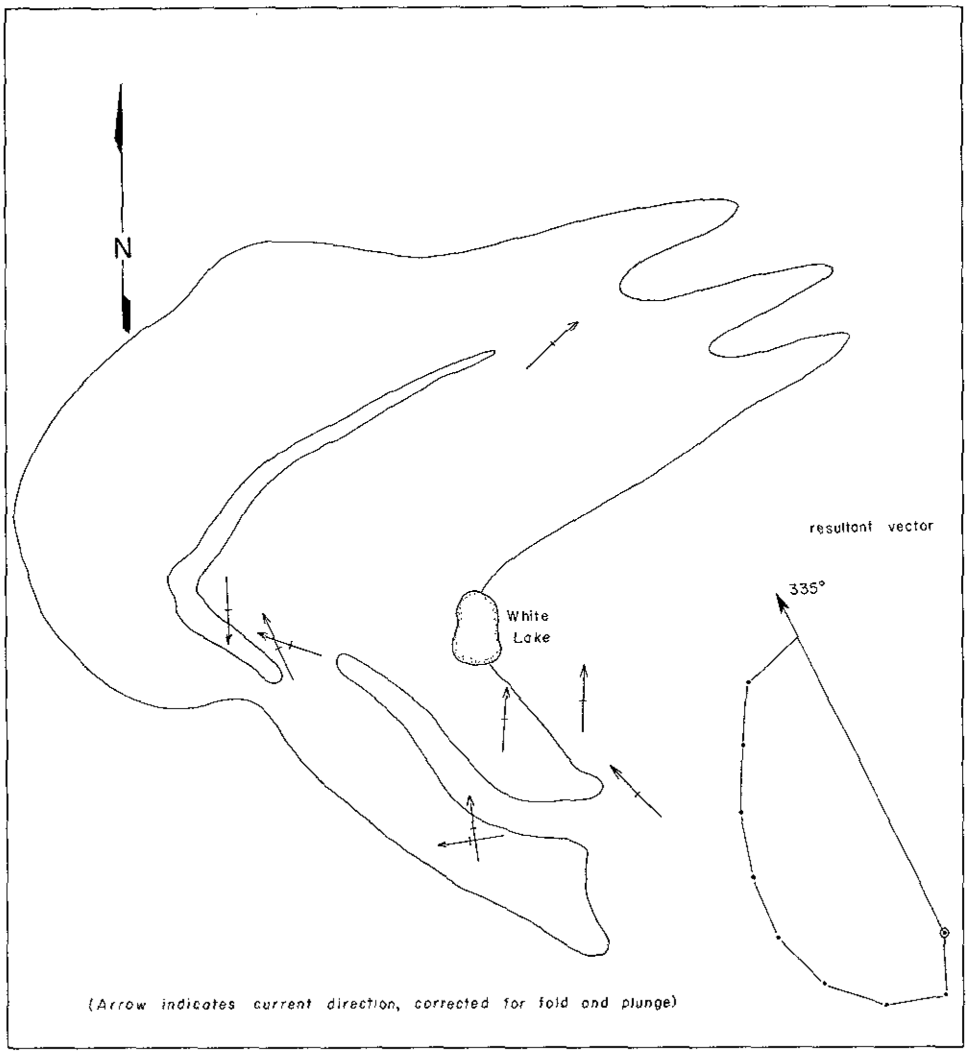


Figure 2.12. Cross-bedding directions in White Lake beds.

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

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

1 – Lower beds rest with angular unconformity on Sanpoil Volcanics and older rocks.

2 – Strata are warped forming a shallow synclinal structure.

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

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

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

SKAHA FORMATION: Skaha Formation is the name proposed in this study for the youngest Tertiary beds of the map-area. These rocks crop out in about 5 per cent of the map-area; the main deposit is centred about 2 miles southwest of Skaha Lake.

The following description, by Bostock (*Geol. Surv., Canada,* Map 627A, 1941), applies to Skaha beds and, in part, to Marron rocks west of Mahoney Lake and White Lake volcanic rocks immediately east of White Lake:

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

The present study shows that the Skaha Formation consists of two members, a lower one composed mainly of slide breccia and some volcanic rock, and an upper one composed of coarse boulder block conglomerate (fanglomerate). The typical stratigraphic relations of these members are shown on section S-T (Fig. 1.3a).

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

Basal Breccia Facies: Basal breccia facies are composed mainly of fragments of the Shoemaker, Old Tom, and Vaseaux Formations. These rocks rest with varying degree of angular unconformity on older Tertiary and pre-Tertiary rocks.

The basal breccia facies occur roughly within the area lying between the Observatory Site, Mahoney Lake, White Lake, and the east boundary of the map-area (Fig. 1.2). These rocks have a maximum thickness of about 300 feet on the ridge one-half mile east of White Lake; elsewhere they thin and wedge out under younger beds.

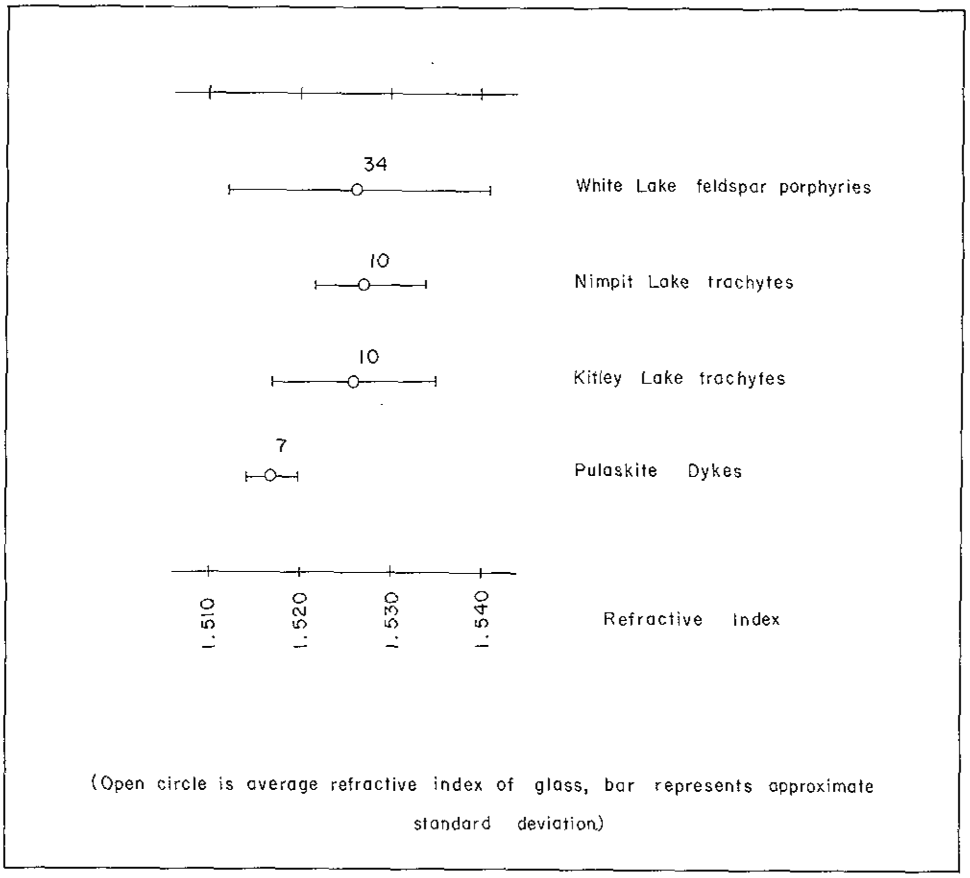


Figure 2.13. Comparison of refractive indices of pulaskite dykes and trachyte-trachyandesite lavas.

The basal breccia facies consist of a chaotic mixture of coarse and finely broken rocks, massive blocks of chert and greenstone, and some conglomerate; the unit varies in detail from place to place. At Indian Head, about one-half mile east of White Lake, blocks of dark chert, some greenstone, together with fine chert breccia form a thick cap on light-coloured White Lake pyroclastic beds (Plate VIIA). Generally, the contact between the basal breccia facies and this rock is abrupt. In a few places, however, thin zones of boulder conglomerate are found immediately below the breccias (Plate VIIB). Immediately east of Kearns Creek near The Hole, the basal breccia facies form a nearly horizontal layer, about 15 feet thick, overlying White Lake volcanic rocks. Basal breccias are roughly bedded and consist mainly of intensely broken chert (Plate VIIIA). Similar deposits of chert breccia are centred about 1,000 feet northwest – and 2,000 feet south of The Hole. In places, the rock has a rough and craggy habit with many holes and caves developed where loose particles have been removed by erosion (Plate VIIIB). Fragments are commonly less than 2 inches in diameter and are mostly cemented together by silica, some carbonate, and minor iron oxides. A disaggregated sample of chert breccia shows little sorting; size disttibution of fragments resembles mechanically crushed quartz (Fig. 2.14).

A deposit of massive chert, some greenstone, and dyke rocks underlies about one-half square mile east and southeast of White Lake. Although dykes and host rocks are locally crushed and sheared, the deposit is generally in tact and could easily be mistaken for Shoemaker or Old Tom Formations in place. However, evidence indicates that this body of rock actually consists of large rafted slabs. For example, at many widely spaced points White Lake beds strike under this deposit (Fig. 1.3 and accompanying sections S-T and X-Y, Fig. 1.3a). Pulaskite dykes are traced without appreciable offset along strike for hundreds of feet, indicating the size of some slabs. None of the dykes cut White Lake rocks. (Correlation of pulaskite dykes with White Lake or Marron trachyte lava is inconclusive on basis of glass bead refractive index work, Fig. 2.13.)

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

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

Augite Porphyry Facies: Augite porphyry lava (tephrite) is present in a small area centred between Kearns Creek and The Hole (Fig. 1.3), accompanied by some light-coloured sedimentary and pyroclastic rocks.

The augite porphyry is massive, dense, dark brown, and contains characteristic large euhedral augite crystals embedded in a fine-grained matrix. Structures such as columnar jointing, flow breccia, and amygdales are only locally well developed. In a few places dykes of similar rock cut Skaha basal breccia facies and older deposits (Plate IXB).

Augite porphyry has a basic alkali-rich composition similar to appinites described by Bowes and Kinloch (1964). High volatile content of the original magma is indicated by

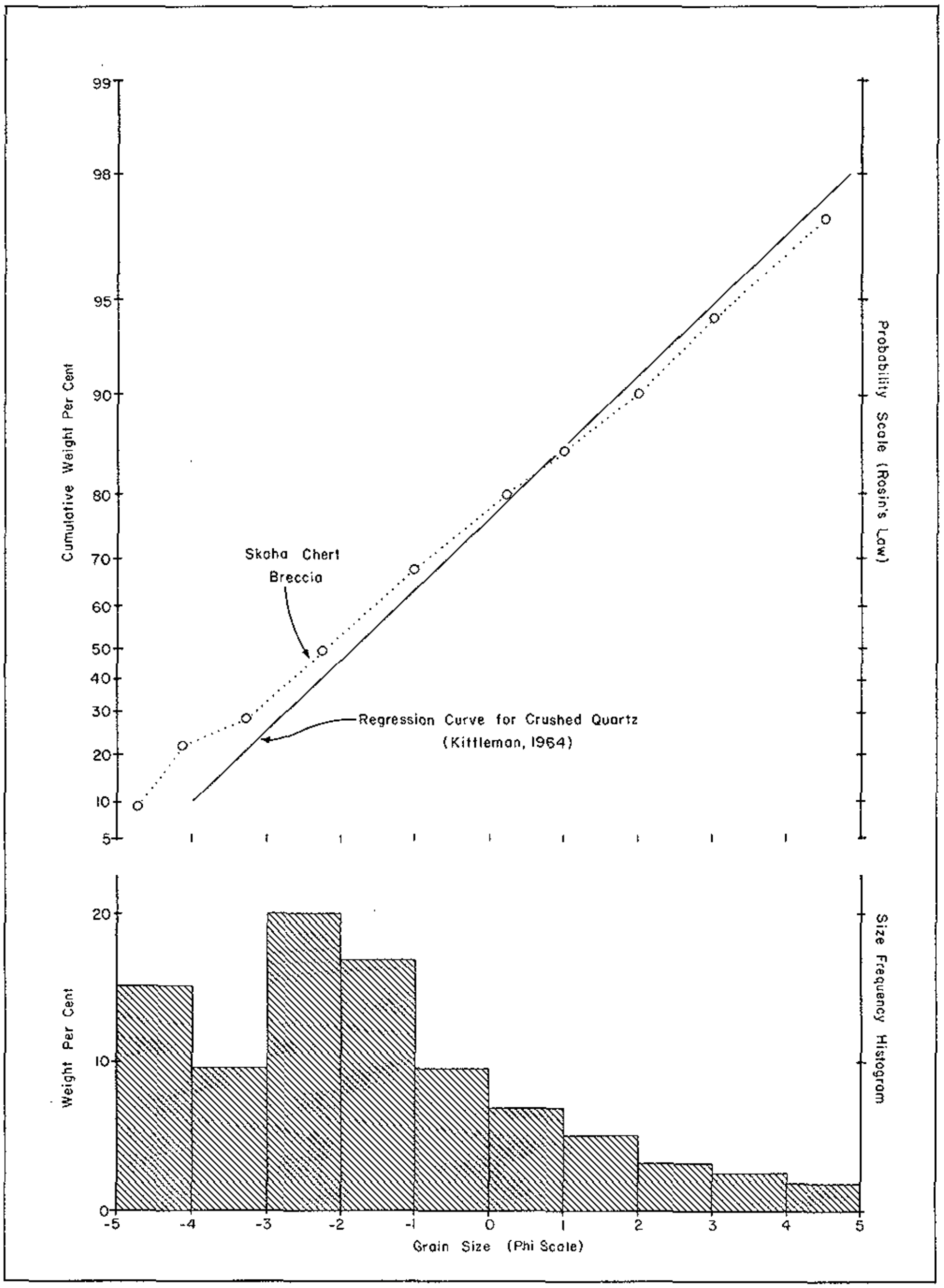


Figure 2.14. Size distribution of Skaha chert breccia.

the abundance of biotite and apatite (petrographic description of augite porphyry, Appendix A).

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

Granite Breccia Facies: The granite breccia facies consists of slide debris, mainly slabs and blocks of granite and some aplite, and a few beds of granite boulder conglomerate and arkose. These rocks rest discordantly on basal Skaha slide debris. It appears that augite porphyry was locally removed by erosion before emplacement of the granite breccia.

Granite breccia forms only about one-quarter of the total outcrop area of Skaha Formation. The main body of granite breccia is found on Mount Hawthorne. East of The Hole the deposit is about 200 feet thick and appears to fill a pre-existing valley developed in Skaha basal breccias. Also, a thin veneer of crushed and highly fragmented granite blocks forms an isolated deposit cropping out on the ridge crest immediately north and northwest of The Hole.

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

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

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

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

North of Green Lake and near the crest of Mount Hawthorne, the facies consists mainly of coarse granite slide breccias, some granite boulder conglomerate, and thin beds of arkosic sandstones (Plate XII). The conglomerate and sandstone probably resulted from stream reworking of slide deposits.

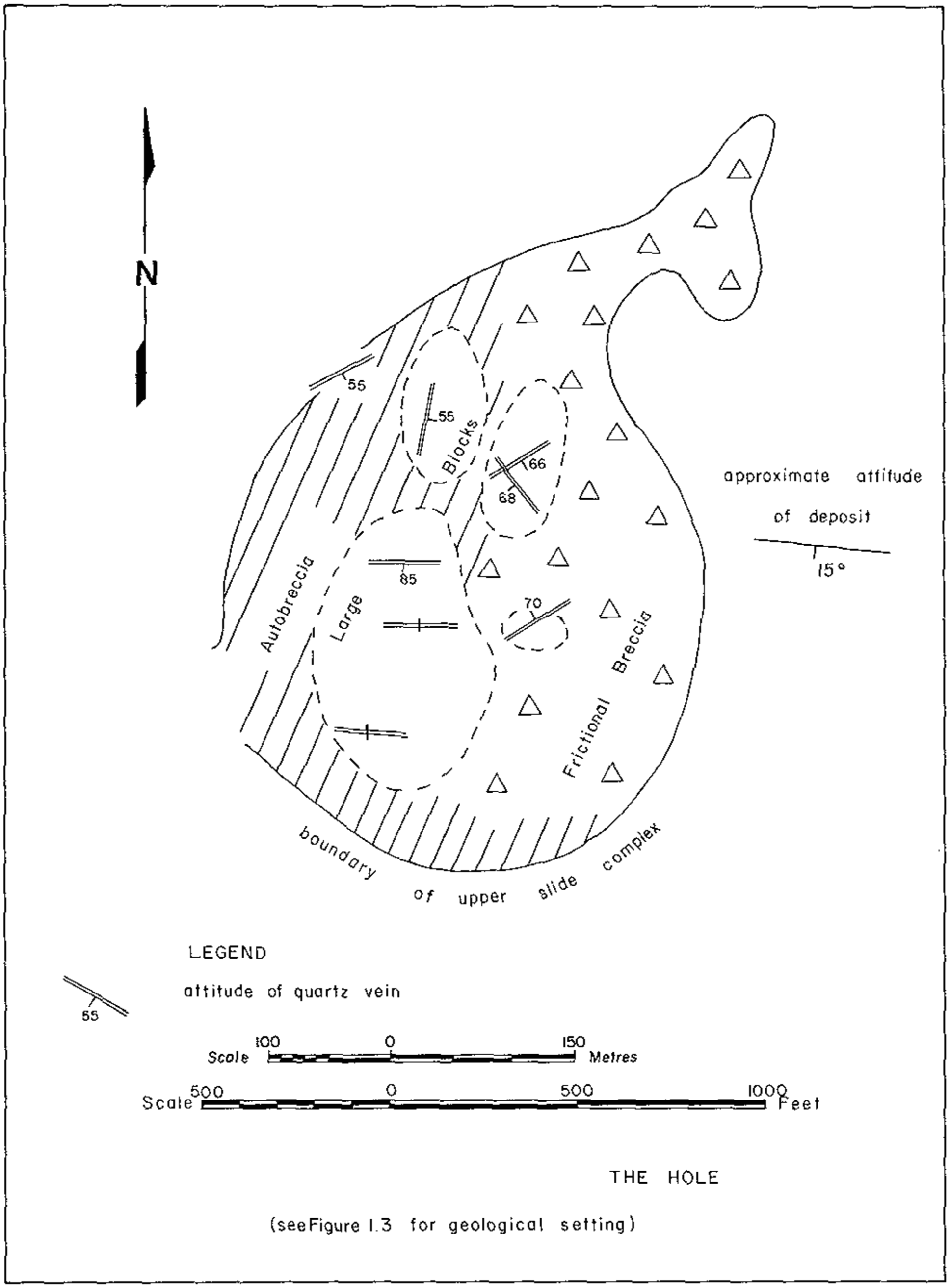


Figure 2.15. Internal structure of part of the granite breccia facies.

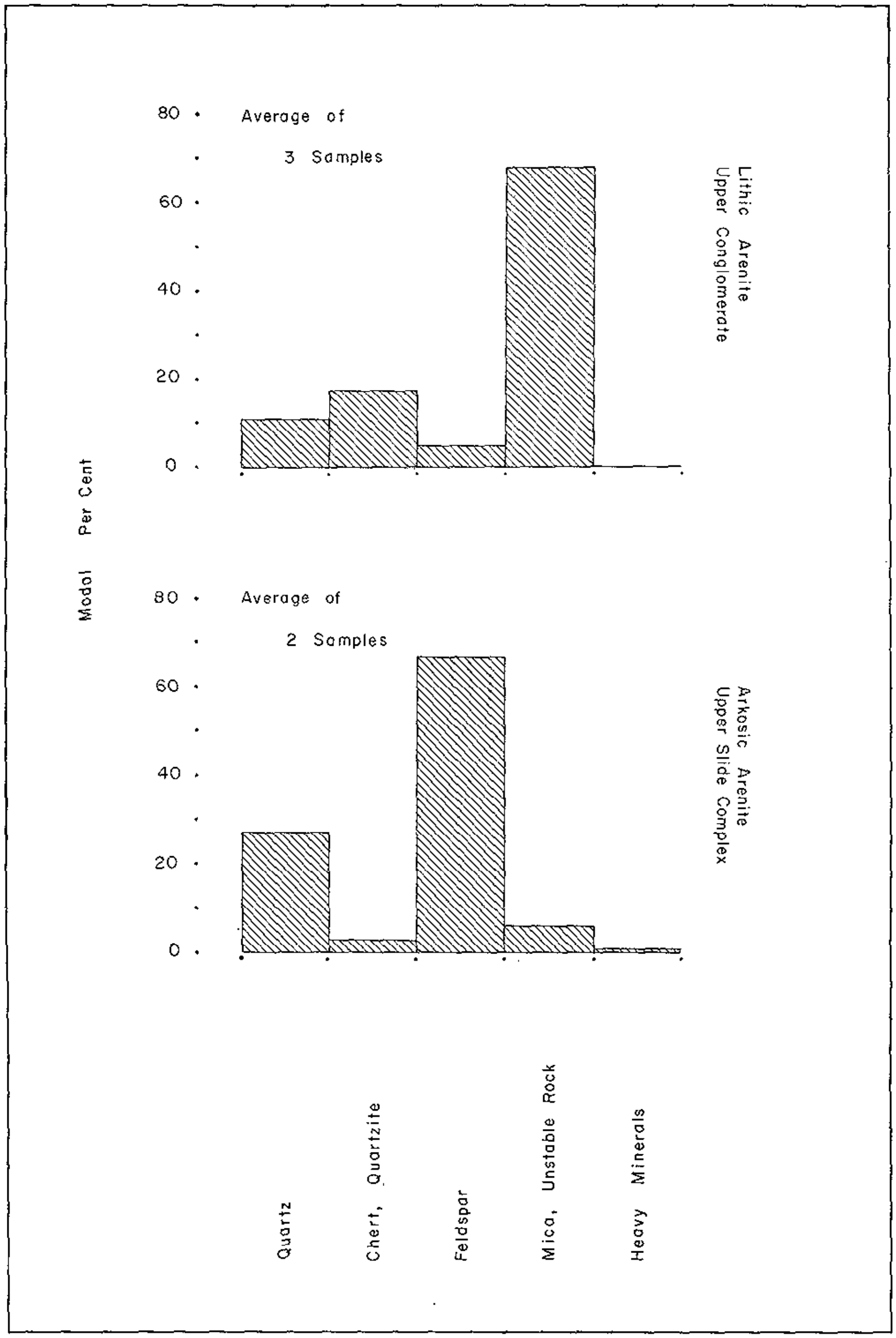


Figure 2.16. Composition of Skaha sandstones.

The granite breccia facies is intruded by a few small, irregular igneous bodies. These intrusions are aphanitic and generally light coloured and mottled with rusty stains. The refractive index of glass beads is high (1.585) suggesting a basic composition. Wallrocks adjacent to these intrusions are somewhat chloritized and show loss of primary textures probably owing to thermal metamorphism and metasomatism (Plate XIII).

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

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

Distribution and Thickness: The main deposit occurs near Mahoney Lake capping the south spur of Mount Hawthorne. Here beds form prominent bluffs and have a maximum thickness of about 600 feet. Small exposures of similar rock are present near Kearns Creek and northeast of The Hole.

Lithology: The unit is a thick-bedded mixed boulder and block conglomerate. It contains fragments measuring as much as 6 feet in diameter, but commonly less than 1 foot, composed of older Tertiary and pre-Tertiary rocks. The mean size of the fragments varies considerably, however, fine-grained beds are scarce. Although about 10 per cent of the fragments in the upper member are of volcanic origin, primary volcanic deposits are not found in this unit. The general aspect of the deposit is that of an alluvial fan developed near a fault scarp or relatively high standing terrain.

Chert and greenstone boulders are most common and were probably derived from the Shoemaker and Old Tom Formations to the south. The presence of a few clasts of chert breccia suggests that some material was eroded from the lower member of Skaha Formation. Clasts of augite porphyry are present, some very large, petrographically identical with augite porphyry from the Skaha and White Lake Formations from which they were almost certainly eroded. (A complete description of the boulders is given in Table 2.4.) These fragments are enclosed in relatively clean pebbly and sandy matrix cemented by carbonate and some iron oxide (Plate XIV).

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

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

TABLE 2.4. DESCRIPTION OF COMMON BOULDERS IN THE UPPER MEMBER OF THE SKAHA FORMATION

TYPE OF FRAGMENTS	DESCRIPTION
Chert and greenstone	Angular and subrounded fragments up to 4 feet in diameter, very common occurrence, probably derived from lower slide complex or Shoemaker Formation and Old Tom Formation.
Feldspar porphyries	Angular fragments up to 5 feet in diameter, very common occurrence, probably derived from Marron and White Lake feldspar porphyries.
Arkose	Rounded fragments up to 6 feet in diameter, leucocratic granite source, possibly from upper slide complex.
Vein quartz	Angular fragments up to 8 inches in diameter, probably derived from upper slide complex.
Augite porphyry	Angular blocks up to 6 feet in diameter, derived from augite porphyry unit of Upper White Lake or Skaha Formations.
Phyllite	Subrounded fragments up to 2 feet in diameter, probably derived from lower slide complex or Vaseaux Formation.
Granite and aplite	Subrounded fragments up to 3 feet in diameter, probably derived from upper slide complex.

STRUCTURE: The Skaha beds have undergone marked deformation. They lie north of The Hole, dip to the south and are roughly parallel to the north limb of the White Lake syncline. Reverse faulting along a northeast trending zone (probably related to concentric folding) has severed the northern part of the formation, mainly chert breccia beds, from the main body of similar rock lying immediately to the south (Fig. 1.3 and structure section X-Y). South of The Hole, the Skaha beds dip easterly. (In this area Tertiary beds are relatively thin and are not simply related to fold structures to the north where beds are thick.) Here, Skaha beds are displaced by steep northerly trending gravity faults similar to those found in southern and western parts of the map-area (*see* description of Marron Formation and structure sections C-D on Fig. 1.2 and S-T on Fig. 1.3a).

Slickensides and cleavages are locally well developed east of White Lake providing evidence of relatively late movement. These structures occur in Skaha, White Lake, and Marron rocks with some directional consistency. Generally, cleavages strike northeast and dip steeply; slickenside lineations plunge, at low angles, in two main directions — northeasterly, approximately coincident with the mean cleavage plane, and southeasterly roughly parallel to the strike of the main faults of the Okanagan system (Figs. 2.17 and 2.18). Figure 2.19 shows a hypothetical relation of structures in conjugate shear plan indicating north as the approximate direction of maximum stress.

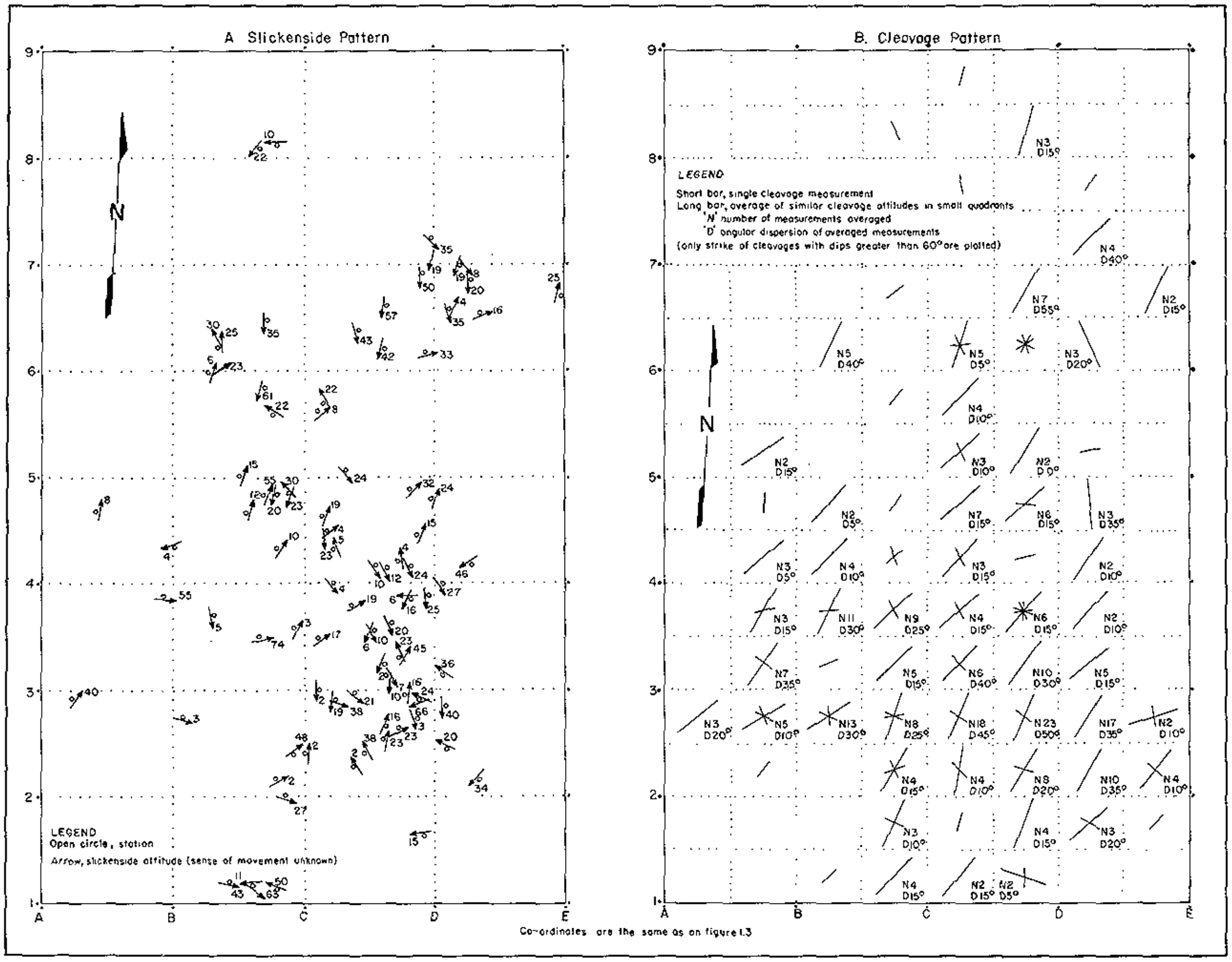


Figure 2.17. Some late structures in rocks east of White Lake.

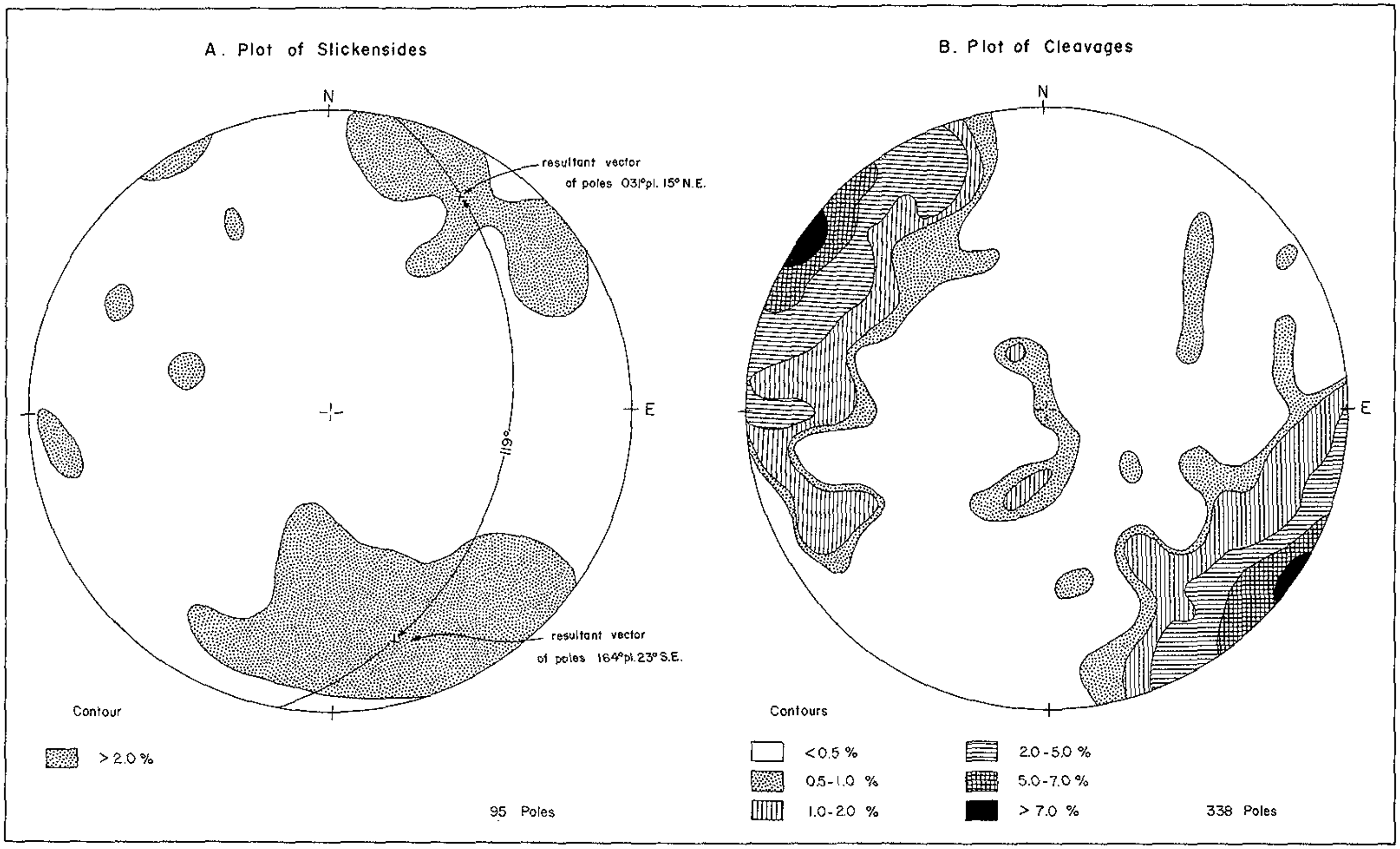


Figure 2.18. Equal area diagrams of poles to slickensides and cleavages.

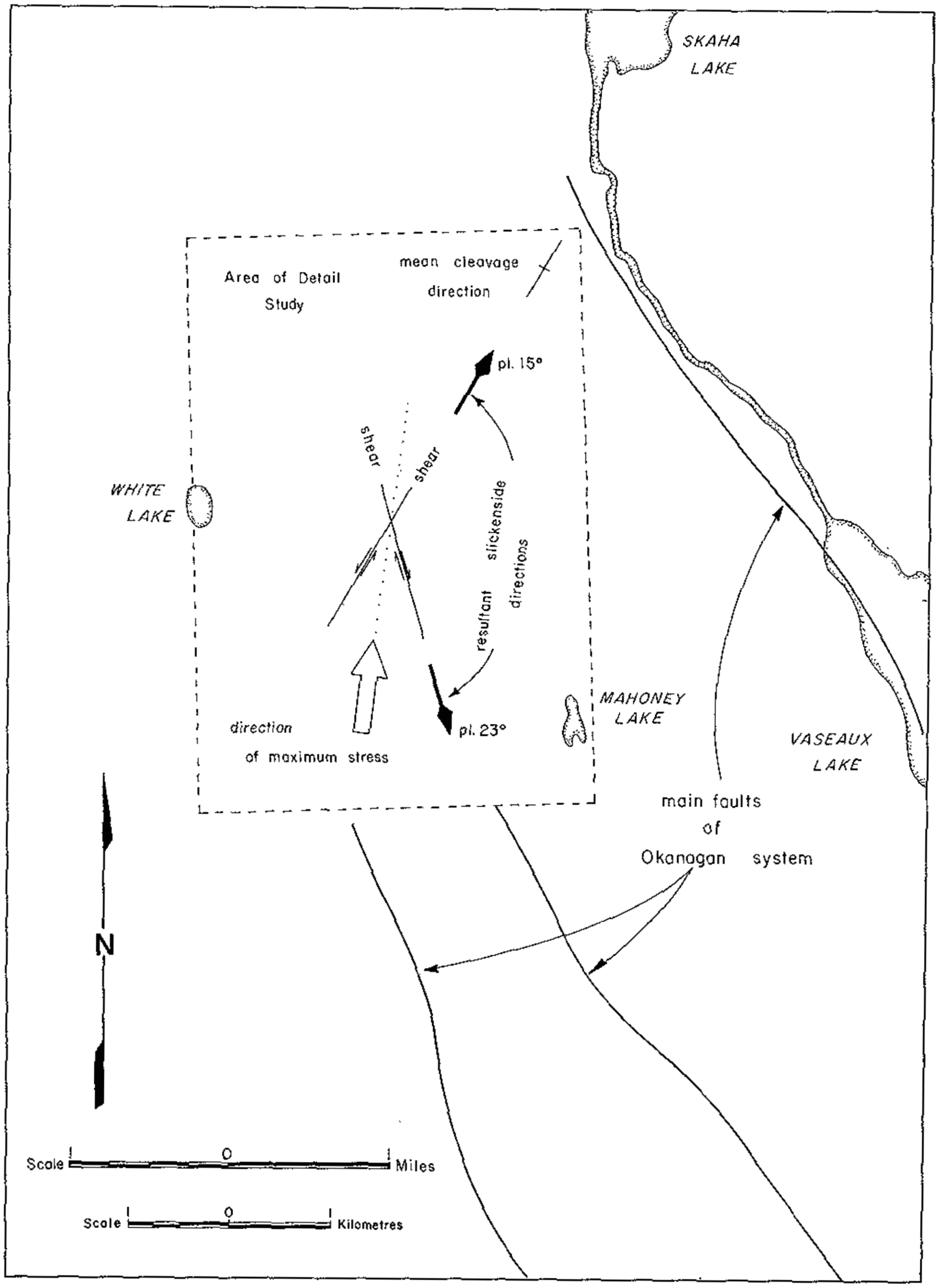


Figure 2.19. Possible stress scheme for late movement, area near White Lake.

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

The only other deposit described to date in southern British Columbia resembling the Skaha rocks occurs in the Flathead area, about 225 miles east of White Lake. This deposit, known as the Kishenehn Formation, consists partly of coarse conglomerate containing boulders commonly 1 foot and some as large as 4 feet in diameter. According to Price (1965), this material was eroded from high terrain underlain by Paleozoic rocks and deposited as a fanglomerate on the downthrow, west side of the Flathead fault in Late Eocene or Early Oligocene time.

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

Structural zone A, the area west of the Marron fault and the Twin Lakes branch, is relatively simple. Typically, the strata here are thin, dip gently east, and are displaced mainly by northerly trending gravity faults with easterly downthrow. Small grabens, such as the Trout Lake graben (Fig. 2.5), occur along the eastern margin of the zone adjacent to the Marron fault system, which shows antithetic displacement.

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

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

In summary, the main structural features are as follows:

1. The area underlain by Tertiary rocks is mostly bounded by gravity faults.
2. The Tertiary pile is thickest and structurally lowest near the Okanagan Valley.
3. Beds commonly dip in an easterly direction – westerly dipping beds are few.

The structure section A-B-C-D (Fig. 2.21) across the main belt of Tertiary rocks shows the typical deformation. It is proposed that a trap-door-like downward rotation along west-dipping faults of the Okanagan system produced easterly dips and marked subsidence of strata near the Okanagan Valley. Also, although details of the structural history are uncertain, this type of movement may have been influential in localizing Skaha and White Lake beds in the east part of the area (*see* section on historical geology in Chapter 4 of this bulletin).

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

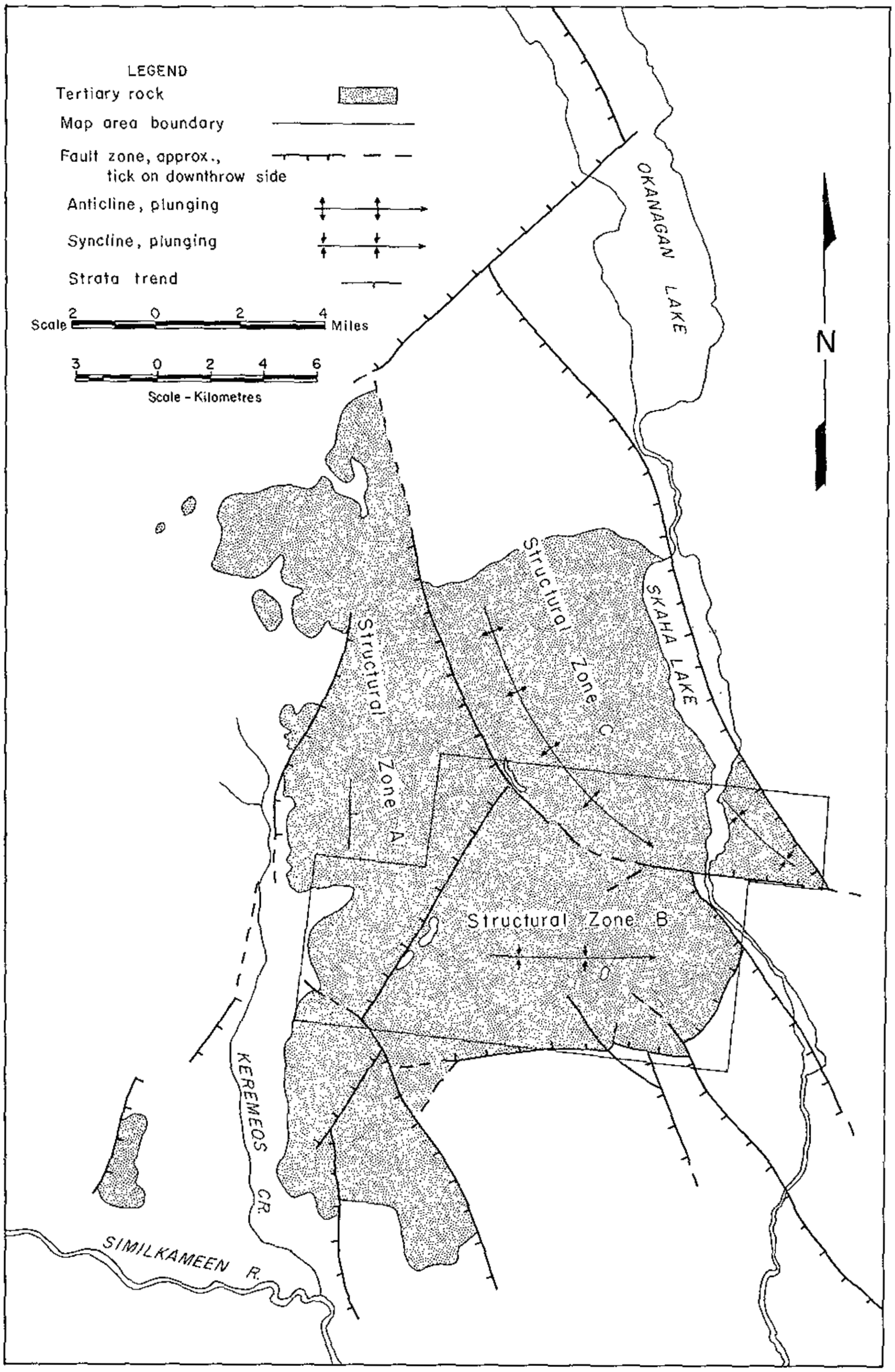


Figure 2.20 Structural subdivisions of the map-area and adjacent region.

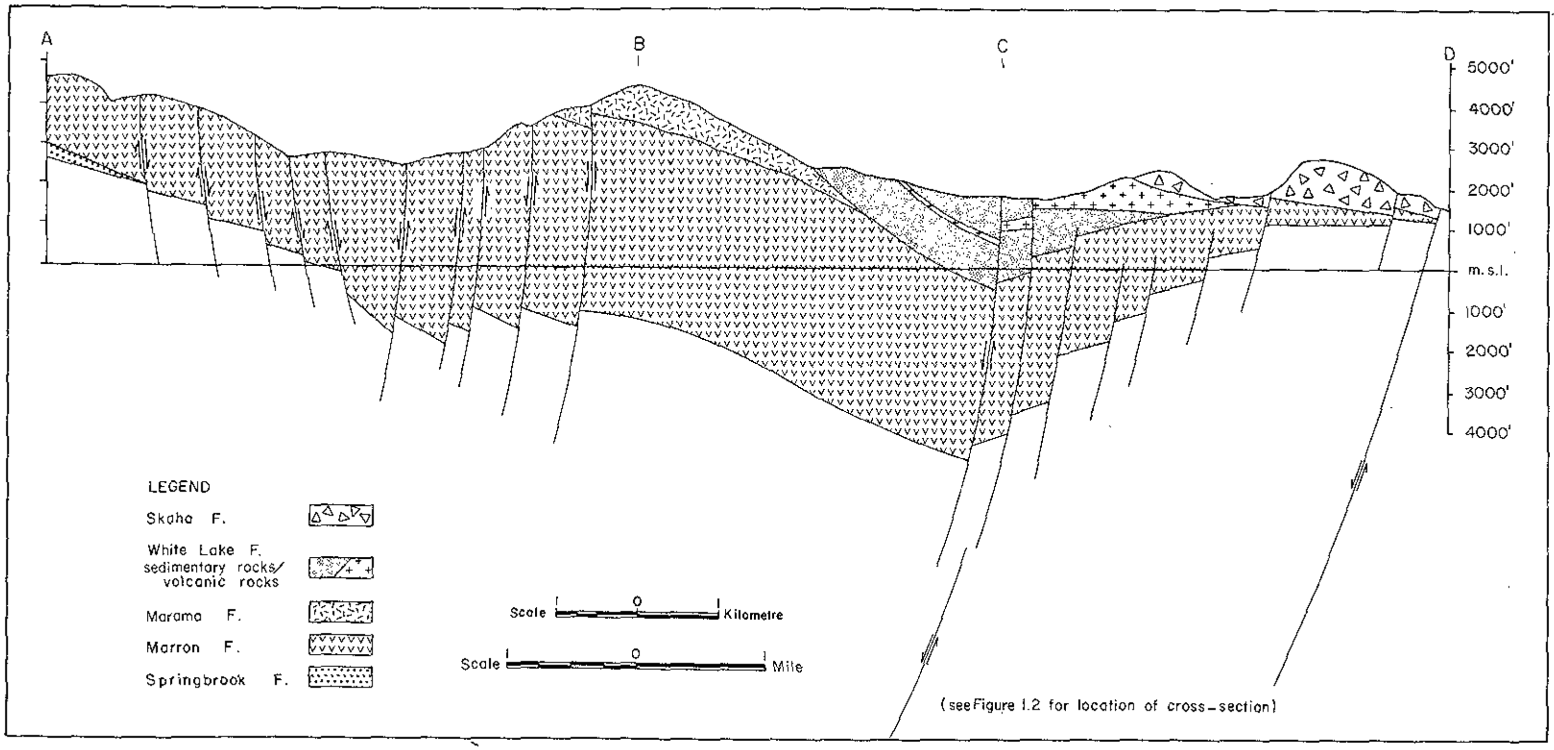


Figure 2.21. Cross-section of the White Lake basin (looking northeasterly).

3

IGNEOUS PETROLOGY

INTRODUCTION

A wide spectrum of lavas is present in the Tertiary stratigraphic succession of the White Lake basin. Petrochemical study of these lead to the recognition of three discrete series that have regional effusive and plutonic affilliates. A model of the origin of these suites is developed.

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

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

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

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

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

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

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

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

CHEMICAL VARIATIONS

The important chemical differences in the igneous rock groups of this study are brought out with the three-axis plot $K_2O + Na_2O$ versus $FeO + Fe_2O_3 + \frac{1}{2}(MgO + CaO)$ versus

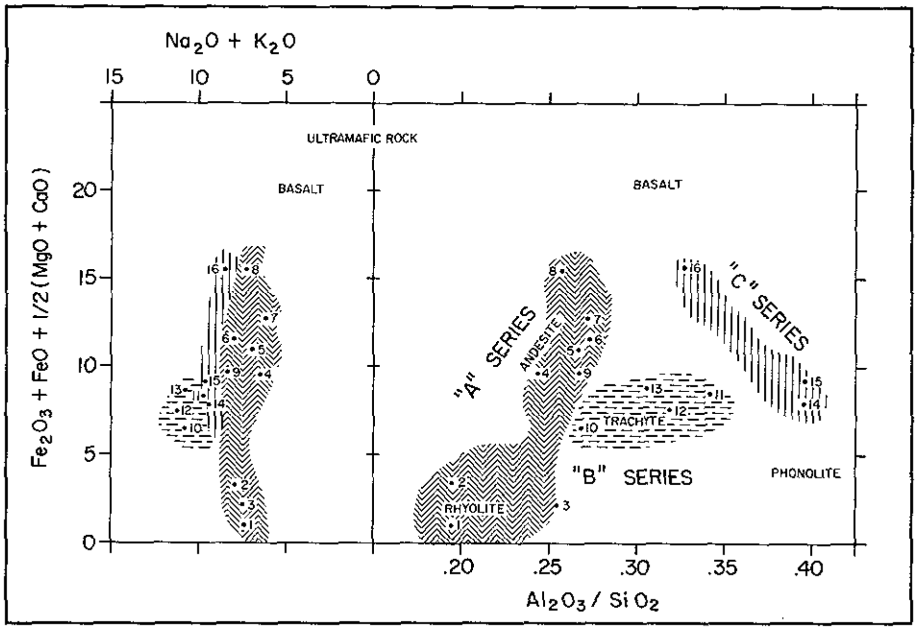


Figure 3.1. Early Tertiary igneous rock series of the White Lake basin (analyses are correspondingly numbered in Table 3.1).

TABLE 3.1. CHEMICAL ANALYSES OF TERTIARY VOLCANIC ROCKS OF THE WHITE LAKE BASIN

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Oxides Recalculated to 100																
SiO_2	75.09	72.71	68.51	62.87	60.20	59.39	56.57	54.33	59.93	62.30	57.53	58.67	58.39	56.21	54.70	50.24
TiO_2	0.18	0.55	0.42	0.90	0.89	1.02	1.54	1.11	1.07	0.75	0.94	1.05	1.22	1.02	0.82	1.12
Al_2O_3	14.73	14.19	17.43	15.27	15.95	16.10	17.03	13.91	15.96	16.65	19.69	18.67	17.79	22.27	21.69	16.41
Fe_2O_3	0.06	1.42	1.41	2.90	1.74	2.95	3.17	4.82	1.73	2.67	3.82	3.75	4.32	3.36	3.97	4.07
FeO	0.57	1.00	0.92	1.85	4.37	3.03	3.98	3.25	3.92	1.14	1.31	1.16	1.33	1.83	1.43	3.44
MnO	0.07	0.03	0.06	0.07	0.11	0.09	0.15	0.15	0.09	0.05	0.11	0.19	0.08	0.11	0.12	0.15
MgO	0.50	1.12	0.51	3.26	4.25	4.03	5.04	8.16	3.54	1.51	1.89	1.07	2.26	0.97	2.43	6.76
CaO	1.20	0.83	2.94	6.32	5.39	5.23	6.41	6.74	5.08	3.94	4.82	4.27	3.88	4.65	4.97	9.12
Na_2O	4.62	4.08	4.67	3.21	4.04	4.13	3.89	2.68	4.31	4.06	4.72	4.59	3.73	6.49	4.87	3.43
K_2O	2.98	4.07	3.13	3.35	3.06	4.03	2.22	4.85	4.37	6.93	5.17	6.58	7.00	3.09	5.00	5.26
	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Oxides as Determined																
H_2O+		1.64		-----				3.71	2.37	-----			1.76			
	0.6		0.9		1.7	3.3	2.7				2.0	1.6		4.9	2.7	2.0
H_2O-		0.18		0.61				1.24	0.18	0.27			0.61			
CO_2	0.1	0.02	0.3	0.02	0.1	3.0	0.1	0.02	0.83	0.02	0.1	0.3	0.01	1.1	0.4	3.5
SrO	0.015	0.037	0.045	0.154	0.118	0.130	0.070	-----	0.068	0.154	0.390	0.189	0.195	0.400	0.602	0.580
BaO	0.20	0.23	0.22	0.16	0.22	0.27	0.097	-----	0.22	0.28	0.62	0.42	0.29	0.81	0.850	0.97
P_2O_5	-----	-----	-----	0.30	-----	-----	-----	-----	-----	Trace	-----	-----	-----	-----	-----	-----
Refractive index	1.499	1.502	1.508	1.538	1.539	1.549	1.553	1.568	1.541	1.517	1.535	1.534	1.529	1.556	1.555	1.582

1 — Marama rhyolite, analysis No. 1, Table A-1, Church, 1967.
2 — Marama rhyolite, Dusty Mac area, analysis by S. Metcalfe.*
3 — Marama rhyodacite, analysis No. 2, Table A-1, Church, 1967.
4 — Park Rill andesite, analysis No. 2, Table A-2, Church, 1967, and partial analysis by S. Metcalfe.*
5 — Park Rill andesite, analysis No. 5, Table A-1, Church, 1967.
6 — Park Rill andesite, analysis No. 4, Table A-1, Church, 1967.
7 — Park Rill andesite, analysis No. 3, Table A-1, Church, 1967.
8 — Kearns Creek andesite, o.4 mile east of Yellow Lake, analysis by S. Metcalfe.*
9 — White Lake andesite, Dusty Mac area, analysis by S. Metcalfe.*
10 — Kitley Lake trachyte, analysis No. 1, Table A-2, Church, 1967, and partial analysis by S. Metcalfe.*
11 — Kitley Lake trachyandesite, analysis No. 7, Table A-1, Church, 1967.
12 — Nimpit Lake trachyte, analysis No. 8, Table A-1, Church, 1967.
13 — Nimpit Lake trachyte, analysis No. 3, Table A-2, Church, 1967, and partial analysis by S. Metcalfe.*
14 — Yellow Lake anorthoclase porphyry, analysis No. 10, Table A-1, Church, 1967.
15 — Yellow Lake mafic phonolite, analysis No. 9, Table A-1, Church, 1967.
16 — Skaha augite porphyry, analysis No. 11, Table A-1, Church, 1967.

*Chief Analyst and Assayer, British Columbia Department of Mines and Petroleum Resources.

Al_2O_3/SiO_2 (Fig. 3.1). This is an adaptation of the alkalis versus silica plot of Tilley (1950) and the alumina/silica based plot of Murata (1960). A detailed explanation is given in Appendix B.

It can be seen that the rocks are readily divisible on chemical basis into three magma series. Andesite-rhyodacite rocks, designated 'A' series, have relatively small alumina to silica ratios and comparatively moderate total alkalis content. In contrast, the tephrite (augite porphyry) and phonolite (rhomb porphyry) rocks, designated 'C' series, typically are alumina-rich and silica-poor, thus have relatively large alumina to silica ratios. The trachyte and trachyandesite rocks, designated 'B' series, are alkali-rich but otherwise intermediate to the 'A' and 'C' extremes. A hypothetical line of silica saturation would bisect the composition field of 'B' series and 'A' and 'C' compositions would fall respectively on the oversaturated and undersaturated sides of such a line on the Al_2O_3/SiO_2 based plot. It will be shown in a later section that the position of this line is important in considering the genesis of the rocks of each series.

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

In summary, the main chemical characteristics of the series are as follows:

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

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

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

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

'A' series		
	andesite	0.77
	rhyolite-rhyodacite	0.66
'B' series		
	trachyte-trachyandesite	1.47
'C' series		
	tephrite (augite porphyry)	1.53
	phonolite (rhomb porphyry)	0.76

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

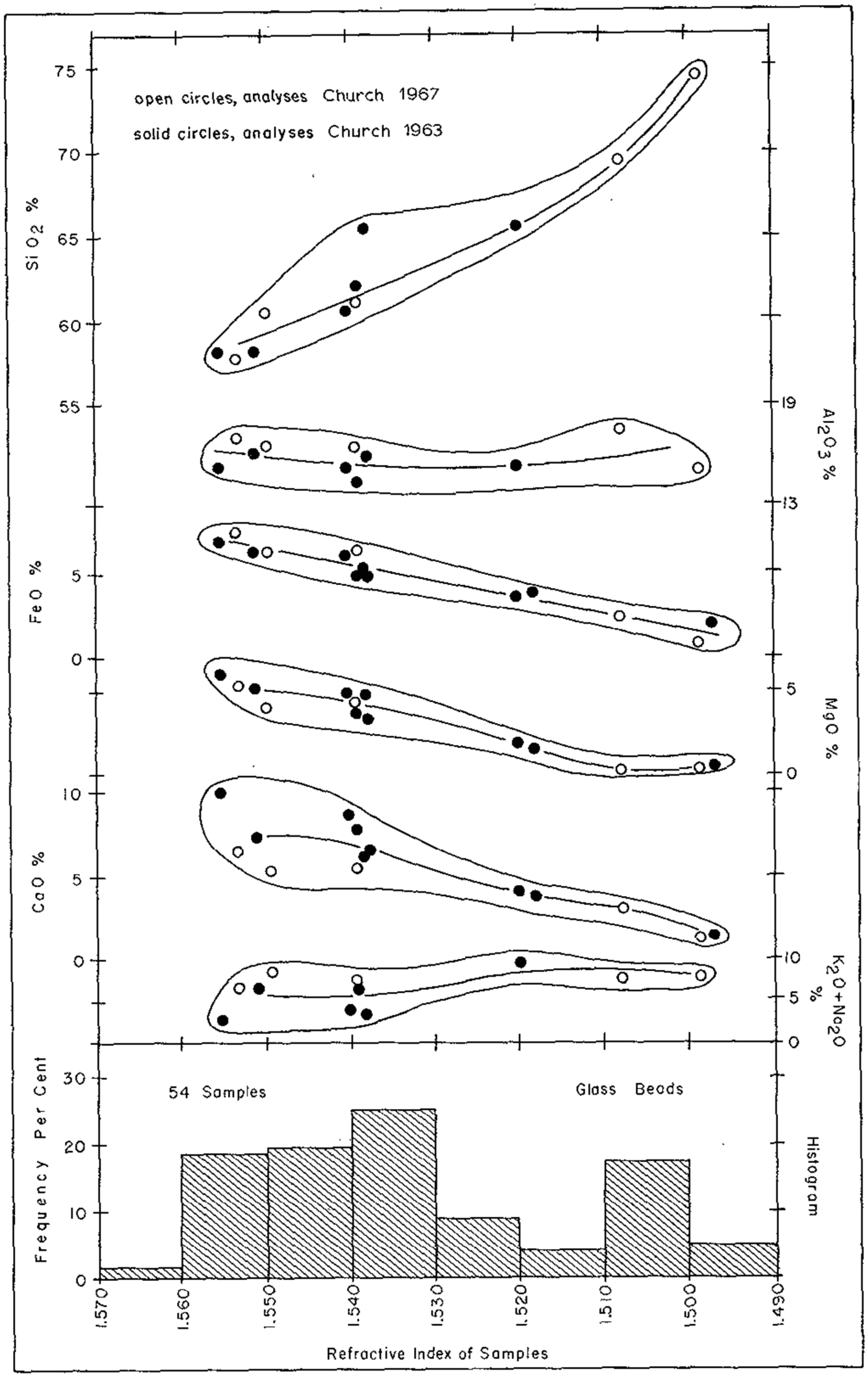


Figure 3.2. Variation diagram, 'A' series.

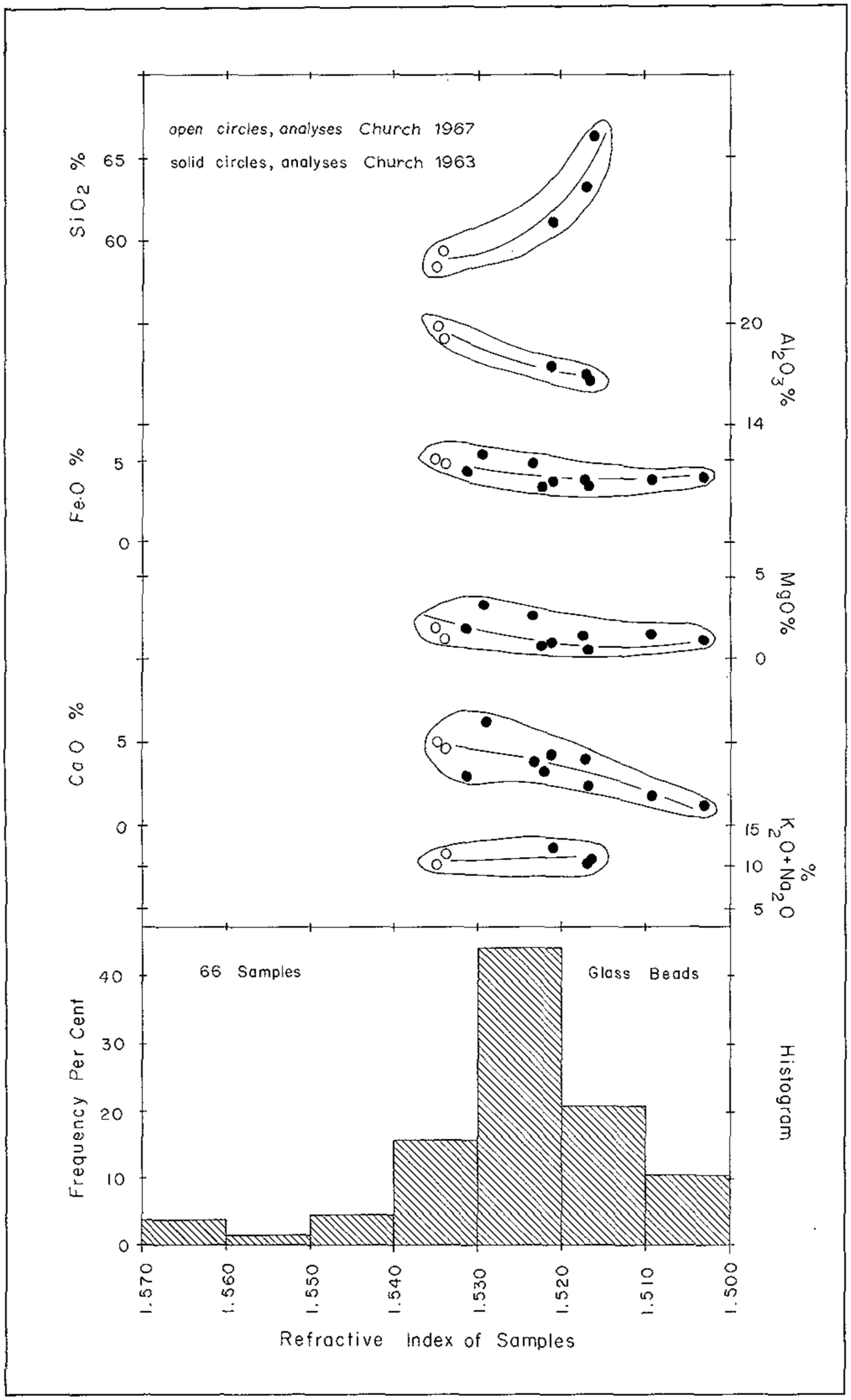


Figure 3.3. Variation diagram, 'B' series.

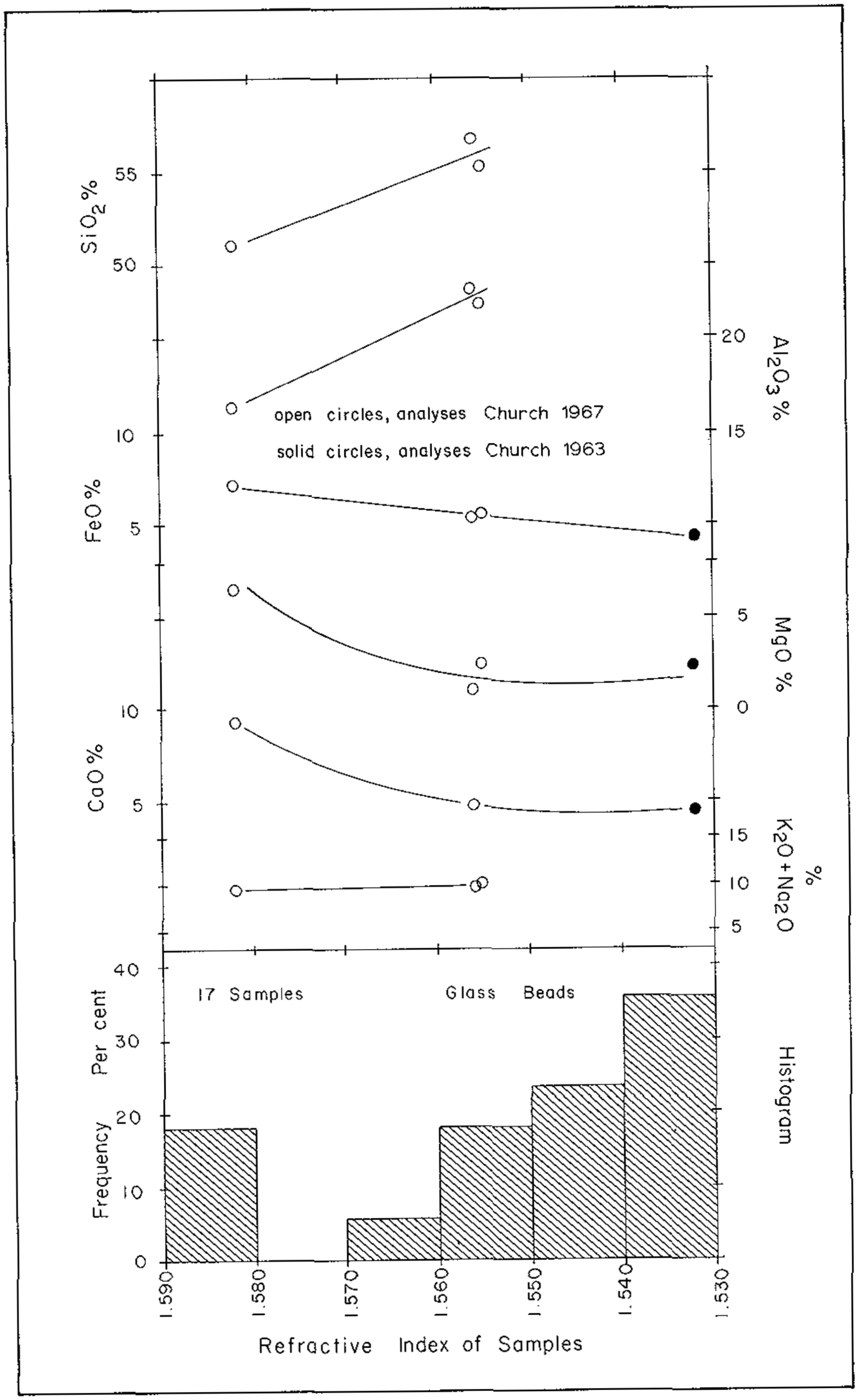


Figure 3.4. Variation diagram, 'C' series.

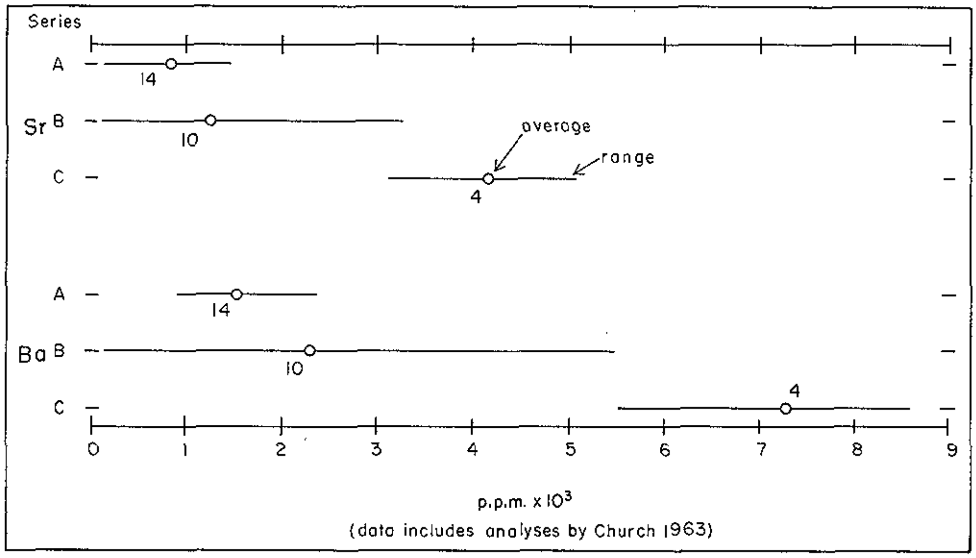


Figure 3.5. Strontium-barium dispersion.

Data are also available for a few important minor elements. Strontium and barium determinations were made on 28 representative rocks. These analyses show that the average strontium to barium ratios are similar for the three igneous series:

'A' series	0.50
'B' series	0.52
'C' series	0.57

However, some differences in concentration levels of strontium and barium are noted (Fig. 3.5). Average concentration of strontium and barium in 'A' series is less than 2,000 ppm and in 'B' series less than 3,000 ppm. Characteristically 'C' series has high strontium and barium concentrations — greater than 3,000 ppm.

PETROGRAPHIC PROVINCES

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

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

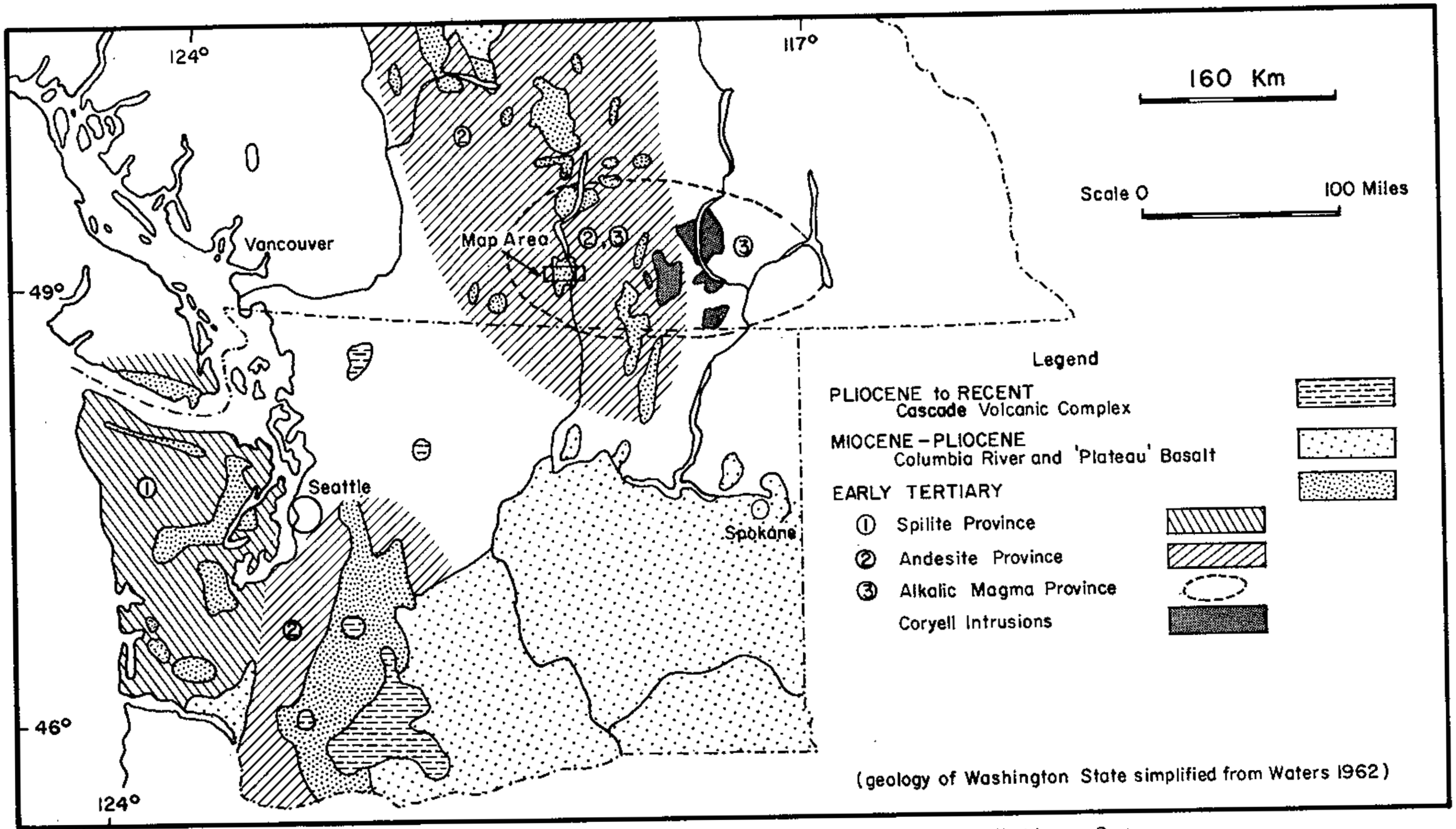


Figure 3.6. Cenozoic petrographic regions of southern British Columbia and Washington State.

Rocks of 'A' series examined by the author are mainly andesites and minor silica-rich acid types (*see* histogram, Fig. 3.2) and are possibly correlative with similar Early Tertiary lavas of the Kamloops and Princeton areas (*see* Stevenson, 1939, p. 446, and description of Kamloops Group by Daly, 1915, pp. 126-130; and description of Princeton lavas by Rice, 1947, p. 29, Shaw, 1952, p. 6, and Camsell, 1913, p. 83). This 'andesitic' suite of volcanic rocks crop out in a broad belt trending northward from northern Washington through south-central British Columbia. The belt may represent a partly eroded northerly extension of the andesite province of the Puget Sound area.

TABLE 3.2. COMPOSITION OF MAIN PHASES OF CORYELL BATHOLITH AND SIMILAR ROCKS OF 'B' AND 'C' SERIES

	1	2	3	4	5
SiO_2	63.2	63.7	60.4	53.4	51.0
Al_2O_3	17.0	17.1	18.5	16.6	16.6
Fe_2O_3 + FeO	4.3	3.5	4.7	8.5	7.6
MgO	2.0	0.7	1.5	5.8	6.9
CaO	2.8	3.4	4.4	8.0	9.2
Na_2O	4.9	} 11.6	4.6	3.4	3.4
K_2O	5.8		5.9	4.3	5.3

1 — Average composition of Coryell 'quartz syenite' (Little, 1960, Table I, Nos. K and L; Table III, No. 1).

2 — Trachyte, Kelowna area (Church, 1963, Table D-3, average Nos. B-5 and B-7).

3 — Average Marron trachyte-trachyandesite (Church, 1967, Table 2.3, Nos. 1 and 2; Table 2.4, No. 1).

4 — Average composition of Coryell 'monzonites and shonkinites' (Little, 1960, Table I, Nos. M and N; Table III, No. 2).

5 — Skaha augite porphyry (Church, 1967, Table 2.8, No. 1).

Rocks of 'B' and 'C' series are alkali-rich and resemble the Coryell batholith in both composition and age. The inference by Daly (1912, p. 419) that the Coryell intrusions are simply the plutonic equivalents of some of these Early Tertiary volcanic rocks is now well founded. Table 3.2 shows the average chemical composition of two phases of the main intrusions of the Coryell batholith near Trail and Lower Arrow Lake, British Columbia. The most acid rocks of 'B' series are similar to the quartz syenite phase, and tephrite of 'C' series (No. 16 of Fig. 3.1) corresponds well with the shonkinite phase of the Coryell batholith. Also, the age of the Midway volcanic rocks determined by Mathews (1964), 48 and 49 million years and the Marron Formation, 51.6 million years are similar to the age of the Coryell rocks determined by Baadsgaard, *et al.* (1961), 54 and 58 million years.

The area of thickest volcanic deposits and largest exposed intrusions of these rocks, termed the 'alkalic magma province,' is roughly outlined in Figure 3.6. Some Early Tertiary trachyte flows and alkali-rich intrusions are reported to occur in the Princeton and Kamloops areas to the west (Rice, 1947; Dawson,1896) but these are comparatively small bodies possibly related to alkaline centres remote from the Okanagan-Boundary region. Knowledge of Early Tertiary volcanic outliers and intrusions to the southwest and northeast is incomplete and the boundaries of alkaline province are more or less arbitrarily drawn.

To the southeast, the 'Petrographic Province of Central Montana,' made famous by the work of Pirsson (1905) and Larsen (1940), contains an assemblage of alkali-rich Tertiary intrusions (shonkinites) and volcanic rocks (mafic phonolites) bearing some resemblance to the alkali-rich rocks of the Okanagan-Boundary region. These are best developed in the Highwood Mountains of Montana and are typically potassic and rich in strontium and barium. Alumina content, however, is generally less than that in rocks of 'B' and 'C' series of the Okanagan-Boundary area and rhomb porphyry rocks are not found.

PETROGENESIS

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

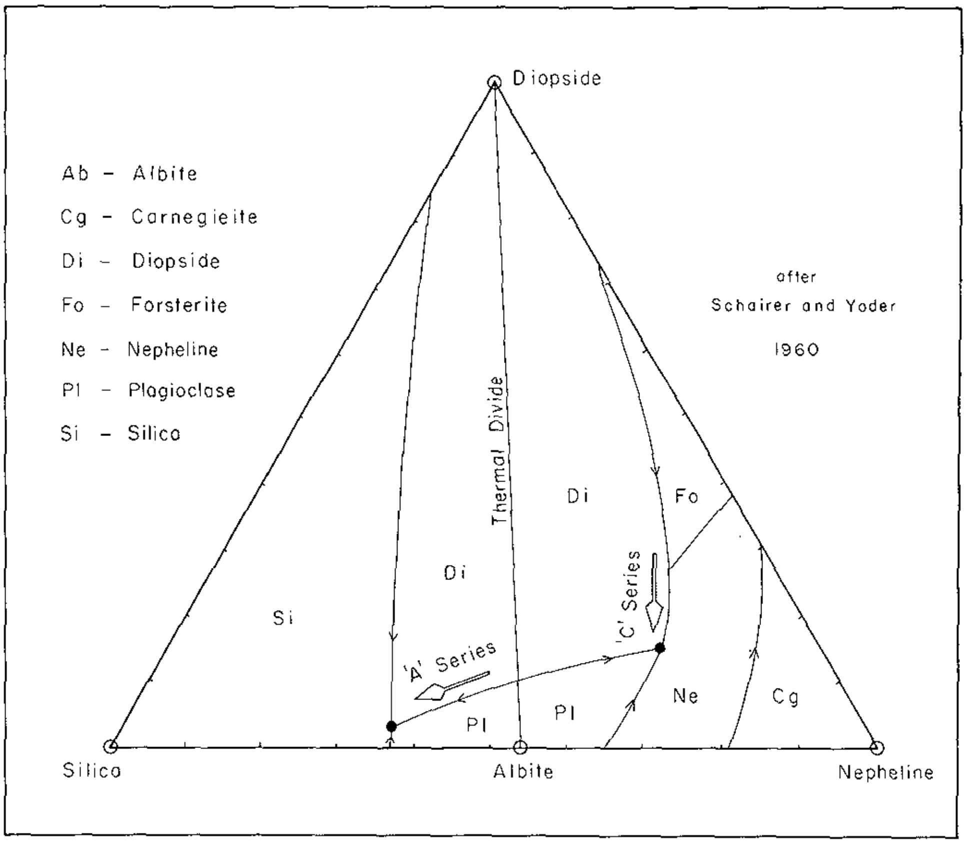


Figure 3.7. Phase diagram, silica-diopside-nepheline system.

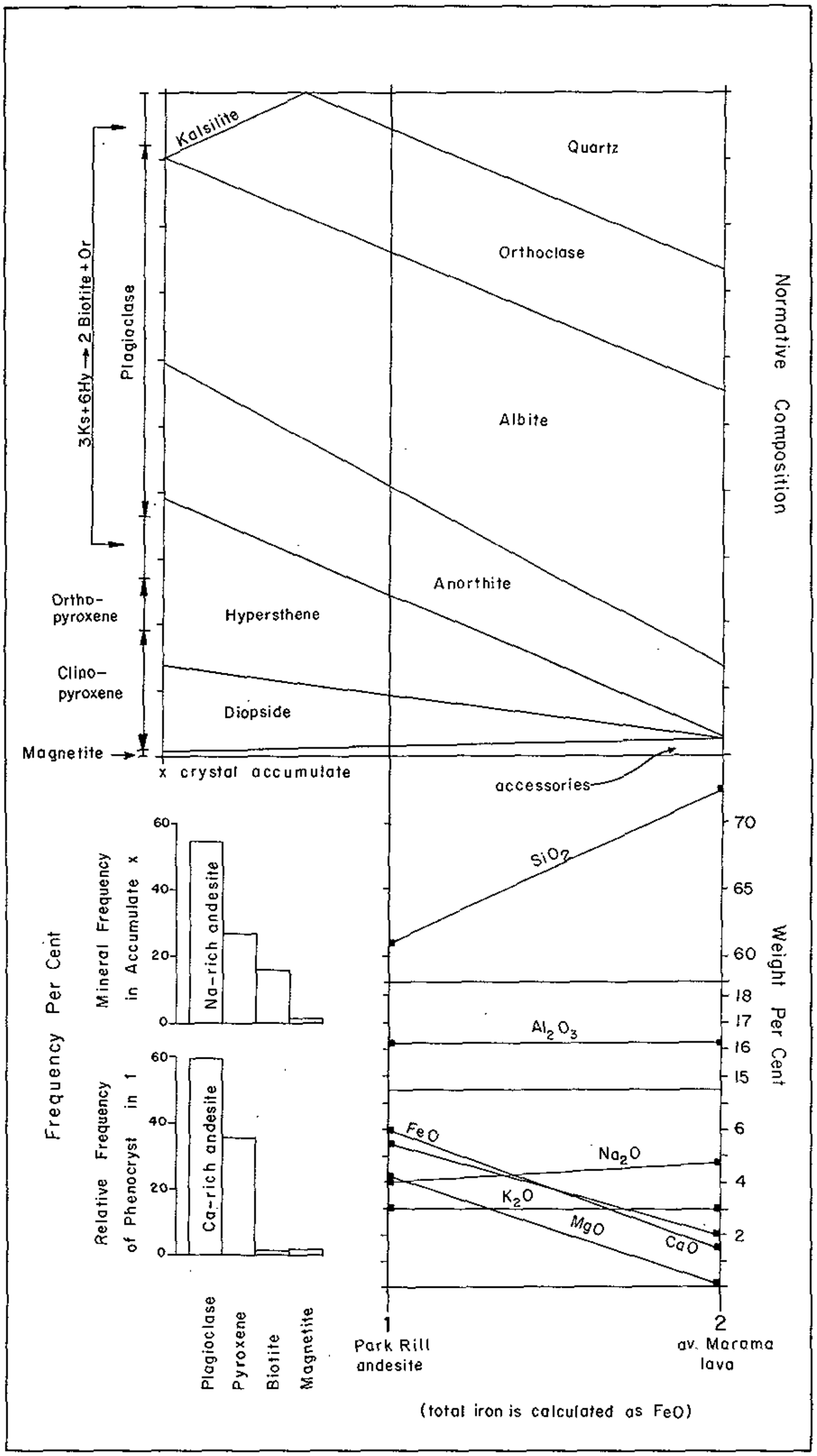


Figure 3.8. Subtraction diagram, 'A' series.

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

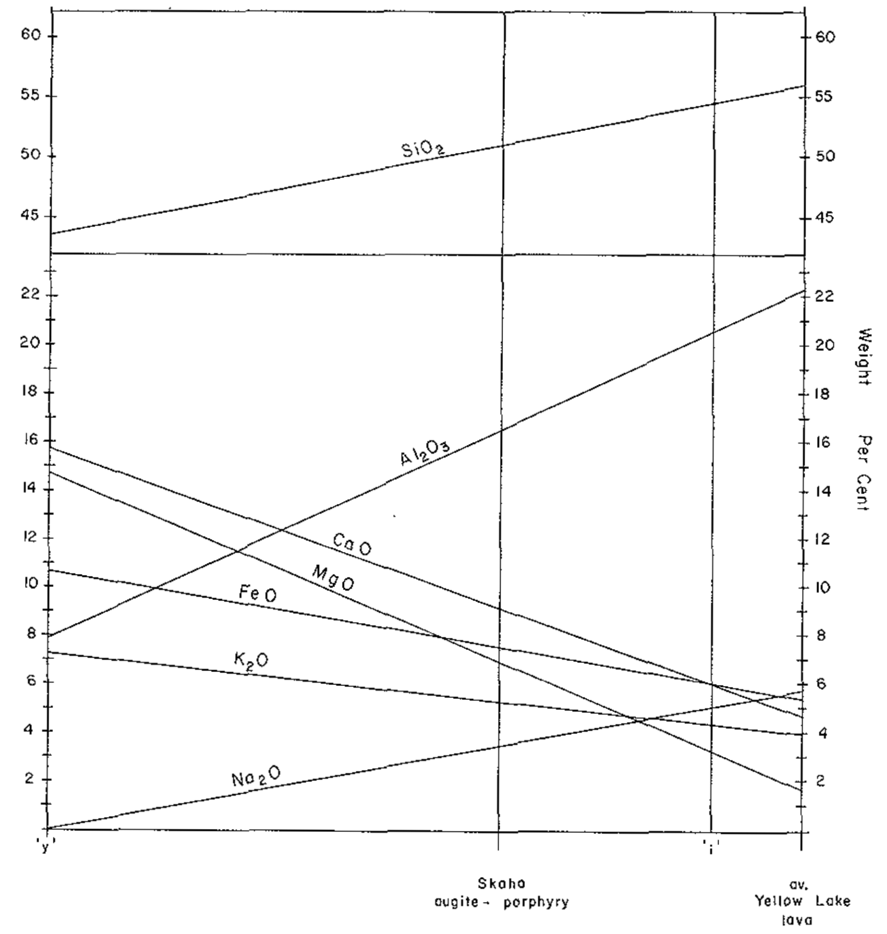


Figure 3.9. Subtraction diagram, 'C' series.

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

In the case of the 'A' series, subtraction (fractionation) of a mineral aggregate, 'x' (composed mostly of plagioclase, some pyroxene, biotite, and minor magnetite), from

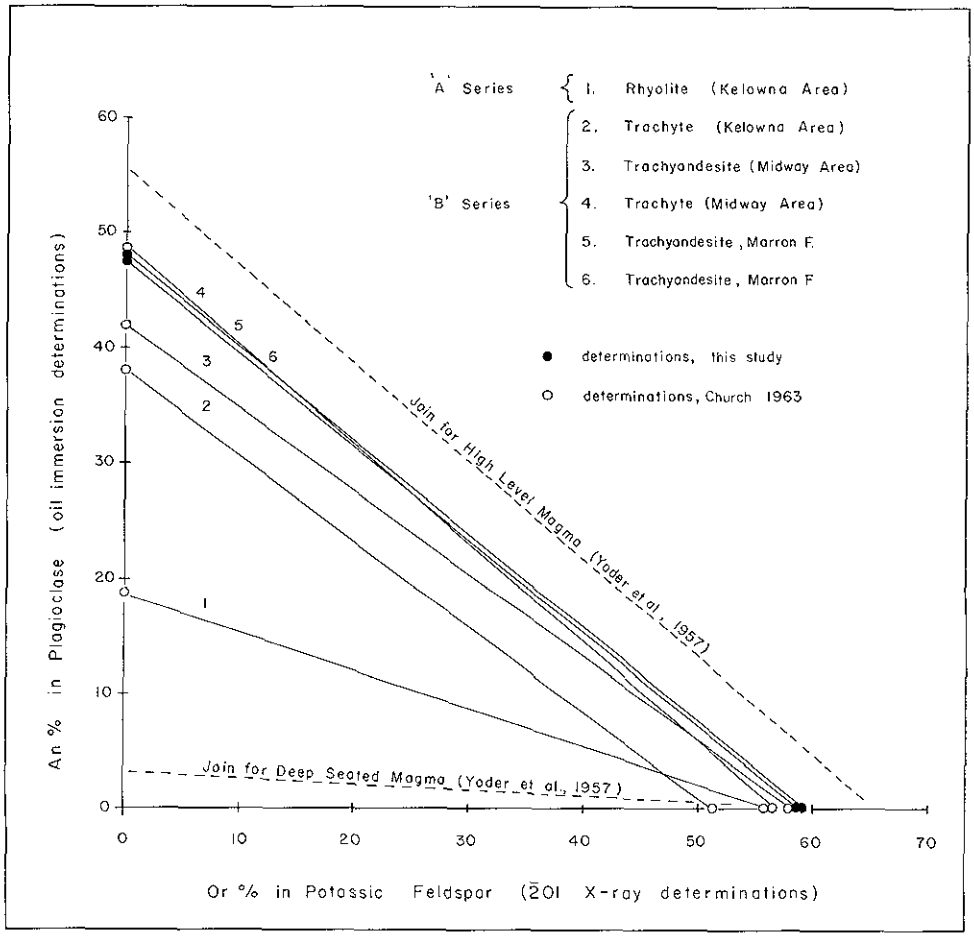


Figure 3.10. Coexisting plagioclase and potassic feldspar in two-feldspar rocks.

Park Rill andesite can produce a silica-rich composition similar to average Marama lava. Roughly, fractionation of andesite yields 60 per cent crystal accumulate 'x' and 40 per cent rhyolitic magma.

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

The magmas of 'B' series, as previously indicated, include silica saturated and undersaturated types. The thermal divide between undersaturated and oversaturated magmas is breached, theoretically, by fractionation of undersaturated minerals or mixing of silica-poor and silica-rich magmas (Tilley, 1957).

TABLE 3.3 NORMATIVE CALCULATIONS, 'y' AS PYROXENE, BIOTITE, AND POTASH RESIDUAL

Formula positions of cations		Z		Y	X		W		totals
		Si	Al	Fe''	Fe''	Mg	Ca	K	
Composition of 'y,' cation molecular per cent		39.7	8.5	8.2		19.9	15.3	8.4	100.0
Clinopyroxene ($Wo_{45}En_{35}Fs_{20}$)	per cent	29.1	4.9	6.8		11.9	15.3		68.0%
general formula	*cation proportions*	1.7	0.3	0.3	0.1	0.7	0.9		
$W(X,Y)Z_2O_6$	charge	+6.8	+0.9	+0.9	+0.2	+1.4	+1.8		+12.0
Biotite	*per cent*	10.6	3.6	1.4		8.0		3.5	27.1%
general formula	cation proportions	3.0	1.0	0.4		2.3		1.0	27.1%
$W(X,Y)_3Z_4O_{10}(OH)_2$	charge	+12.0	+3.0	+1.4		+4.6		+1.0	+22.0
Residual	per cent							4.9	4.9%

(Composition $Wo_{45}En_{35}Fs_{20}$ *is determined* optically for pyroxene in Skaha augite porphyry.)

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

A more adequate explanation of the origin of the 'B' series is simply mixing of 'A' and 'C' magmas. Variation diagram, Figure 3.11, shows mostly regular chemical change from a composition intermediate in 'C' series (Fig. 3.9), through undersaturated and saturated rocks of 'B' series, to the average Marama lava. Trachytes and trachyandesites of 'B' series represent mixtures of an average of 'C' series and the average Marama lava at about 2:1.

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

Concentration differences of strontium and barium in rocks and minerals support the fractionation and mixing hypotheses outlined above. Church (1963, Table 4.8) shows average plagioclase much richer in strontium and barium than clinopyroxene (plagioclase, 3,300 ppm Sr and 1,260 ppm Ba, average of four analyses; clinopyroxene, 174 ppm Sr and 90 ppm Ba, average of six analyses). High strontium and barium content of 'C' compared to 'A' series rocks (Fig. 3.5) is possibly due to partitioning of these elements between crystal and liquid phases such that marked fractionation of pyroxene from 'C' magmas leaves residual liquid enriched in strontium and barium, whereas, fractionation of large amounts of plagioclase in the case of 'A' series leaves residual liquids impoverished in these elements. Average concentration of strontium and barium in 'B' series is intermediate to 'A' and 'C' supporting the mixing hypothesis.

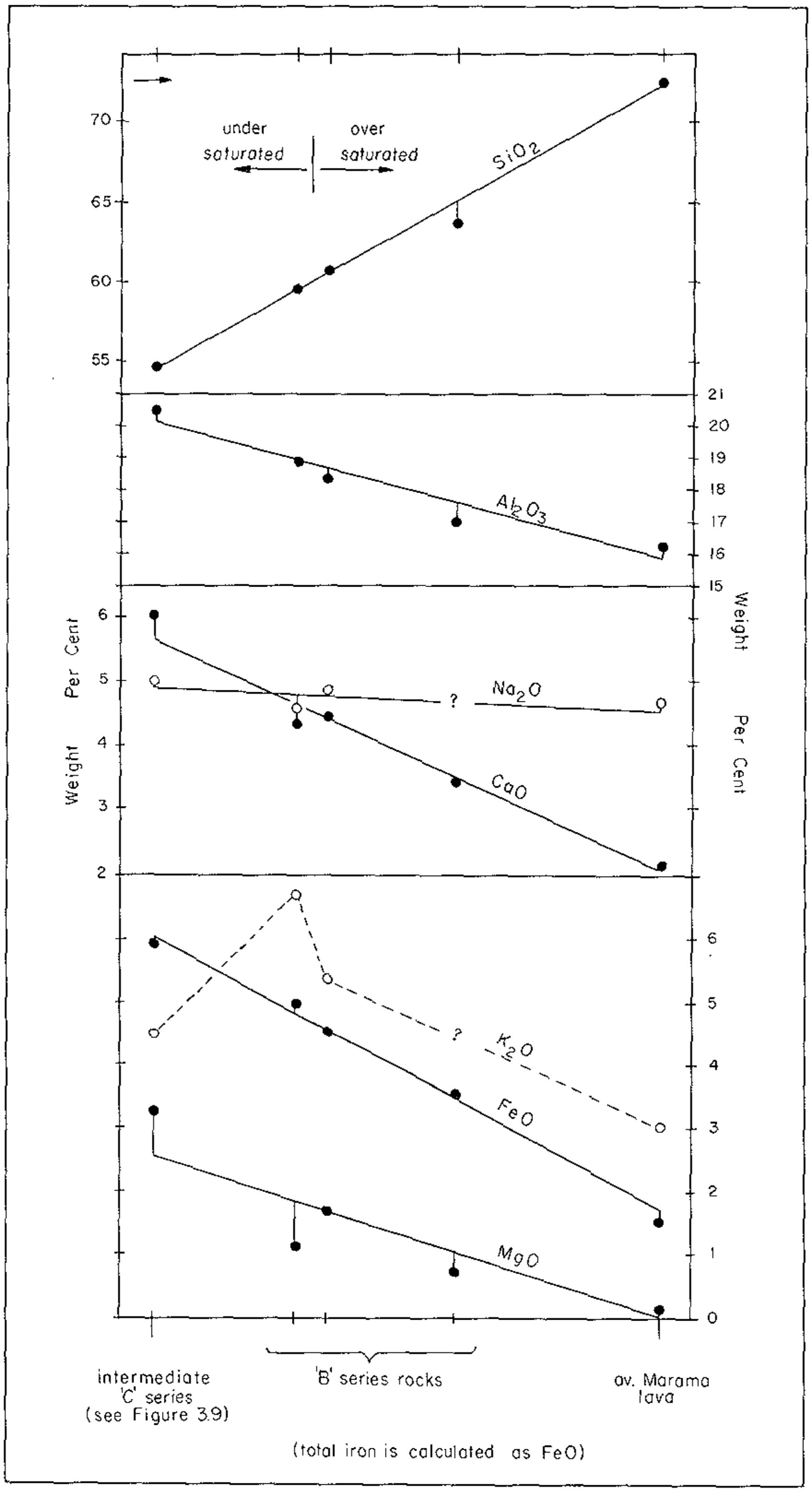


Figure 3.11. Mixing diagram.

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4

SUMMARY AND CONCLUSIONS

GEOLOGICAL HISTORY

A summary of Cenozoic geological events in southern interior of British Columbia is given in Table 4.1, based mainly on publications by Schofield (1943), Russell (1954), Mathews (1964), and Bally *et al.* (1966).

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

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

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

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

An interval of erosion and gravity faulting followed. At this time, the Okanagan Valley was probably a prominent geomorphological feature containing an important stream course.

Deposition of White Lake sedimentary rocks coincided with the eruption of trachyte and trachyandesite lavas from vents centred near the Okanagan Valley. In this area, a northerly flowing stream was probably dammed by volcanic debris forming a lake several miles in diameter (Tertiary White Lake). Large volumes of laharic and pyroclastic material were periodically ejected from water-filled vents spilling debris into the Okanagan Valley

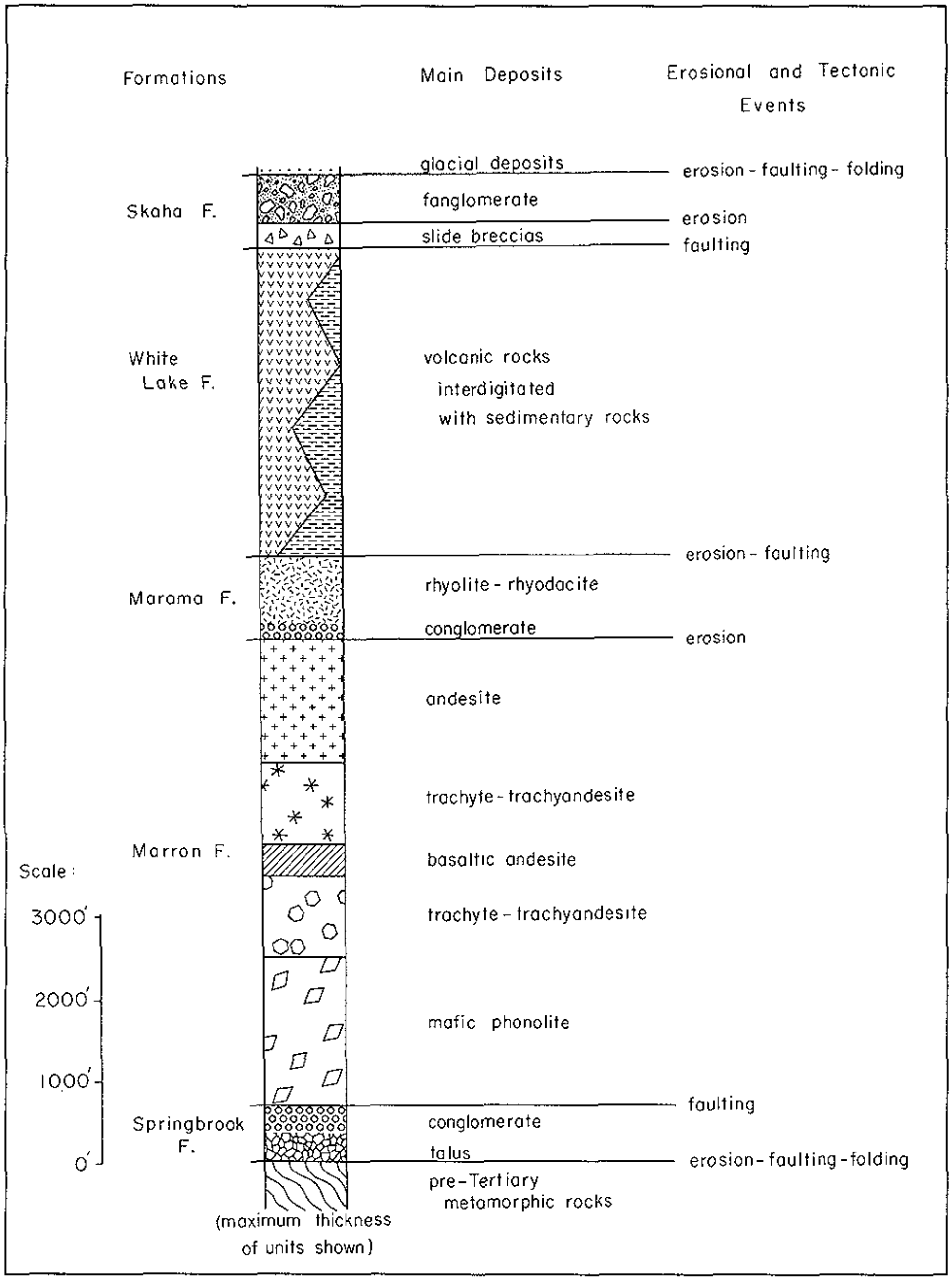

Figure 4.1. Generalized columnar section.

TABLE 4.1. OUTLINE OF CENOZOIC GEOLOGICAL EVENTS

Epochs	K-Ar Age	Main Events
Recent		Uplift and downcutting of streams; development of river terraces, deposition of alluvial fans in main valleys.
Pleistocene		Extensive glaciation, general beveling of topography and widening and deepening of valleys by ice action, formation of melt water channels; deposition of tills and drift, deposition of white silts of Kamloops and Okanagan Valleys.
	1 m.y.	
Pliocene		Uplift and dissection of landscape followed by local volcanic eruptions, 'valley basalt.'
	10 m.y.	
Miocene		Short period of widespread volcanic eruption, 'plateau basalts.'
	25 m.y.	
Oligocene		Uplift followed by development of late mature erosion surface.
	38 m.y.	
Eocene		Extensive and prolonged volcanic eruption; deposition of lake and stream sediments and some coal.
	57 m.y.	
Paleocene		Record in Rocky Mountain area – end of imbricate thrusting and molasse-type deposition.

K-Ar dates for epoch boundaries, average from Holmes (1960), Kulp (1961), and Geological Society of London (1964).

and the nearby lake. The lake was filled by considerable thickness of shale, sandstone, and some coal. Extrusion of a small amount of tephrite lava marked the climax of volcanic activity.

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

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

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

PETROLOGY

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

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

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

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

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

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

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

Consideration of the results of experimental petrology suggests that two processes were mainly responsible for genesis and diversification of these rocks:

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

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

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

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

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

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

5

ECONOMIC GEOLOGY

Traditionally the rocks of Tertiary basins of the southern interior of British Columbia have been known principally for their coal deposits. These rocks have also been noted for an abundance of zeolite minerals, some perlite, and opal and agate localities. However, in recent years, with the advent of advanced geochemical and geophysical methods of prospecting and precise methods of rock dating, it is now known that the Tertiary suite is important in the search for base metals. Tertiary uraniferous conglomerates have also recently attracted attention in southern British Columbia.

In the White Lake area a few small showings of ferrimolybdite are reported in the granite slide breccia of the Skaha Formation north of Green Lake. However, the Dusty Mac gold-silver discovery east of Skaha Lake has been the most interesting recent discovery in the area.

THE DUSTY MAC PROSPECT

The Dusty Mac prospect is located about 1 mile east of Okanagan Falls (Figs. 1.2 and 5.1). The deposit consists of a lens-like zone of silicified Eocene volcanic rocks and sedimentary debris containing minor disseminated pyrite and native silver. Also, some quartz veins on the property carry minor bornite and chalcopyrite.

The host rocks belong to the White Lake Formation of the upper part of the local Tertiary section. These beds consist of light-coloured pyroclastic rocks, thick lahar deposits of feldspathic andesite, minor andesitic lavas, and some sandstones and carbonaceous shales. The older rocks in the immediate area belong to the Marama Formation comprising mainly massive rhyodacite lava well exposed on the high bluffs, known locally as Peach Cliff, overlooking the village of Okanagan Falls.

These units are on the south limb of a southeasterly trending syncline. The beds have variable dips ranging from about 30 to 55 degrees northeast. A strong cross-fracture system strikes about 010 degrees dipping about 80 degrees westerly almost perpendicular to the synclinal axis (Fig. 5.3).

In addition these rocks are cut by an important system of reverse faults. The system trends generally southeasterly, with interwoven easterly and southerly striking segments and splays. The direction and magnitude of movement on these faults are indicated at a number of points where large slices of Marama lava have been thrust outward and upward

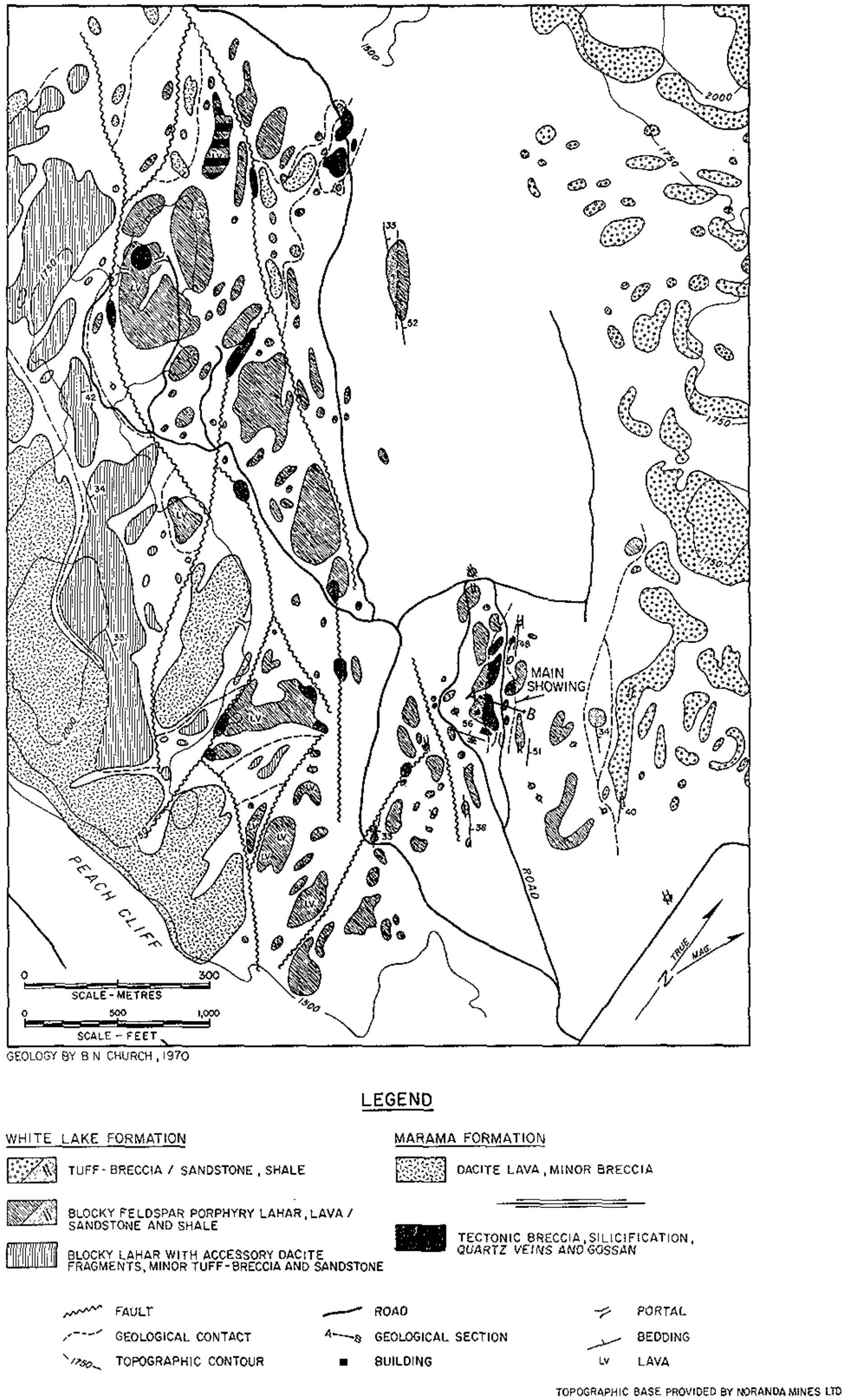

Figure 5.1. Geology of the Dusty Mac prospect, Okanagan Falls.

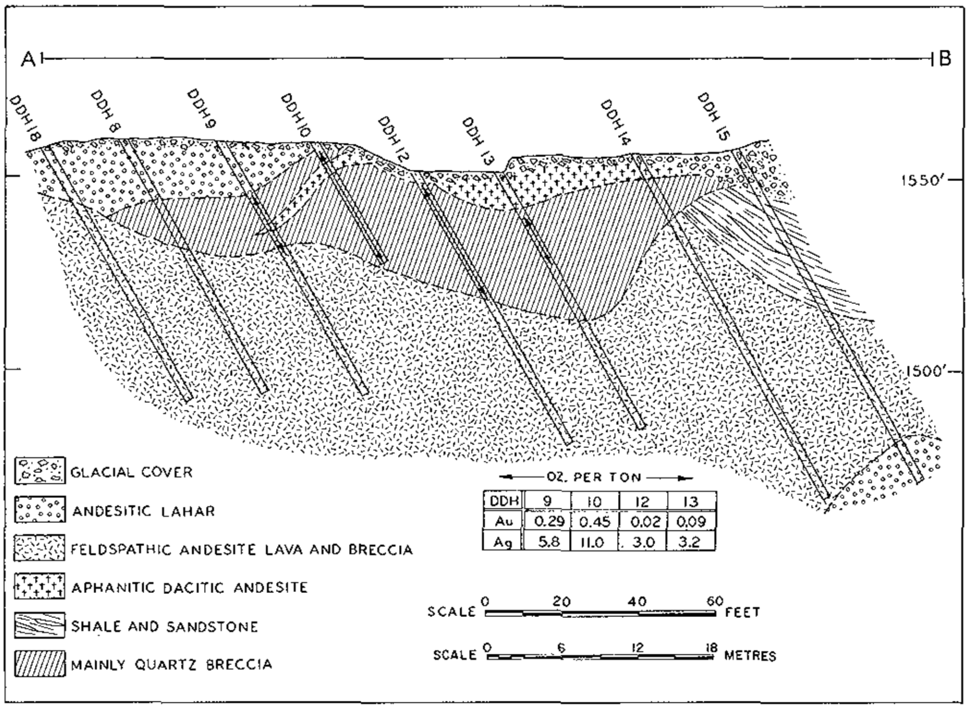

Figure 5.2. Diamond-drill hole section, Dusty Mac Mines Ltd.

from the core of the syncline through several hundred feet of White Lake strata. As in the White Lake basin, reverse faulting is thought to be the result of concentric folding and accommodation of the stratigraphic pile to bedding plane slip.

At Dusty Mac, mineralization appears to be largely controlled by the fault system. Quartz veins and gossans are present in or adjacent to most of the main faults.

The main mineralized zone, located in the east central part of the property, is a gently dipping lens of quartz breccia (Plate XVI) with varying admixtures of crushed andesite. The body is exposed over a length of about 700 feet striking roughly 140 degrees with a central cross-section width of about 160 feet and a maximum thickness of 30 feet. Surface sampling of this zone by the writer showed some disseminated native silver yielding erratic grades. Assays on five composite samples gave an average value of 0.47 ounce per ton gold and 11.3 ounces per ton silver and a range of 0.02 to 4.31 ounces per ton gold and 1 to 121.4 ounces per ton silver. A published statement by Dusty Mac Mines Ltd. indicates 67,790 tons of ore averaging 0.23 ounce per ton gold and 4.97 ounces per ton silver, according to calculations based on exploration up to December 1969.

A similar large lens of quartz breccia is located about 2,500 feet northwest of the ore zone. Preliminary testing of this body shows only a trace of gold and silver.

The large quartz breccia zones, including the main mineralized zone, are thought to be the result of the following events:

(1) Development of dilations in major shears.

(2) Filling of the dilations with quartz, accompanied by gold and silver mineralization.

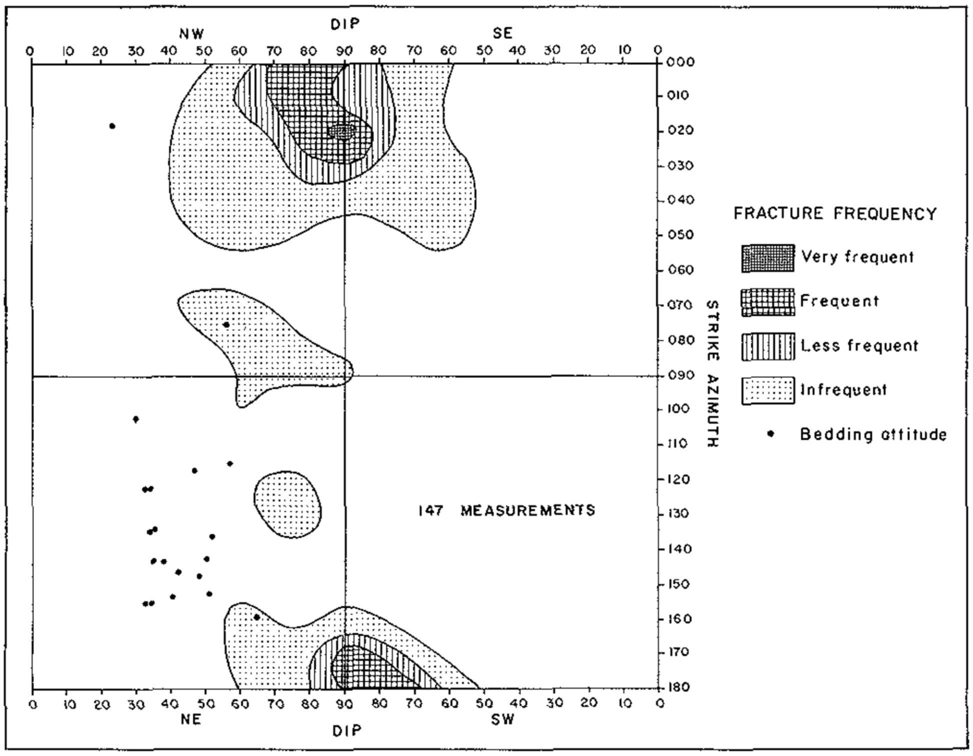

Figure 5.3. Fracture frequency plot, Dusty Mac prospect.

(3) Late-stage movement in the shear zones resulting in brecciation of the quartz and intermixing of the quartz with crushed andesite wallrocks.

Work done on the property to the end of 1970 includes 52 diamond-drill holes totalling 7,610 feet, 101 percussion holes, 2 bulk samples, and 1 crosscut adit about 150 feet long.

REFERENCES: *Geol. Surv., Canada,* Map 627A, Okanagan Falls; *B.C. Dept. of Mines & Pet. Res.,* G.E.M., 1969, pp. 294-296; 1970, pp. 402-406.

APPENDIX A

PETROGRAPHIC DESCRIPTIONS

The following petrographic descriptions of distinctive lava types supplement data given in Chapters 2 and 3. Descriptions are arranged according to the main rock series, as defined in Chapter 3, then in order of relative stratigraphic position of the rocks.

Rock colour names and symbols are adapted from the 'rock-color chart' distributed by the Geological Society of America (1963). Textural terms are those suggested by Williams, Turner, and Gilbert (1954).

Methods used for determination of the main minerals are as follows:

Alkali feldspar — $\bar{2}01$ X-ray method (Tuttle and Bowen, 1958, p. 13).

Plagioclase — cleavage flake oil immersion method by Tsuboi (Winchell and Winchell, 1956, p. 281).

Clinopyroxene — optic axial angle and refractive index method (Deer, *et al.* 1961, Vol. 2, p. 132).

ROCKS OF 'A' SERIES

BASALTIC ANDESITE: This rock comprises the Kearns Creek Member occurring near the middle of the Marron Formation and conveniently exposed in a road cut 0.4 mile east of Yellow Lake on Highway 3A.

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

Relatively high refractive indices of glass artifically prepared from several samples suggest a slightly more basic composition than that of typical andesites of 'A' series (Fig. 2.4).

The following modal composition is determined from four thin sections:

Phenocrysts	—	Clinopyroxene	—	10 per cent
		Plagioclase	—	1 per cent
Groundmass	—	Feldspar	—	60 per cent
		Chlorite	—	15 per cent
		Magnetite Biotite Apatite Quartz	—	accessory

Clinopyroxene composition is about $Wo_{42}\ En_{39}Fs_{19}$ ($2V\gamma = 51^\circ$, $n\gamma = 1.693$). Grains are commonly subhedral, slightly elongate in prismatic section, and rarely exceed 3.5 millimetres in maximum diameter. Alternate medium and pale green (oscillatory) zones are developed in many large crystals. Inclusions of small apatite rods, magnetite granules, and glass blebs are common in some phenocrysts (Plate XVIIB).

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

The groundmass is composed of small (less than one-quarter millimetre in diameter) interlocking equant grains of plagioclase, potassic feldspar, and chlorite. Magnetite granules are disseminated throughout the groundmass and are interstitial to slightly larger silicate minerals.

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

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

ANDESITE: Typical andesite forms the uppermost unit of the Marron Formation and is given the local name 'Park Rill andesite.' Two textural phases can be distinguished in the field, a merocrystalline and a vitric phase (Plate XVIIIA and XVIIIB). Merocrystalline andesite is distributed widely throughout the map-area but is most conveniently exposed immediately north of the gravel road about 0.8 mile northwest of Stewart Ranch. Vitric andesite, stratigraphically equivalent to merocrystalline andesite, is observed only on the north limb of the White Lake syncline. A fresh and readily accessible exposure of vitric andesite is located immediately east of the gravel road 1.1 miles north of the Observatory Site.

The colour of these rocks is somewhat variable. Merocrystalline andesite is commonly dusky yellowish brown (10YR2/2) where fresh but moderate brown (5YR3/4) on rusty weathered surfaces. Altered (chloritized) andesite observed on the ridge south of Stewart

Ranch is commonly greenish grey (5GY6/1) flecked with small white altered feldspar crystals. Vitric andesite is dark grey (N3) where fresh but yellowish brown (10YR4/2) on weathered surfaces.

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

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

Glass	—	60 per cent
Plagioclase	—	25 per cent
Clinopyroxene	—	15 per cent
Magnetite	—	1 per cent
Biotite	—	~1 per cent
Orthopyroxene	—	trace
Apatite	—	trace

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

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

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

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

Vitric andesite composition, estimated from 12 thin sections of fresh rock, is as follows:

Phenocrysts	– Clinopyroxene	–	5 per cent
	Orthopyroxene	–	1 per cent
	Plagioclase	–	1 per cent
Groundmass	– Glass plus microlites	–	95 per cent

Clinopyroxene composition is estimated $Wo_{49}En_{39}Fs_{12}$ ($2V\gamma = 59^{\circ}$, $n\gamma = 1.688$). These crystals are clear, almost colourless, anhedral, and commonly 0.25 to 0.5 millimetre in diameter.

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

The composition of plagioclase phenocrysts is in the range An_{45} to An_{65} (relatively high refractive index; positive optic axial angle). Phenocrysts are lath-shaped and small, generally less than 0.5 millimetre long. Twinning is not highly developed.

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

Secondary alteration of andesite, partly due to weathering, results in replacement of pyroxene by chlorite and of plagioclase by white mica, clay minerals, and calcite. Chemical analyses of both weathered and fresh merocrystalline andesite shows high total water and carbon dioxide in the weathered rock. Fresh and weathered rocks are almost chemically identical when major oxides, excluding water and carbon dioxide, are recalculated to 100 per cent.

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

RHYODACITE: Rhyodacite lava comprises most of the Marama Formation and is intermixed with minor rhyolite lava and breccia. The rock is conveniently exposed in a road cut immediately east of Prather Lake.

The rock is varicoloured in tones of grey on fresh surfaces (N3 to N6) and brown (10YR6/2, 5YR5/2, and 5YR6/4) where weathered. Typically, partly weathered samples are mottled medium grey (N5) and dark yellowish brown (10YR4/2) (Plate XIXA).

The rock has vitrophyric texture and is easily confused with vitric andesite in the field. However, rhyodacite is chemically distinctive and has low refractive index (average R.I. on glass beads = 1.508, 10 samples) and specific gravity (average S.G. = 2.538, 14 samples).

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

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

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

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

The glassy groundmass of rhyodacite is commonly light coloured and charged with plagioclase microlites and magnetite grains.

Most samples of rhyodacite show signs of secondary alteration. The groundmass is commonly birefringent indicating devitrification and replacement by microcrystalline minerals. Calcite and minor chlorite have replaced phenocrysts and patches of groundmass in some of the rock.

RHYOLITE: Rhyolite was observed only in the Marama Formation and is well exposed on the hillside immediately north of Green Ranch.

The rock is typically a light-coloured (yellowish grey 5Y8/1) quartz feldspar porphyry locally showing fluidal banding (Plate XXA).

Chemical analysis shows unusually high silica content of rhyolite compared to other lavas of this study. Also, specific gravity and refractive index of rhyolite is relatively low (S.G. = 2.33; R.I. = 1.499).

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

Phenocrysts –	Plagioclase	– 10 per cent
	Quartz	– 5 per cent
	Biotite	– 1 per cent
Groundmass –	Mainly devitrified glass	– 85 per cent

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

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

Biotite is pleochroic in deep browns and appears fresh. Books are subhedral in outline and commonly less than 2 millimetres in diameter. Inclusions are few and consist mainly of magnetite and apatite grains.

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

Magnetite and other accessory heavy minerals are scarce.

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

ROCKS OF 'B' SERIES

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

These rocks are multicoloured, commonly dark yellowish brown (10YR4/2) and olive grey (5Y4/1) where fresh and brownish grey (5YR4/1) and medium grey (N5) on weathered surfaces. Some severely weathered rocks have a blackish red matrix (5R2/2) and bleached white feldspar phenocrysts.

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

Phenocrysts	Plagioclase, Sanidine	25 per cent
	Clinopyroxene	2 per cent
	Biotite, Magnetite, Apatite	1 per cent
Groundmass	Feldspar	60 per cent
	Magnetite, Biotite, Pyroxene, Chlorite, Apatite, Quartz	accessory

The composition of plagioclase phenocrysts determined from two samples is $Ab_{52}An_{48}$ and $Ab_{55}An_{45}$ (nx' = 1.553, nx' = 1.551; Tsuboi method). Zoning is slight. Solitary crystals have tabular or lath-shaped habits, commonly one-half to 3 millimetres in maximum diameter, with rounded or embayed outlines. Glomerophenocrysts commonly consist of five or six asymmetrically arranged crystals joined along sinuous contacts. These 'clots' range from 3 to 7 millimetres in diameter. Minor pyroxene, biotite, and magnetite are observed in some aggregates (Plate XXIB).

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

Sanidine phenocrysts are generally scarce. The compositions of slightly zoned crystals from two trachytes are $(Ab + An)_6 Or_{94}$ and $(Ab + An)_{42} Or_{58}$ ($\bar{2}01$ X-ray method). The sanidine is commonly fresh and relatively free from inclusions and occurs as solitary laths as much as 2 centimetres long or as mantles on plagioclase (Plate XXIA).

The clinopyroxene, determined from two samples, is $Wo_{45}En_{35}Fs_{20}$ and $Wo_{42}En_{40}Fs_{18}$ ($2V\gamma = 51^\circ$, $n\gamma = 1.693$; $2V\gamma = 54^\circ$, $n\gamma = 1.696$). Phenocrysts are pale green, slightly zoned, and commonly have equant habits with subhedral outlines. Generally individual pyroxene crystals are small, one-half to 2 millimetres in diameter, however, a few glomerophenocrysts are as much as 4 millimetres in diameter.

Biotite is strongly pleochroic in shades of brown. Basal plates are generally darker than prismatic sections. Phenocrysts are commonly solitary showing subhedral or corroded amoeboid-like outline. The thin outermost shell of biotite books is usually charged with magnetite dust.

Magnetite and apatite phenocrysts are few and less than one-half millimetre in diameter. Magnetite generally occurs as equant subhedral or anhedral grains, and apatite as subhedral prisms. Many of these minerals form poikilitic inclusions in pyroxene and biotite and, to a much lesser extent, in feldspar phenocrysts.

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

The lowermost clot porphyry beds, west of Mahoney Lake, are distinctive and are mapped separately (termed small feldspar porphyry on Fig. 1.3). The modal composition of this rock is as follows:

Phenocrysts —	Plagioclase	— 20 per cent
	Biotite	— trace
Groundmass —	Feldspar	— 70 per cent
	Magnetite Calcite pseudomorphic after pyroxene Apatite	— accessory

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

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

The upper part of the clot porphyry rocks, west of Mahoney Lake, also forms a mappable unit. The mode is as follows:

Phenocrysts –	Plagioclase	– ~5 per cent
	Biotite Calcite pseudomorphic after pyroxene	– trace
Groundmass –	Feldspar	– 25 to 75 per cent
	Magnetite	– ~2 per cent
	Chlorite Submicroscopic undetermined material, possibly devitrified glass	– 20 to 70 per cent

The rock generally contains markedly fewer feldspar phenocrysts and has a lower ratio of glomerophenocrysts to solitary crystals than does that of normal clot porphyry described previously. Plagioclase occurs mainly as plates (1 to 6 millimetres in diameter) with broad equidimensional (010) faces and thin lath-shaped sections in zones normal to (010).

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

'ROSETTE PORPHYRY' TRACHYTES: The field name 'rosette porphyry' applies to trachytic and trachyandesitic rocks that typically contain small glomerophenocrysts of radially oriented feldspar. These rocks comprise the Nimpit Lake Member in the upper middle part of the Marron Formation. The unit is conveniently exposed in road cuts along Highway 3A near Trout Lake (Plate XXIIA).

Rosette porphyry trachytes are typically dark yellowish brown (10YR4/2) on fresh surfaces and commonly light olive grey (5Y5/2) or greyish red (10R4/2) where weathered.

Refractive indices and specific gravities of rosette porphyry (R.I. = 1.527, average of 10 samples; S.G. = 2.59, average of 42 samples) and clot porphyry (R.I. = 1.526, average of 10 samples; S.G. = 2.59, average of 46 samples) are markedly similar as are their chemical compositions.

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

Phenocrysts –	Plagioclase Sanidine	– 8 per cent
	Clinopyroxene	– ~3 per cent
	Biotite	– trace
Groundmass –	Feldspar	– ~70 per cent
	Glass	– ~10 per cent
	Biotite Pyroxene Magnetite Apatite	– accessory

In view of the low phenocryst to groundmass ratio, shown above, distinction between trachytes and trachyandesites is best made on the basis of chemical data. Since the most pronounced differences between rocks of this series is silica composition (Chapter 3), rocks containing normative quartz are arbitrarily called trachytes and undersaturated rocks with normative nepheline are termed trachyandesites.

Plagioclase phenocrysts are only slightly zoned. Their composition range, based on determination of feldspar from two rocks, is from $Ab_{52}An_{48}$ to $Ab_{44}An_{56}$ (ny = 1.553 and ny = 1.558; Tusboi method). Individual crystals are lath-shaped and most of them form gomeroporphyritic bursts 2 to 5 millimetres in diameter. Carlsbad and polysynthetic albite twinning is displayed by most crystals. Inclusions are few and consist mainly of small apatite rods.

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

The clinopyroxene is approximately $Wo_{45}Hy_{35}Fs_{20}$ ($2V\gamma = 54^{\circ}$, ny = 1.696). Crystals are pale green in thin section and only slightly zoned. Most commonly it occurs as solitary crystals one-half to 1 millimetre in diameter showing equant habits and subhedral outlines. Apatite and magnetite inclusions are common.

Biotite phenocrysts are generally few. They are pleochroic in yellowish browns, commonly corroded and charged with magnetite dust.

The groundmass is composed mainly of felted feldspar microlites about 0.1 millimetre long. Interstices are filled mostly with a dark brown substance, probably devitrified glass, some biotite and pyroxene. Magnetite grains are disseminated uniformly throughout.

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

The rocks are commonly weathered, perhaps due to their fragmented character (Chapter 2), and they vary in colour from medium grey (N7) to greenish grey (5GY6/1) and moderate yellowish brown (10YR5/4) on rust-stained surfaces.

The refractive index of glass prepared from the White Lake feldspar porphyry rocks indicates a marked composition range. The chemical analysis of a weathered sample obtained near Indian Head resembles trachyte in composition except for low silica, and high lime and carbon dioxide (Church, 1967; Appendix Table A-1, No. 6).

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

Plagioclase Sanidine	} –	5 to 20 per cent
Biotite Clinopyroxene	} –	less than 5 per cent
Magnetite Apatite	} –	trace

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

Groundmass	– Glass and partially devitrified glass	–	70 per cent
	Feldspar microlites	–	25 per cent
	Ferromagnesian minerals	–	5 per cent

Plagioclase is commonly replaced by mica, calcite, or patches of sodic feldspar. Composition based on refractive index of glass prepared from a sample of this altered plagioclase is about $Ab_{70}An_{30}$ (R.I. = 1.512). The mineral occurs both as single crystals and glomerophenocrysts, usually less than 5 millimetres in diameter, showing embayed and rounded outlines.

Sanidine amounts to less than one-quarter the total modal feldspar phenocryst content in rocks examined. Composition of phenocrysts determined from a trachyandesite are about $(An + Ab)_5Or_{95}$ ($\bar{2}01$ X-ray method). Crystals are clear, except for minor alteration products, and occur as mantles on plagioclase or as solitary laths.

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

Clinopyroxene is commonly replaced by calcite, chlorite, and iron oxide. The composition of fresh unzoned phenocrysts from a trachyandesite is $Wo_{45}En_{37}Fs_{18}$ ($2V\gamma = 54^\circ$; ny = 1.695). Crystals generally range from one-half to 2 millimetres in diameter and show subhedral outlines.

Magnetite and apatite crystals, which are less than one-half millimetre in maximum diameter and subhedral in outline, occur as solitary crystals or form glomerophenocrysts with pyroxene alteration products.

ROCKS OF 'C' SERIES

RHOMB PORPHYRY (PHONOLITE): Lavas bearing distinctive rhomb-shaped anorthoclase phenocrysts constitute most of the Yellow Lake porphyry beds, the basal unit of the Marron Formation. This rock is conveniently exposed in road cuts on the north shore of Yellow Lake and near the switchback on Highway 3A about 1.7 miles west of Kaleden Junction. The best textural development of this rock is displayed by basal Marron lavas in the valley cut by Kearns Creek, about a half mile northwest of Mahoney Lake.

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

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

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

Phenocrysts	–	Anorthoclase	(varying abundance)
		Clinopyroxene	(varying abundance)
		Biotite	(minor abundance)
		Plagioclase	(present in some rocks)
		Analcite	(uncommon as phenocrysts)
		Olivine	(uncommon; mainly altered to bowlingite)
		Apatite	(rare as phenocrysts)
		Magnetite	(rare as phenocrysts)
Groundmass	–	Feldspar	(very abundant)
		Pyroxene	(common)
		Biotite	(common)
		Apatite	(common)
		Magnetite	(common)
		Analcite	(common in some rocks)
		Glass	(scarce)

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

The composition of anorthoclase from a microporphyry phase is approximately $(Ab + An)_{80}Or_{20}$ ($\bar{2}01$ X-ray determination). This is roughly in agreement with X-ray fluorescence determination of large anorthoclase phenocrysts by Bostock (1966, p. 13) from basal Marron flows, Shingle Creek, British Columbia.

The usual habit of anorthoclase is illustrated in Plate XXIII. Goniometric measurements on two large crystals, obtained from basal lavas near Kearns Creek, show that the *characteristic rhomb-outline of (010) sections, faces, and cleavage plates is due to* modifications of the type (110), ($1\bar{1}0$), and ($20\bar{1}$):

$$110 \text{ to } 010 \cong 58^\circ$$
$$1\bar{1}0 \text{ to } 001 \cong 68^\circ$$
$$20\bar{1} \text{ to } 001 \cong 80^\circ$$
$$\beta = 116^\circ$$
$$a : b : c = 0.66 : 1 : 0.58$$

Examination of many thin sections shows a $2V\gamma$ range of 38 to 80 degrees and extinction angle with (001) cleavage trace on (010) plates, 3 to 14 degrees.

Many anorthoclase crystals examined in thin section show marked zoning. Cobaltinitrite stain tests indicate that the thin outer zones of some crystals are rich in potassium. This is verified by X-ray determination on part of the outer shell of a large rhomb-shaped crystal *which gives* Or_{90} *($\bar{2}01$ method). Also, the X-ray diffraction pattern of this outer shell is* comparable to that of hyalophane, suggesting a significant content of barium (Table A.1). [Since barium is commonly divalent and is markedly similar to potassium in ionic radius (Ba^{++} = 1.46A, K^+ = 1.45Å) it is not surprising that this minor element is captured by potassium-rich zones in feldspar.]

Grid twinning (combination of albite and pericline polysynthetic twinning) is observed on some anorthoclase crystals. Significantly, sections showing good grid twinning also show (001) and (010) cleavage traces and generally squarish or equant rather than rhomb-shaped outlines (Plate XXIIIC).

Chemcial compositions of rhomb-shaped anorthoclase crystals from the White Lake area and Midway area, British Columbia, and Mount Erebus, Ross Island Antarctica, are given in Table A.2.

Plagioclase phenocrysts are infrequent, however, when present they are commonly corroded and mantled with alkali feldspar. The estimated composition of the plagioclase, based on relative relief and extinction angles, is An_{40}.

The clinopyroxene composition is $Wo_{50}Hy_{35}$ Fs_{15} ($2V\gamma = 60^\circ$, $n\gamma$ = 1.694; average of three similar determinations). Phenocrysts show oscillatory zoning and variations in light and medium green colours. Large crystals are prismatic, commonly with euhedral outline; however, microporphyries generally contain stubby subhedral crystals.

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

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

Apatite and magnetite are relatively abundant in rhomb porphyry rocks. These minerals occur in the groundmass and as inclusions in feldspar, pyroxene, and biotite phenocrysts. Prismatic cleavage ($10\bar{1}0$) is commonly well developed in apatite.

TABLE A.1. FELDSPAR X-RAY DIFFRACTION DATA

1		2	
dÅ	I	dÅ	I
6.48	5	6.53	30
5.90	5	5.87	10
4.678	5		
4.216	10		
4.027	5	4.01	60
		3.93	20
3.798	25	3.77	80
3.675	5	3.60	10
3.457	7	3.46	50
3.318	100	3.30	90
3.190	70	3.22	100
2.993	20	2.98	80
2.904	15	2.901	70
2.765	7	2.759	50
2.576	40	2.572	80
2.393	7	2.427	10
2.322	5	2.319	20
2.167	15	2.162	60
2.126	10	2.113	10
2.065	5	2.057	10
2.009	5	2.004	10
1.973	5	1.969	10
1.932	5	1.920	20
1.849	5	1.852	10
1.792	30	1.796	80
		1.673	10
1.620	3	1.626	20
1.587	3		
1.562	3	1.570	20
1.534	3	1.529	10
1.498	15	1.494	70

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

2 – 'Hyalophane' containing 3.8 per cent BaO (Vermaas, 1953).

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

TABLE A.2. ANALYSES OF RHOMB-SHAPED ANORTHOCLASE

	1	2	3
SiO_2	56.16	62.61	59.90
TiO_2	0.62	----	0.28
Al_2O_3	22.80	21.98	19.23
Fe_2O_3	2.06	0.33	0.74
FeO	----	0.86	1.00
MnO	----	----	0.02
MgO	1.34	0.08	1.14
CaO	4.75	3.75	1.33
Na_2O	4.59	7.27	2.94
K_2O	5.74	3.12	3.83
BaO	1.12	----	1.06
SrO	0.82	----	0.05
H_2O+	----	----	2.94
H_2O-	----	----	0.12
CO_2	----	----	0.19
Mol. %	$(Ab + An)_{60}Or_{40}$	$(Ab + An)_{82}Or_{18}$	$(Ab + An)_{39}Or_{61}$

1 – Anorthoclase from Rock Creek Chonolith, near Midway, British Columbia (Daly, 1912).

2 – Anorthoclase from ash deposit, crater of Mount Erebus, Ross Island Antarctica (Mountain, 1925).

3 – Zoned rhomb-shaped anorthoclase-sanidine from White Lake area (analysis by S. W. Metcalfe, British Columbia Department of Mines and Petroleum Resources).

AUGITE PORPHYRY (TEPHRITE): Augite porphyry is a basic alkali-rich rock similar in composition to tephrite, the extrusive equivalent of shonkinite. It occurs in two stratigraphic zones in the map-area; at the top of the White Lake Formation and near the middle of the Skaha Formation. The rock from the White Lake Formation is typically a microporphyry containing many xenoliths (mainly quartz grains and lumps of granite and shale). Skaha augite porphyry is relatively coarse, fresh, and free from xenoliths. A good exposure of this rock is to be seen beside the logging road about a mile southeast of the Observatory Site.

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

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

The modal composition of fresh, xenolith-free rock (based on examination of three thin sections) is comparable to the normative composition calculated from chemical analysis of the same rock using the Barth method (Barth, 1962, p. 65).

Mode	per cent	per cent	Norm	per cent	per cent
Potassic feldspar			Or	30.7	
and plagioclase	50	65	Ab	2.0	63.4
			An	14.0	
Analcite	15		Ne	16.7	
Clinopyroxene	25		Di	24.5	
Biotite	4		Olv	9.5	
Magnetite	4		Mg	2.6	
Apatite	2				

Clinopyroxene shows oscillatory zoning indicating somewhat variable composition; however, many optical measurements give an average of $Wo_{45}En_{35}Fs_{20}$ ($2V\gamma = 55°$; $n\gamma = 1.696$). Crystals commonly have prismatic elongation, euhedral outline, and range in length between 0.25 millimetre and 1.5 centimetres. They vary in colour from medium to very pale green and display high second order interference colours under crossed nicols. Inclusions are mainly magnetite and apatite, some biotite, feldspar, and glass.

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

Partial replacement of plagioclase by secondary minerals prevents accurate determinations, however, relatively high normative anorthite content of the rock suggests a calcic composition.

Fresh olivine is not observed in augite porphyry; however, a few patches of serpentine-like substance in the groundmass appear to be pseudomorphic after this mineral. The relatively high normative olivine composition of the rock is probably accounted for by the presence of biotite which is, in part, chemically equivalent to olivine.

APPENDIX B

THE CLASSIFICATION OF VOLCANIC ROCKS

The standard methods of identification and classification of coarse and medium-grained igneous rocks, using mineral content and composition, are only partially applicable to porphyritic volcanic rocks and of little application to glassy, very fine-grained, or recrystallized metamorphosed volcanic rocks. Arc fusion analyses performed on large numbers of field samples are helpful in establishing the basicity of volcanic rocks, however, in the end the petrologist usually resorts to chemical analyses for precise identification, comparison, and classification of volcanic suites.

THE COMPOSITION DIVISION OF VOLCANIC ROCKS: The simplest and most natural division of fine-grained igneous rocks is four fold: (1) basalt, (2) the acid-line rocks of rhyolite, dacite, and andesite composition, (3) trachytes, and (4) rocks of phonolitic affinity. These names have historical petrographic significance and are deeply ingrained in the literature. Of the six rock types distinguished above, three are end-member compositions: basalt, rhyolite, and phonolite, and the remainder are of intermediate compostion: dacite, andesite, and trachyte. The most distinctive petrological traits of the three end-members are illustrated on Figure B.1 by the generalized phase system: silica - nepheline - anorthite - diopside (olivine). Basaltic liquids, which occur compositionally between the diopside (olivine) and anorthite apices, are highly refractory and therefore remote from any eutectics. Melts of rhyolitic and phonolitic composition, which are distinctively enriched in alkali feldspar and quartz or feldspathoids, lie along phase boundary curves approaching the low temperature 'eutectic points' of Figure B.1. However, the paths of descent for rhyolitic acid-line liquids and phonolitic liquids are separated by a thermal divide. If potassium is added to the system, especially in the form of the orthoclase and kalsilite molecules, the liquids pass into 'Petrogeny's Residua System' (Bowen, 1937).

The composition tetrahedron illustrated on Figure B.2 is the writer's idealization of the natural division of the common fine-grained igneous rocks. More than 90 per cent of all igneous rock compositions fall within the limits defined by the apicies of the tetrahedron rhyolite, phonolite, ultramafics, and anorthosite. Indeed most compositions lie close to a section through the tetrahedron containing rhyolite, phonolite, and basalt. The terms andesite and dacite apply to compositions on the 'acid-line' of thermal descent between

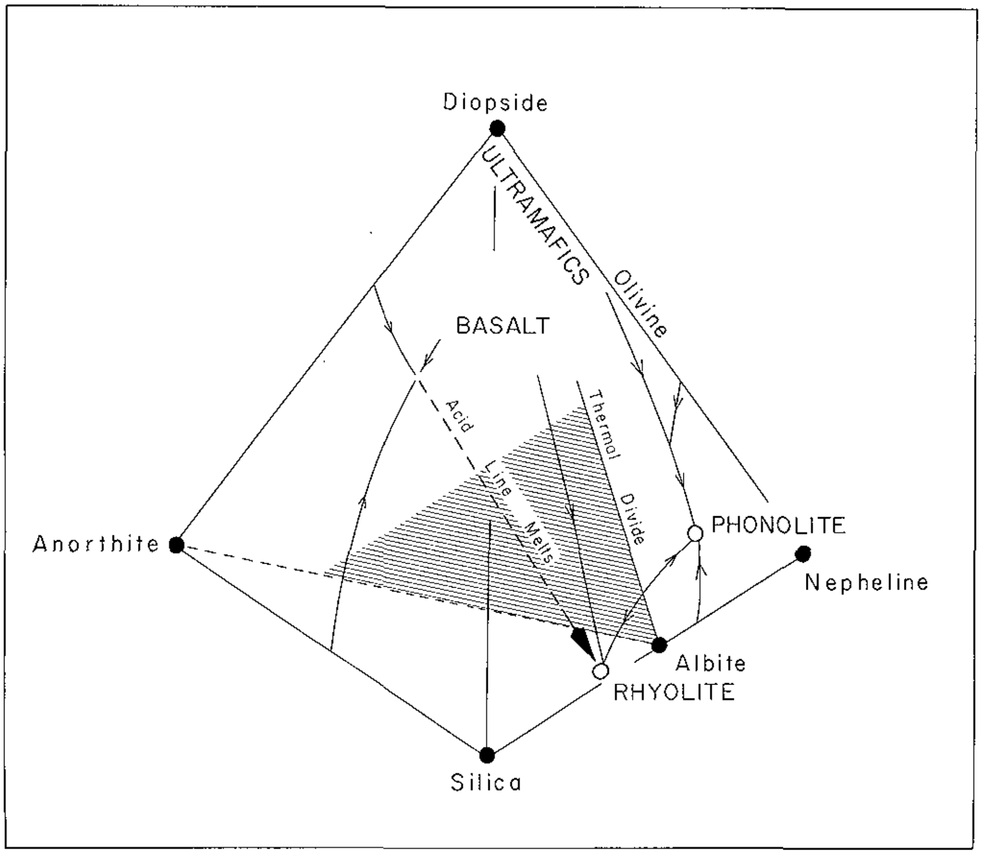

Figure B.1. The generalized phase system Di-An-Ne-Qz.

basalt and rhyolite; similarly basic phonolite lies between basalt and phonolite in the alkaline field. Trachyte and trachyandesite are compositions more or less on the silica saturation divide between the acid-line and phonolitic rocks.

QUANTITATIVE PARAMETERS OF CHEMICAL VARIATION: The idealized compositional tetrahedron (Fig. B.2) does not itself display the complete petrochemical system and furthermore the tetrahedron cannot be adequately represented two dimensionally. However, 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 $FeO + Fe_2O_3 + ½(MgO + CaO)$ and versus Al_2O_3/SiO_2. The method combines some of the better aspects of the alkali-based variation diagram proposed by Tilley (1950) with Al_2O_3/SiO_2 based diagrams modified from those of Murata (1960). These diagrams effectively separate alkali-rich and aluminous volcanic suites from those of more common compositions. The ordinate of the newly proposed plot $FeO + Fe_2O_3 + ½(MgO + CaO)$ contains the most refractory of the major oxides and therefore serves as an index of basicity. The purpose of weighting this basicity index by a factor of two in favour of iron oxides is to achieve a polarization of the common ultramafic rock compositions and the important ferromagnesian components olivine, orthopyroxene, and augite. This is illustrated on Figure B.3, which is a modified Murata-type plot with the new basicity index as ordinate and forms the right side of subsequent diagrams. Figure B.3 shows the relative position of important silicate minerals together with a selection of Daly's (1933) average rock compositions.

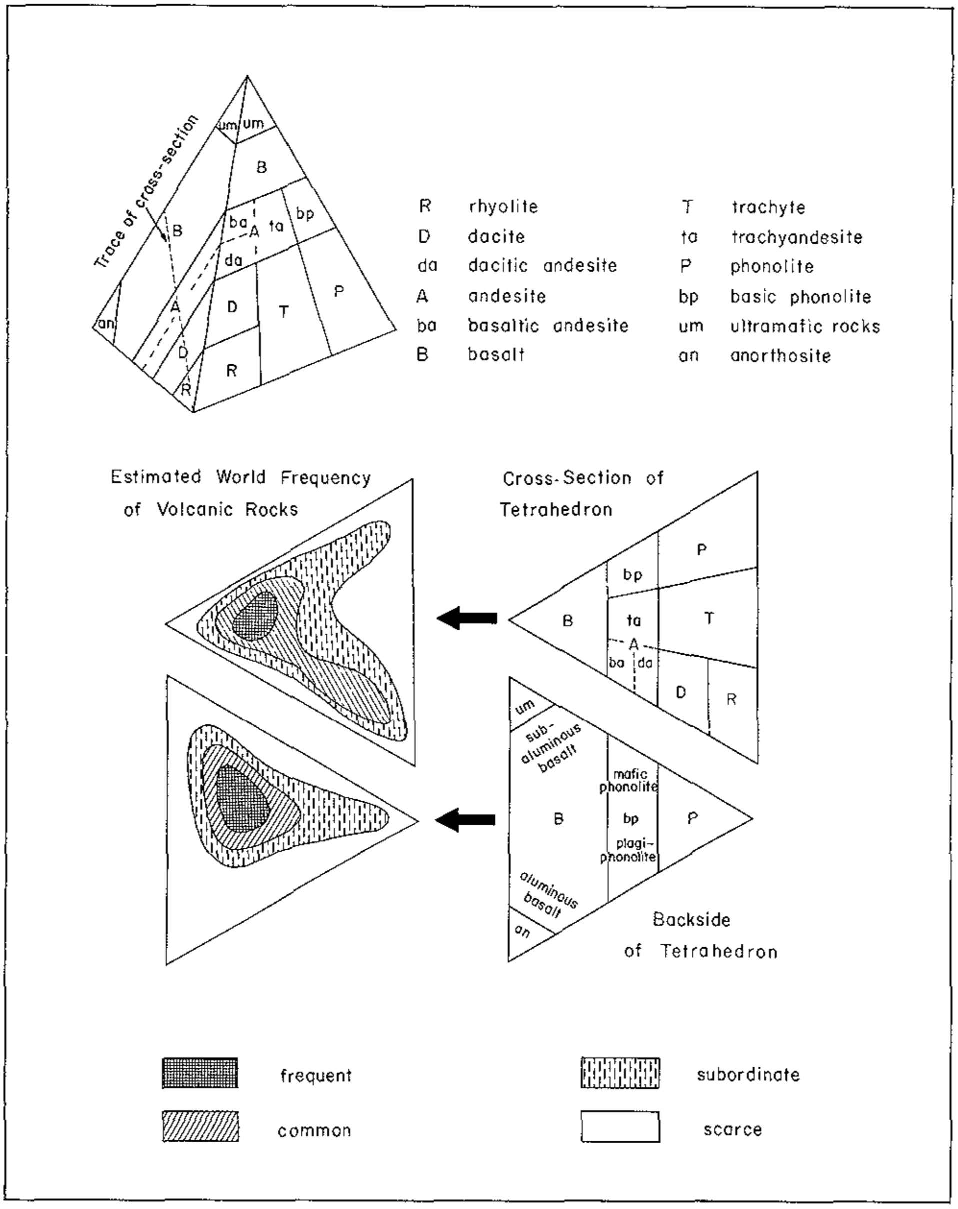

Figure B.2. The composition tetrahedron for volcanic rocks.

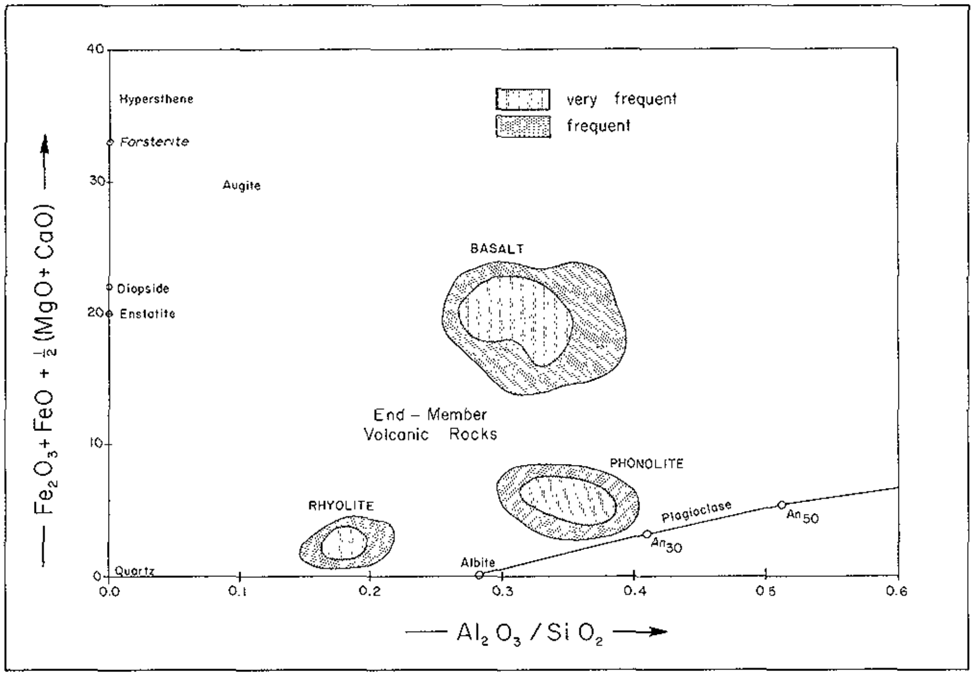

Figure B.3. Murata-type variation diagram showing the composition distribution of the common minerals and igneous rocks.

Figure B.4 is the complete triaxial orthogonal graph on which is plotted the major oxides from 1,486 superior analyses of volcanic rocks from Washington's tables (1917). This total array of points was first subdivided into groups according to the rock names used by the field geologists and each group was statistically contoured using the integrating square petrofabric method, Figure B.5. For simplicity only the contour level inclusive of two-thirds of the total points plotted for each rock type is shown. The data used for this purpose comprises: 162 rhyolites (including liparites), 112 dacites, 364 andesites, 155 trachytes, 64 phonolites, and 444 basalts; 185 analyses representing a variety of obscurely named volcanic species were omitted from the contouring procedure.

In summary the method offers important advantages, firstly, by adoption of a simple system of nomenclature of popular acceptance and long-standing usage and, secondly, in achieving general harmony with the findings of theoretical and experimental petrology. In addition and more specifically all the major oxides of rock analyses are used in a generalized manner with de-emphasis on the possible effects of chemical analytical error and stressing only the gross differences in rock composition, showing possible interrelations between rock compositions and certain important mineral groups. Also, employment of the method requires a minimum of data manipulation and processing.

The utility of the major oxide variation diagram is proved by plotting analyses of some of the classical magma suites and trends (Fig. B.6). For example good discrimination is achieved comparing plots of silicic or 'acid-line' rocks, represented by the Cascade volcanic suite; the phonolitic trend, exemplified by the Highwood lavas; the iron-enrichment tholeiitic basalt trend, typified by the primary Skaergaard liquids; and the ophiolite suite, exemplified by the Cyprus lavas.

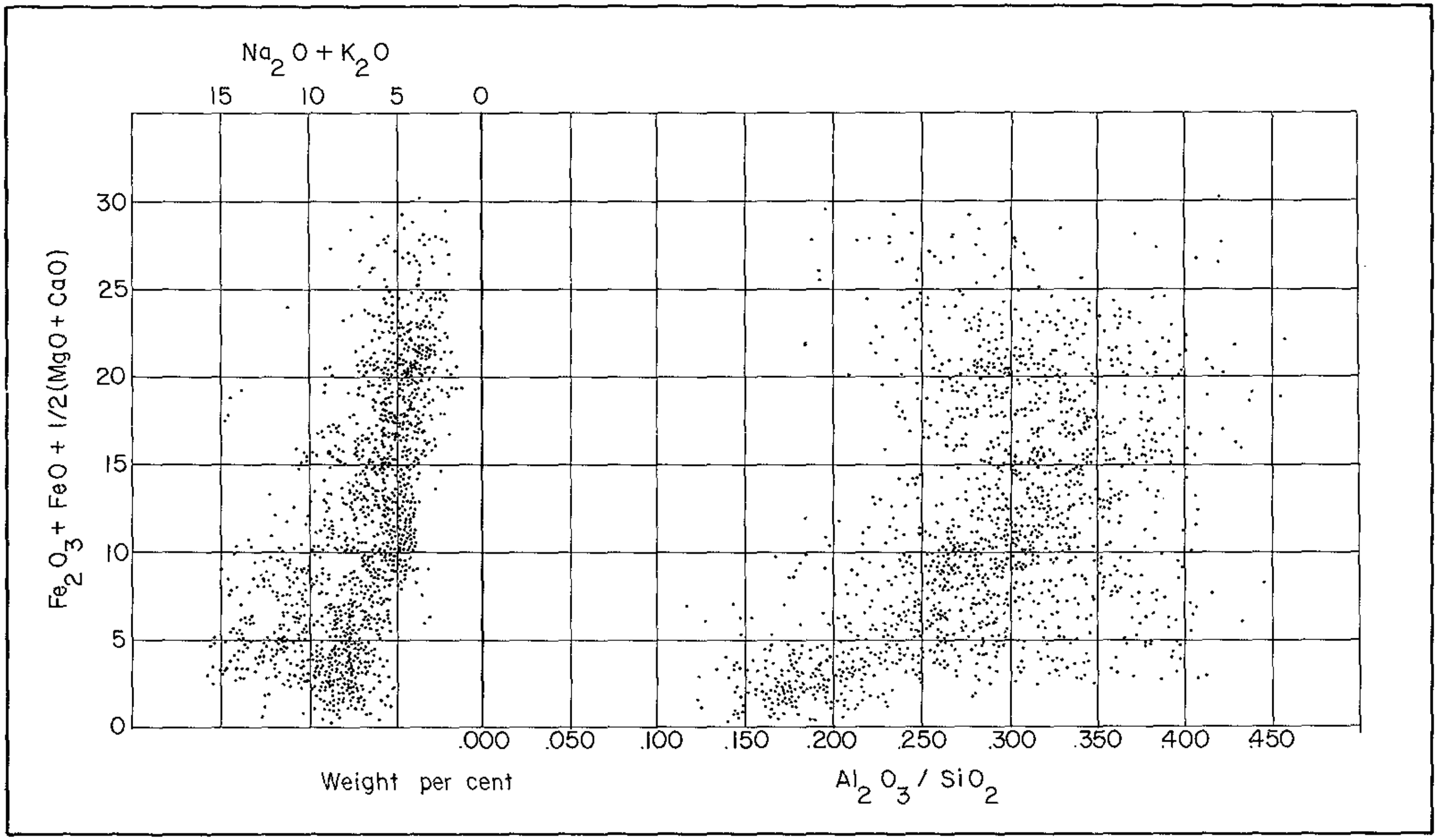

Figure B.4. Major oxide variation diagram showing the composition dispersion of volcanic rocks, data from Washington's tables.

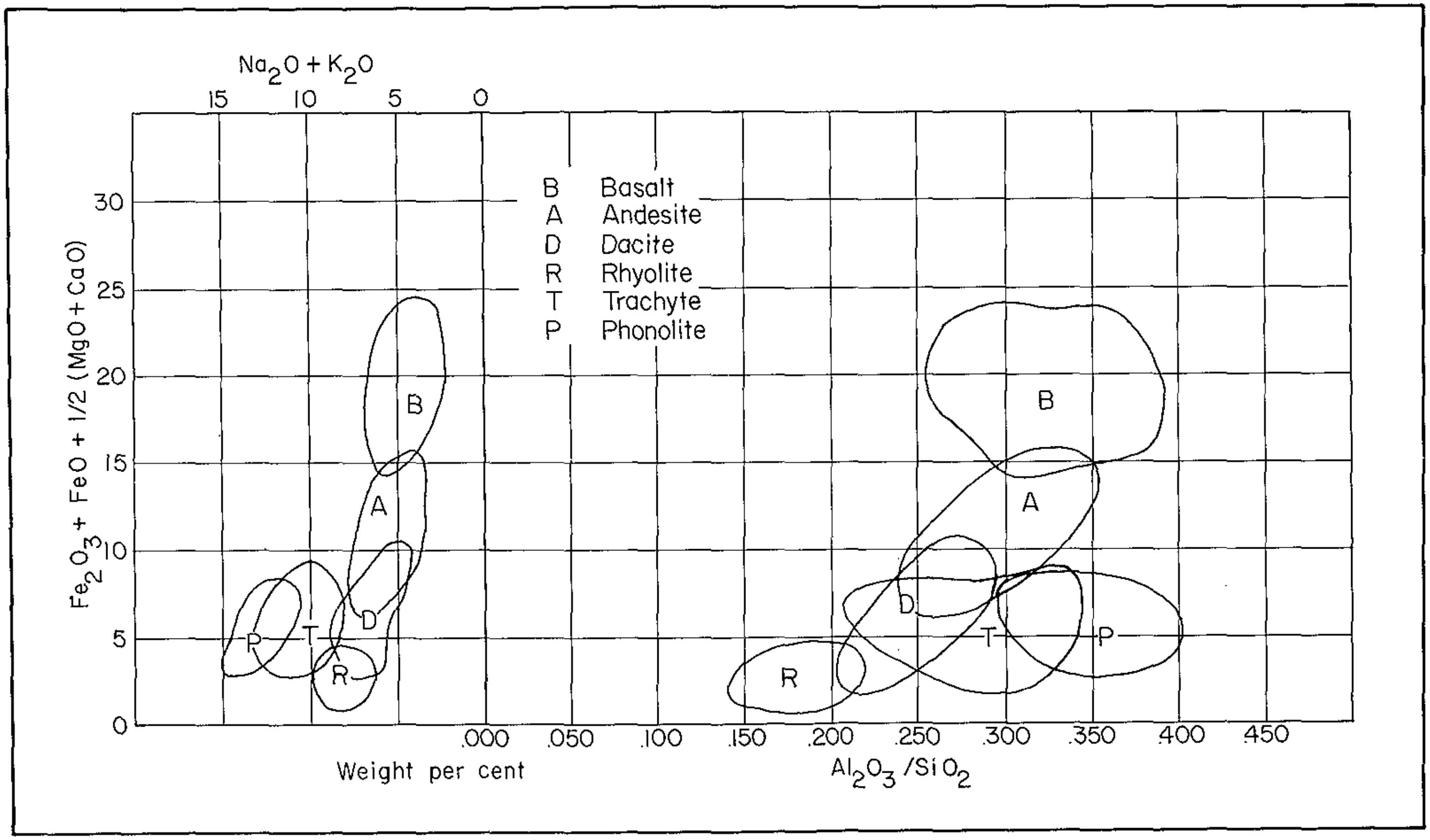

Figure B.5. Major oxide variation diagram showing the average composition of the principal volcanic rock types; the encircled areas enclose two-thirds of the points plotted for each rock.

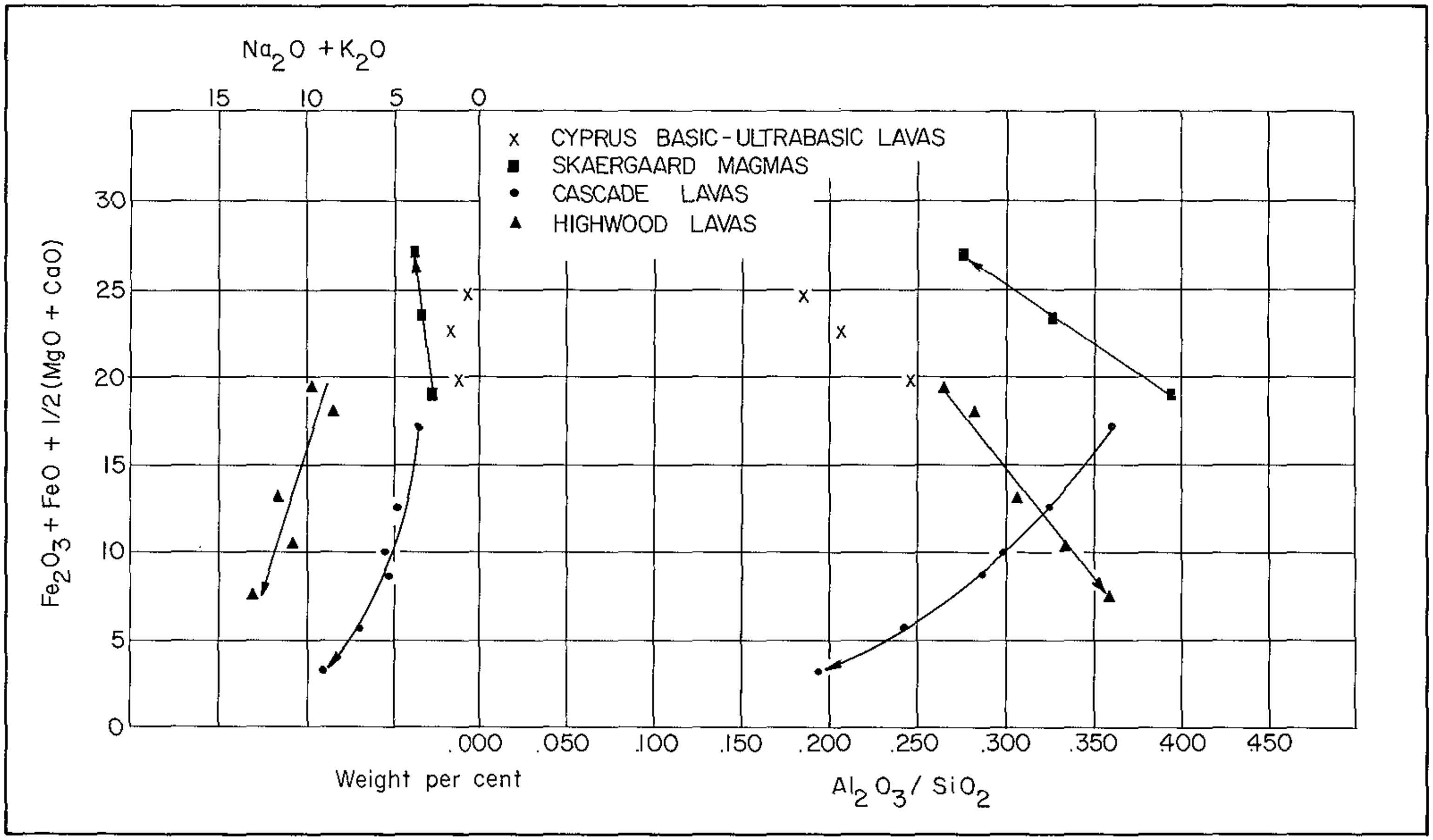

Figure B.6. Major oxide variation diagram showing some of the classical magma suites and trends.

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Plate I. Marron volcanic rocks overlying Springbrook beds at the west boundary of the map-area near Olalla.

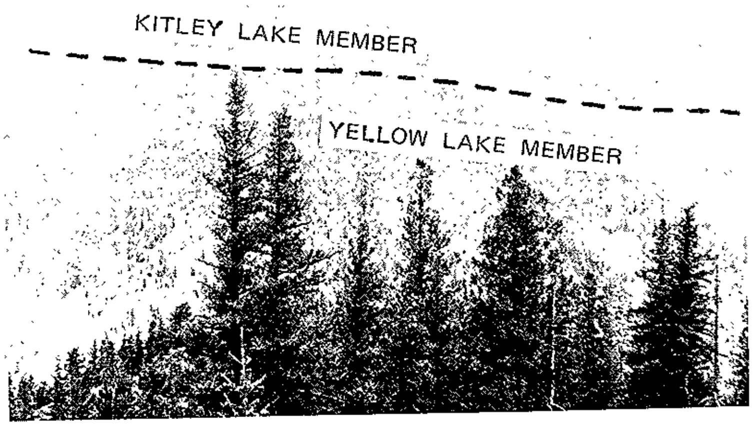


Plate IIA. Conformable contact between Kitley Lake lavas and Yellow Lake lavas in the lower part of the Marron Formation north of Yellow Lake.

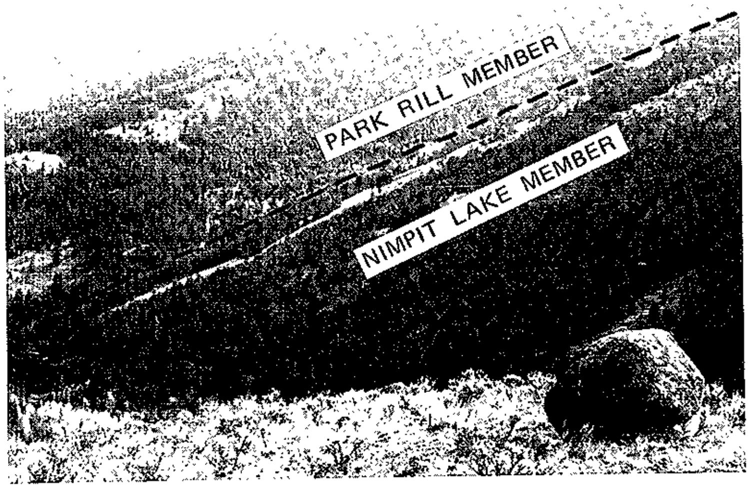
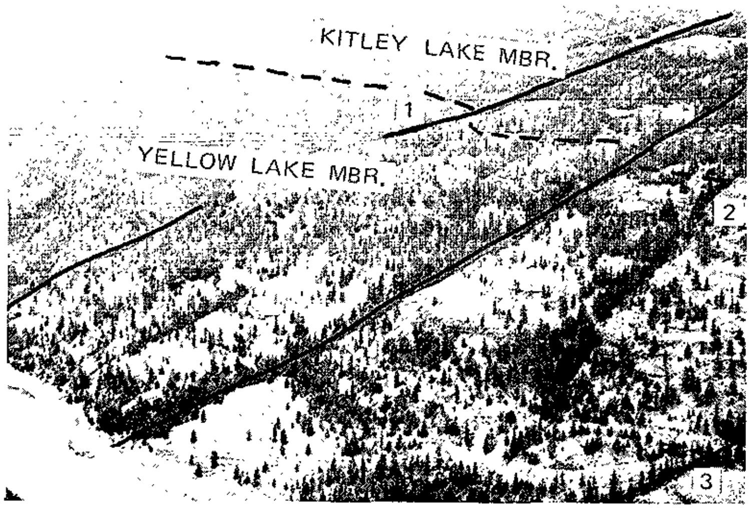
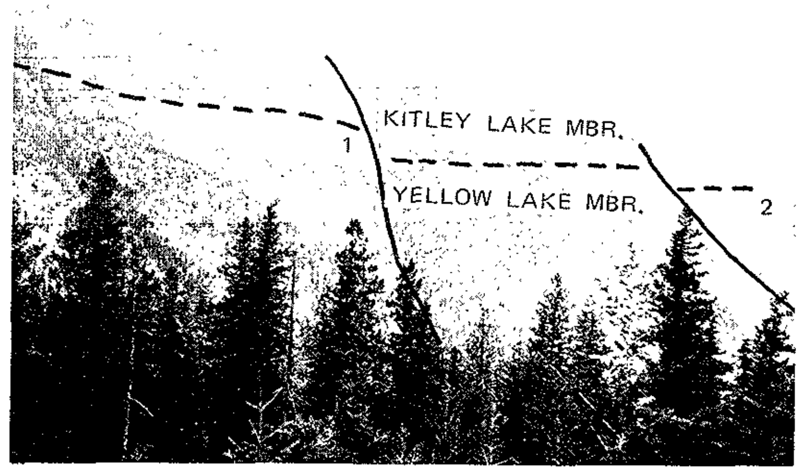


Plate IIB. Conformable contact between Park Rill andesite lavas and Nimpit Lake trachyte lavas, view south of Park Rill near the T. L. Ranch.





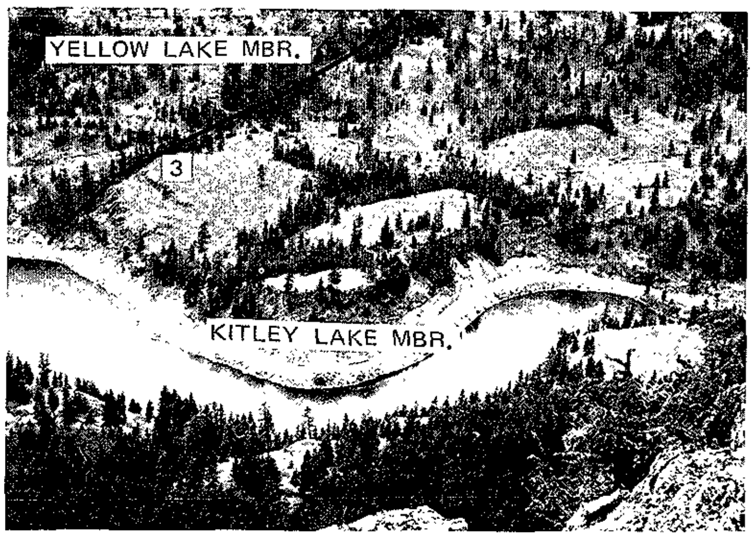


Plate IIIA, B, C. Gravity fault displacement of Marron rocks north of Yellow Lake.

Plate IV. Panoramic view of the Marama Formation and the upper members of the Marron Formation northwest of Highway 3A near Marama Creek.

Top of
infill cycle.

Base
of cycle.

Plate VA and B. Small infill cycle, White Lake sedimentary rocks, south limb of the White Lake syncline.

Plate VIA. Bluffs of White Lake volcanic rocks, near White Lake.

Plate VIB. Interbedded lahar and pyroclastic deposits, White Lake volcanic rocks near White Lake.

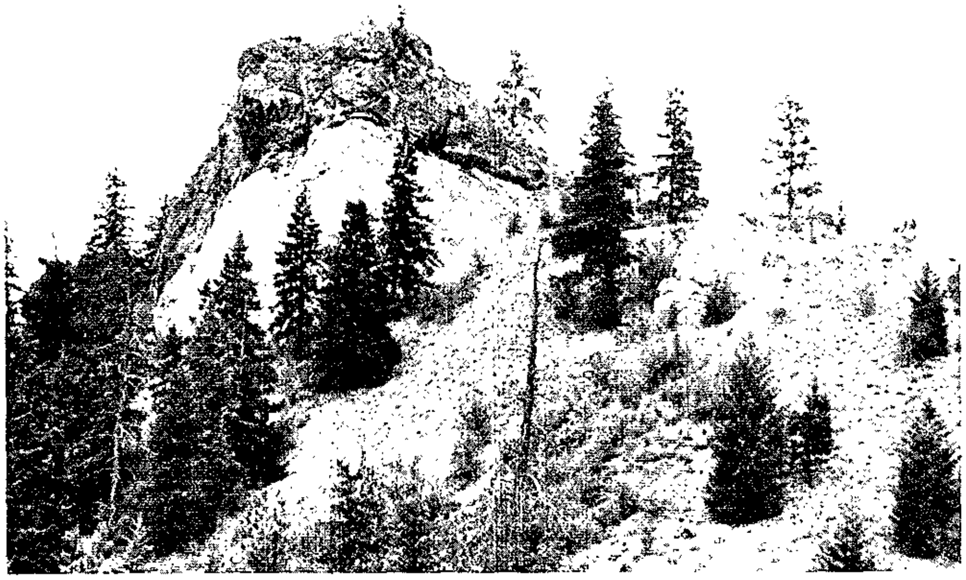


Plate VIIA. Skaha 'basal breccias' (mainly dark chert) overlying White Lake beds (mainly light-coloured pyroclastic rocks) at Indian Head.

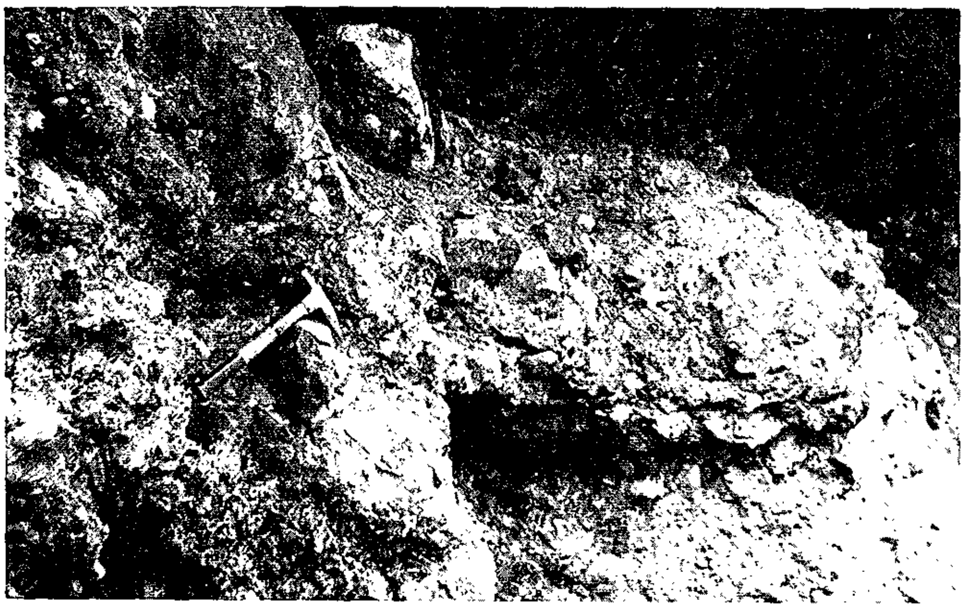


Plate VIIB. Conglomeratic zone immediately below 'basal breccias' at Indian Head.

Plate VIIIA. Skaha 'basal breccias' (highly fragmented bedded chert breccia) overlying White Lake volcanic rocks, canyon of Kearns Creek west of The Hole.

Plate VIIIB. Highly fragmented chert breccia, Skaha Formation.

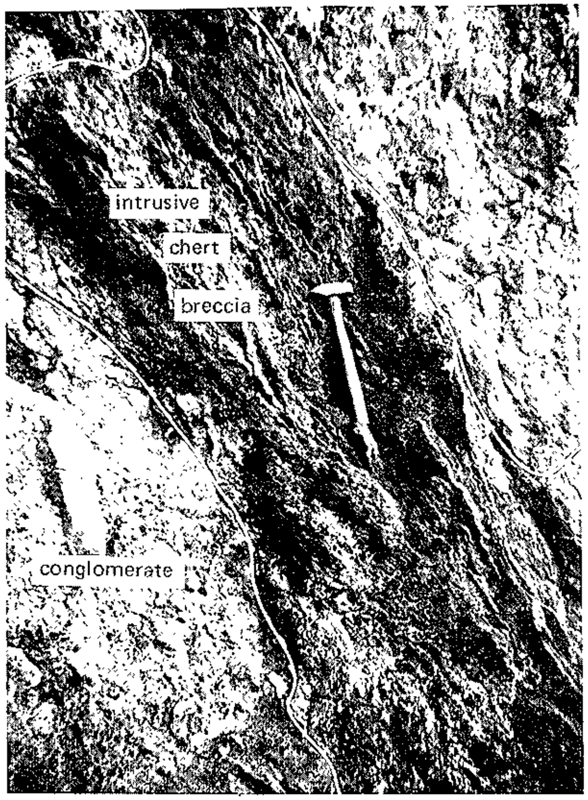


Plate IXA. Intrusive chert breccia in conglomerate beds, lower member Skaha Formation.

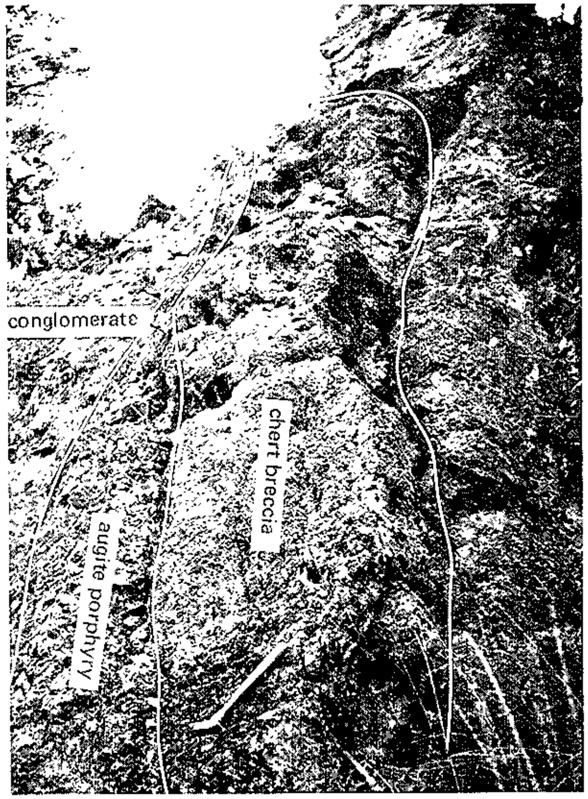


Plate IXB. Augite porphyry dyke and intrusive chert breccia in conglomerate, lower member Skaha Formation.

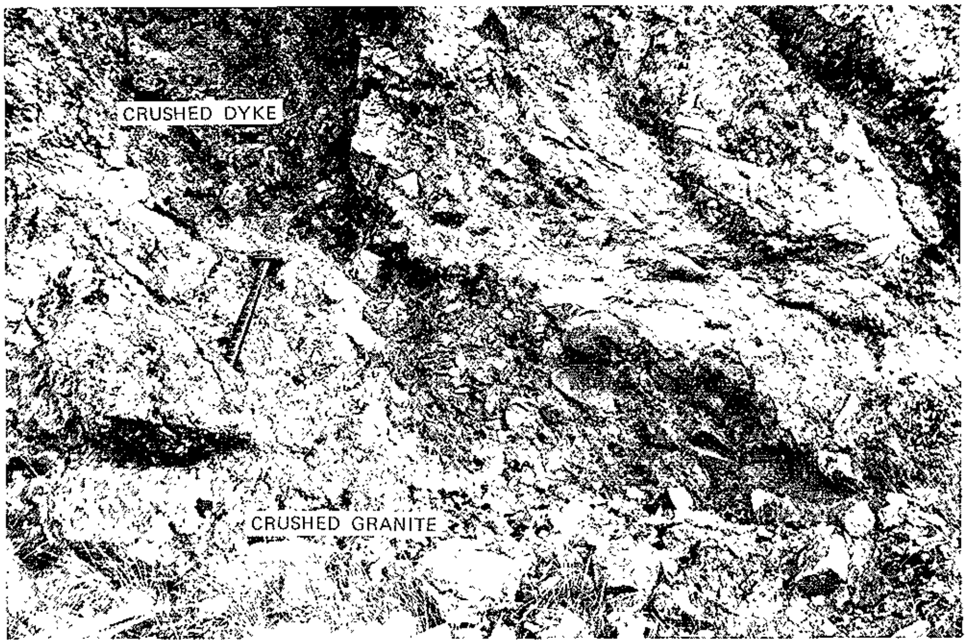


Plate XA. Granite 'autobreccia' and crushed dyke.

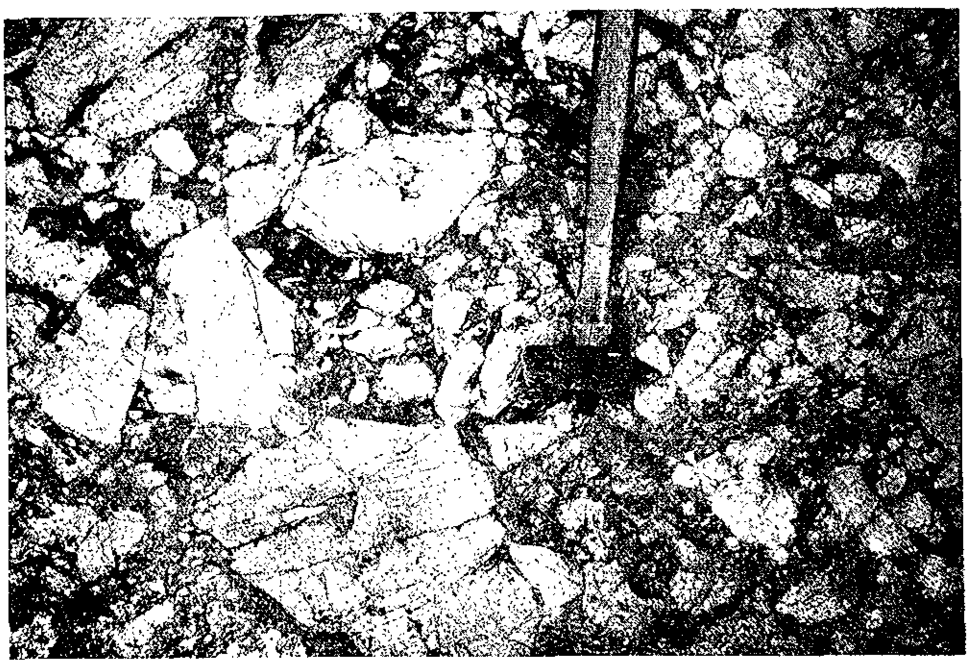


Plate XB. Internal structure of 'autobrecciated' dyke.

Plate XI. 'Frictional breccia,' layered deposits of mobilized granite and dyke rock breccia, east of The Hole.

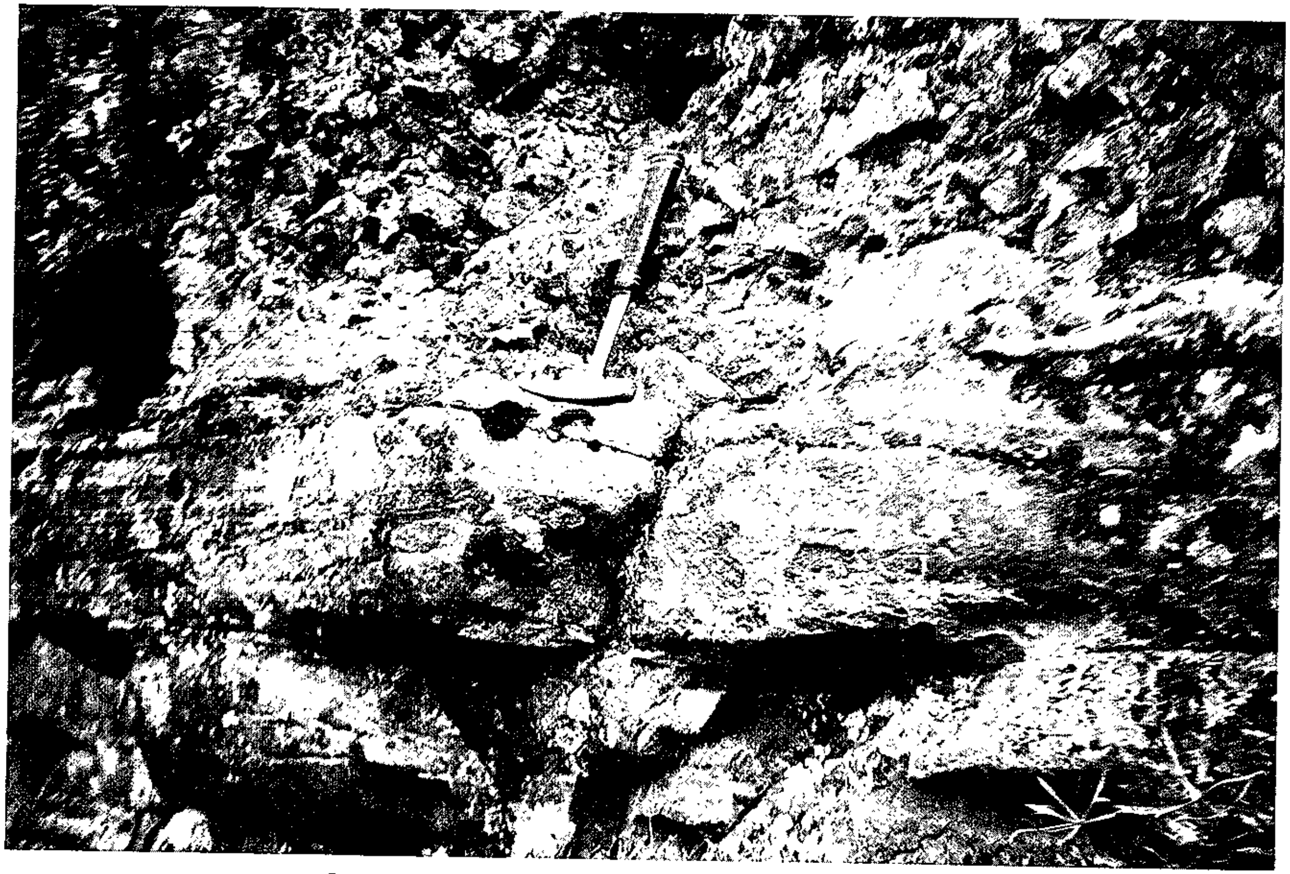


Plate XII. Arkosic sandstone bed in granite boulder conglomerate.

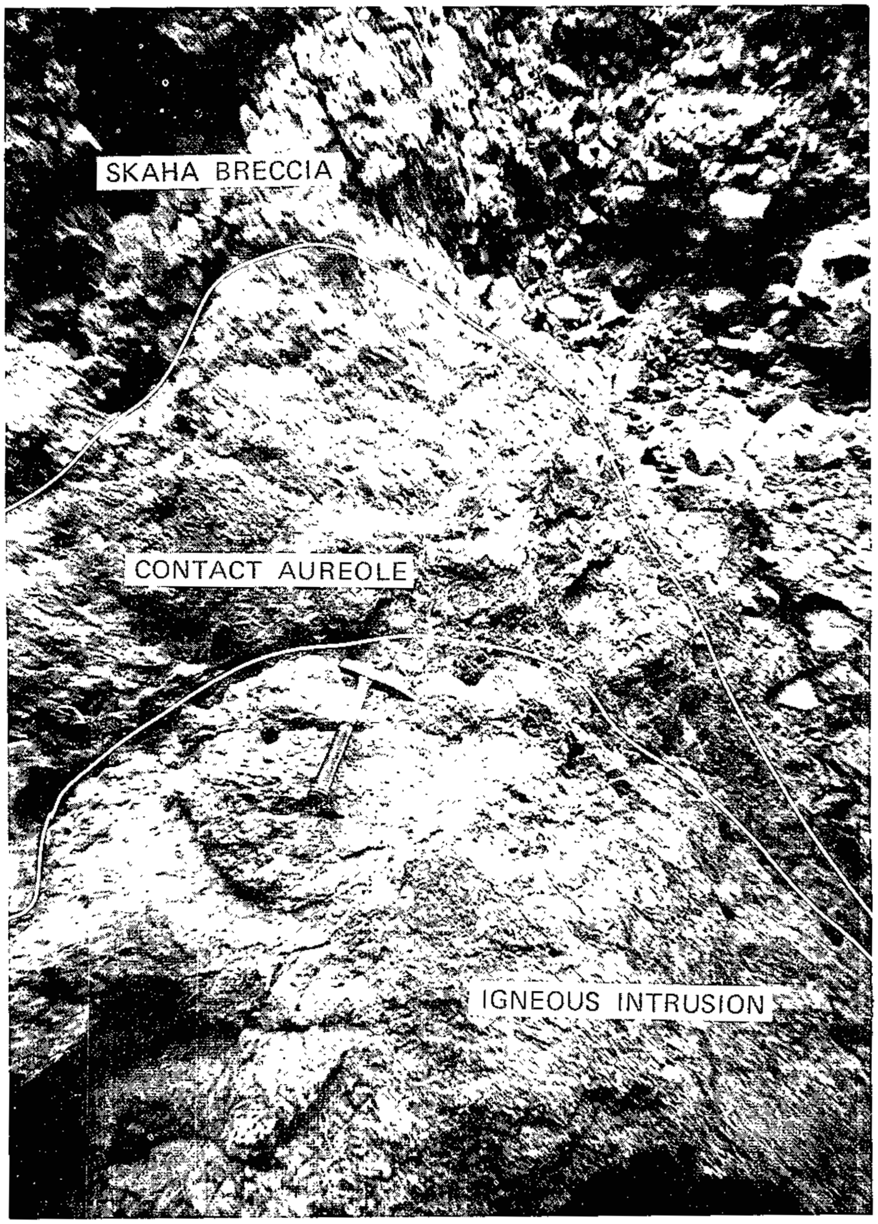


Plate XIII. Igneous intrusion in Skaha breccias.

Plate XIVA. Boulder of arkosic sandstone in upper member, Skaha Formation.

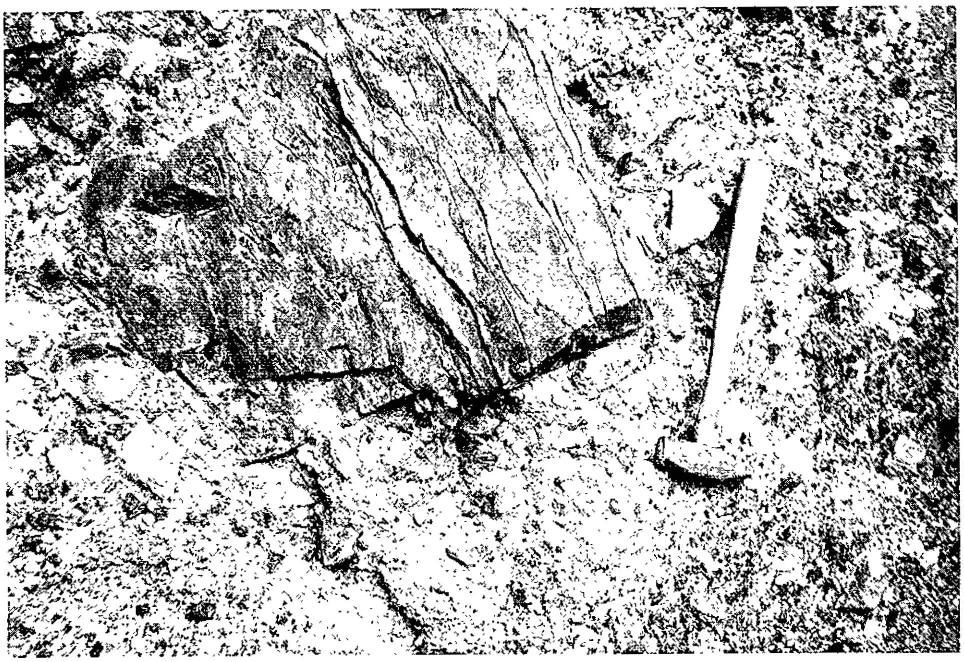


Plate XIVB. Chert block in upper member, Skaha Formation.

Plate XVA. Hoodoo structure in conglomerate, upper member, Skaha Formation.

Plate XVB. Channel deposit in upper member, Skaha Formation.

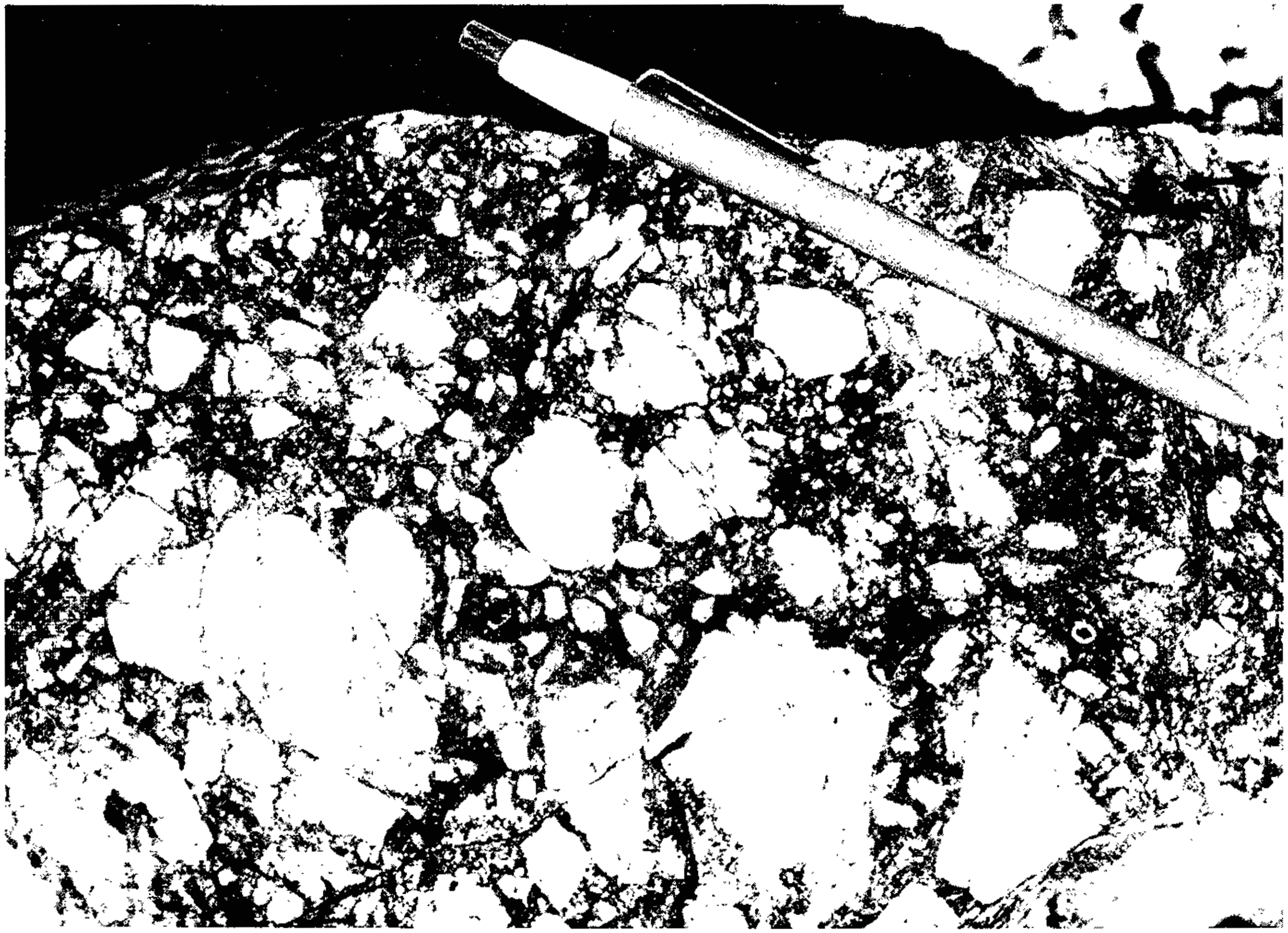


Plate XVI. Dusty Mac prospect, mineralized quartz breccia.

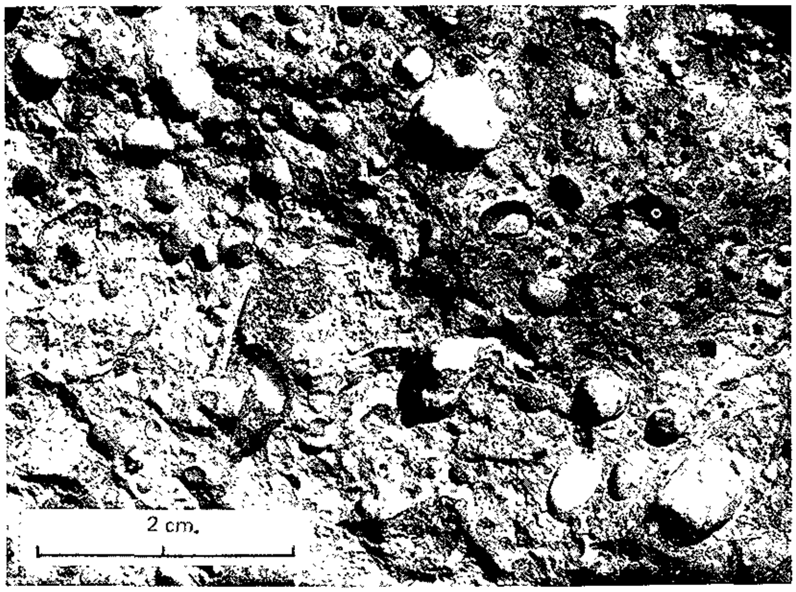


Plate XVIIA. Hand specimen of typical basaltic andesite.

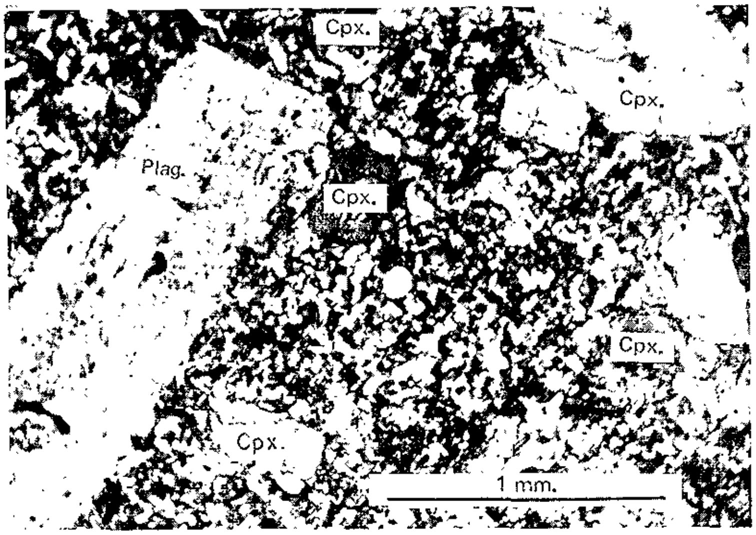


Plate XVIIB. Photomicrograph of basaltic andesite.

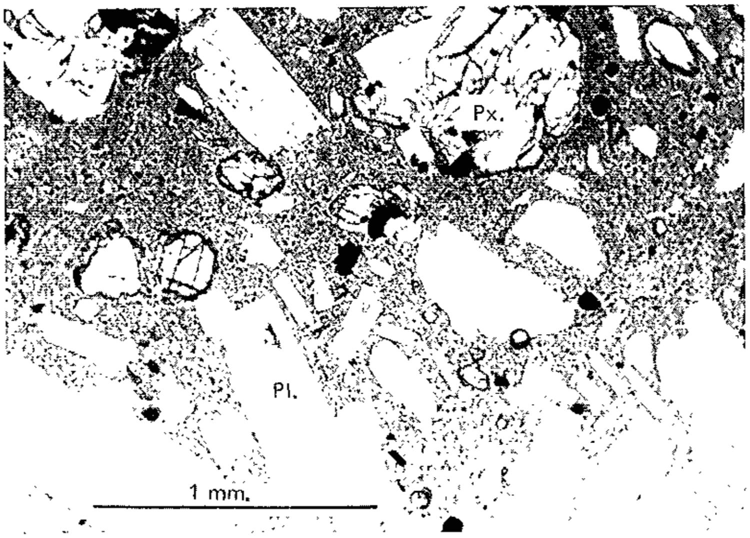


Plate XVIIIA. Photomicrograph of merocrystalline andesite.

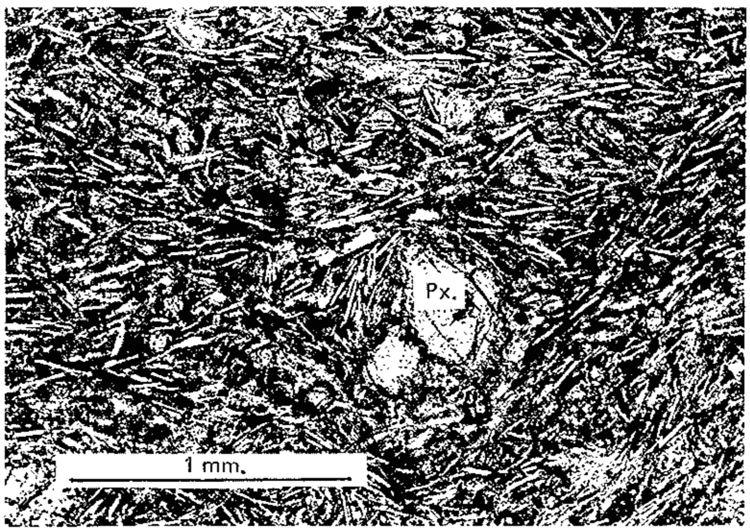


Plate XVIIIB. Photomicrograph of vitric andesite.

Plate XIXA. Typical platy habit of rhyodacite lava.

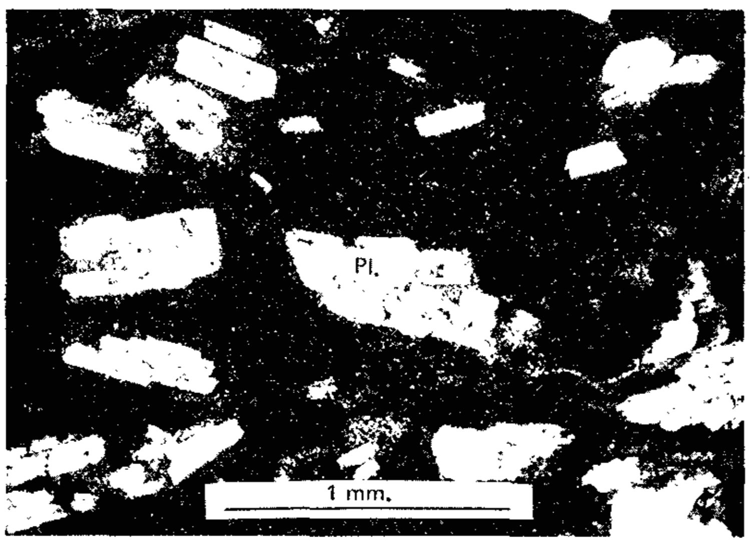


Plate XIXB. Photomicrograph of rhyodacite.

Plate XXA. Fluidal banding in rhyolite.

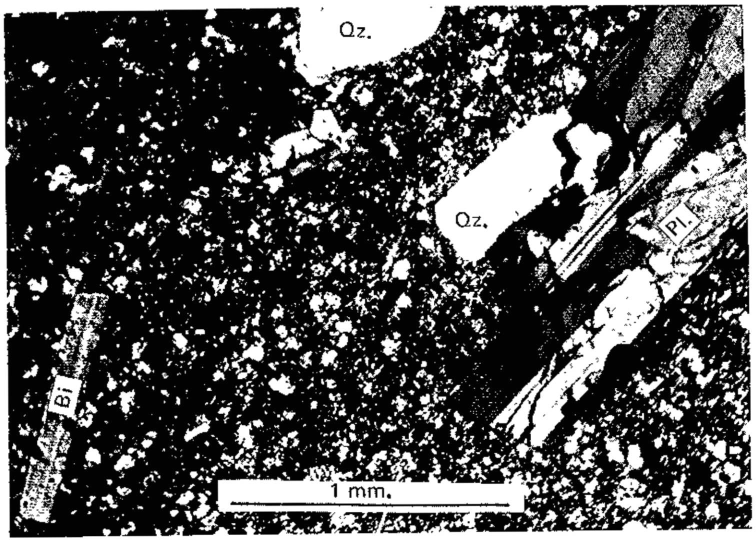


Plate XXB. Photomicrograph of rhyolite.

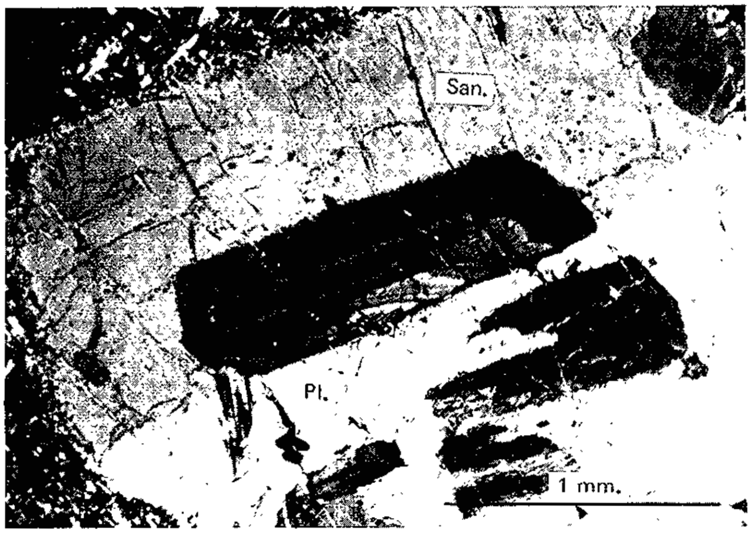


Plate XXIA. Photomicrograph of clot porphyry trachyte.

Plate XXIB. Photomicrograph of clot porphyry trachyandesite.

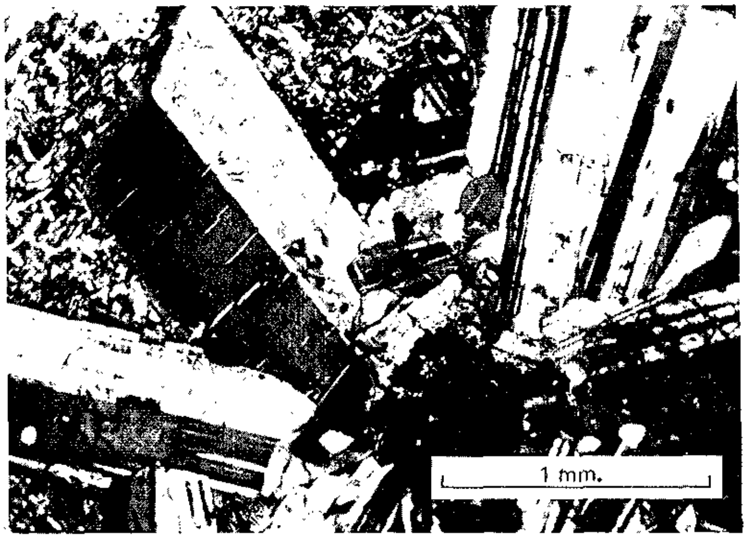


Plate XXIIA. Photomicrograph of rosette porphyry trachyandesite.

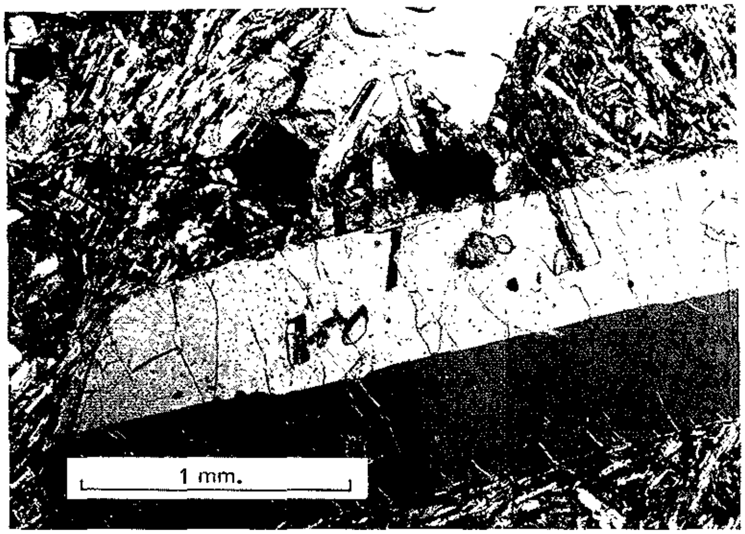


Plate XXIIB. Photomicrograph of rosette porphyry trachyte.

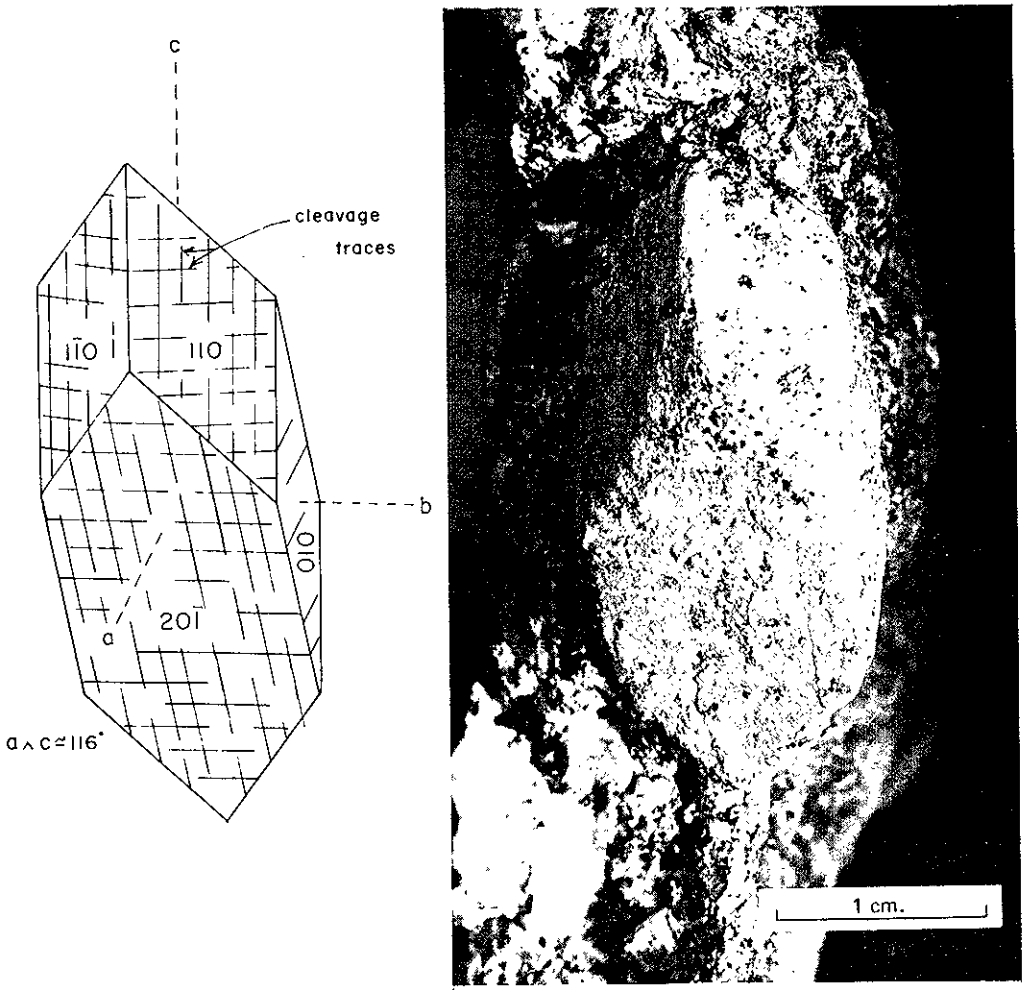


Plate XXIIIA. Rhomb-shaped anorthoclase-sanidine phenocryst from the Yellow Lake member of the Marron Formation.

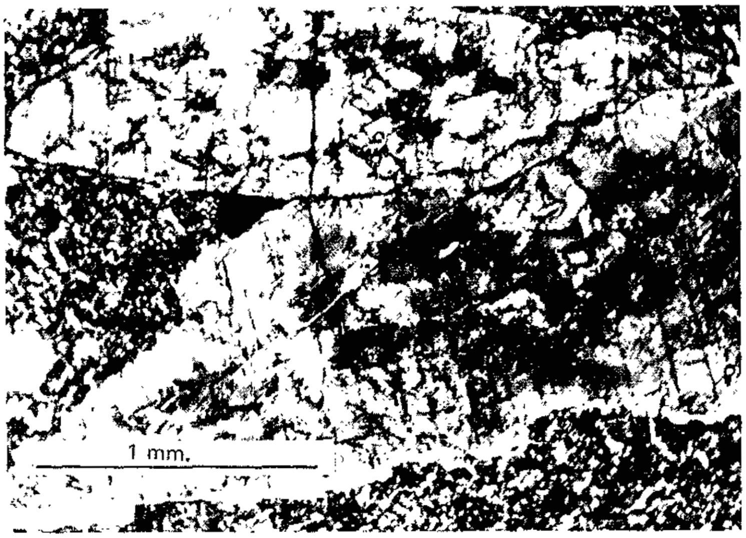


Plate XXIIIB. Photomicrograph of (010) section of anorthoclase.

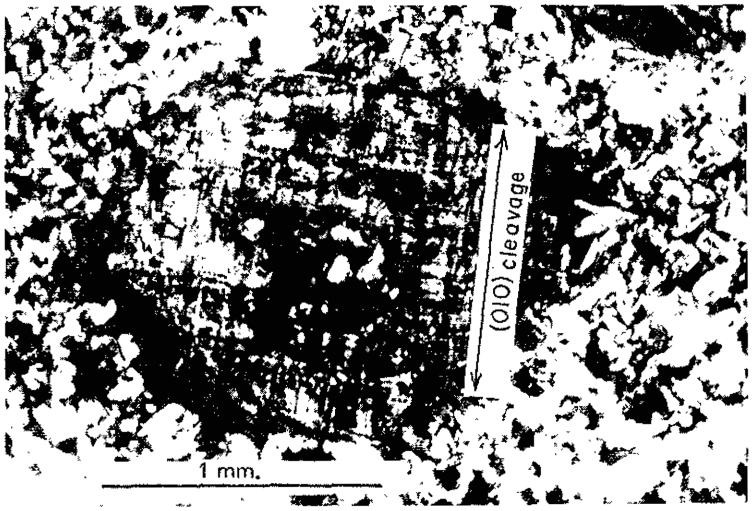


Plate XXIIIC. Photomicrograph of (001) section of anorthoclase.

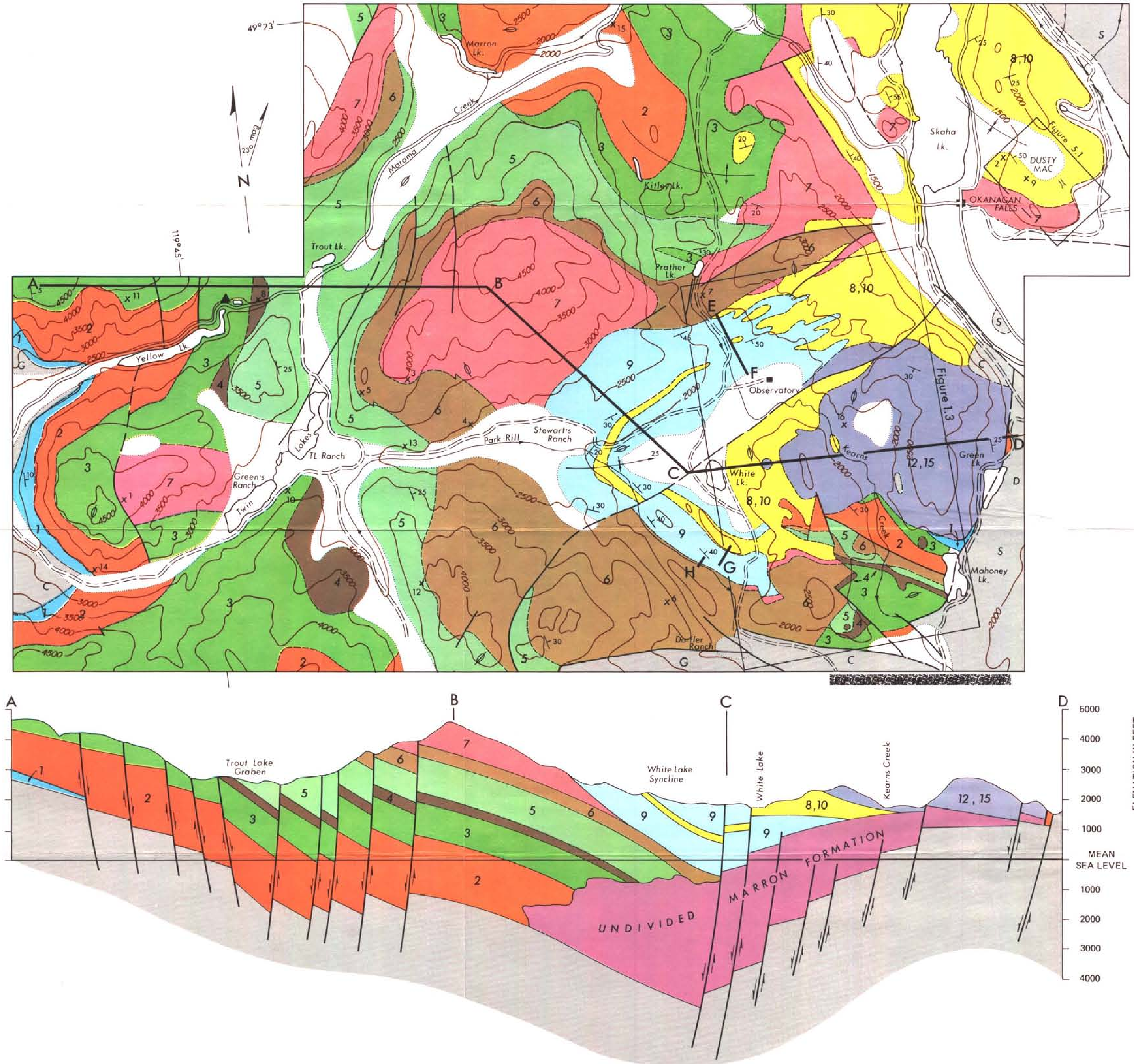


FIGURE 1.2.

GEOLOGY OF THE WHITE LAKE BASIN

GEOLOGY BY B. N. CHURCH, 1967

SCALE – MILES (0, 1, 2)

KILOMETRES (0, 1, 2, 3)

LEGEND

EARLY TERTIARY ROCKS

- 12, 15 — SKAHA FORMATION
- 9 / 8,10 — SEDIMENTARY/ VOLCANIC ROCKS } WHITE LAKE FORMATION
- 7 — MARAMA FORMATION
- 6 — PARK RILL MEMBER
- 5 — NIMPIT LAKE MEMBER
- 4 — KEARNS CREEK MEMBER } MARRON FORMATION
- 3 — KITLEY LAKE MEMBER
- 2 — YELLOW LAKE MEMBER
- 1 — SPRINGBROOK FORMATION

PRE-TERTIARY ROCKS

- G — OLD TOM FORMATION
- C — SHOEMAKER FORMATION
- S — VASEAUX FORMATION

SYMBOLS

- DRIFT-COVERED AREA
- GEOLOGICAL BOUNDARY (APPROXIMATE)
- BEDDING (HORIZONTAL, INCLINED) — 25
- SYNCLINE (PLUNGING) — 25
- ANTICLINE
- FAULT (APPROXIMATE, ASSUMED)
- TOPOGRAPHICAL CONTOUR (INTERVAL, 500 FEET) — 2000
- STRUCTURE SECTION — A—B
- BOUNDARY OF FIGURES 1.3 AND 5.1
- STREAM
- MAIN ROAD
- SECONDARY ROAD
- GLACIAL STRIAE
- CHEMICAL ANALYSIS STATION — x10
- K-Ar SPECIMEN LOCALITY — 51.6±1.8 M.Y.

To accompany Bulletin 61.
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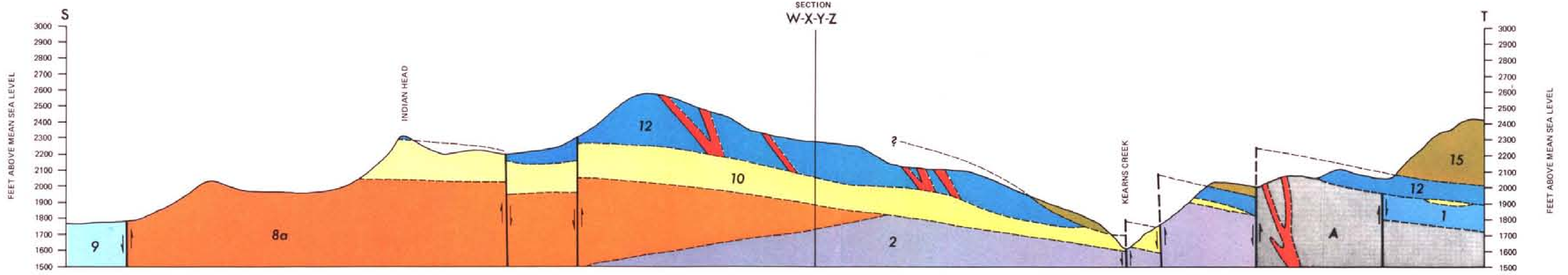
FIGURE 1.3a.

STRUCTURE SECTIONS TO ACCOMPANY FIGURE 1.3

Geology by B. N. Church



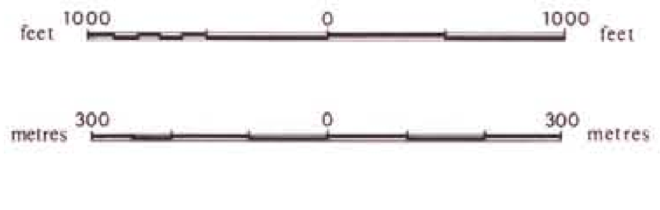


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FIGURE 2.6. GENERALIZED COLUMNAR SECTIONS OF WHITE LAKE BEDS

(POSITIONS OF MEASURED SECTIONS ARE SHOWN ON FIGURE 1.2)

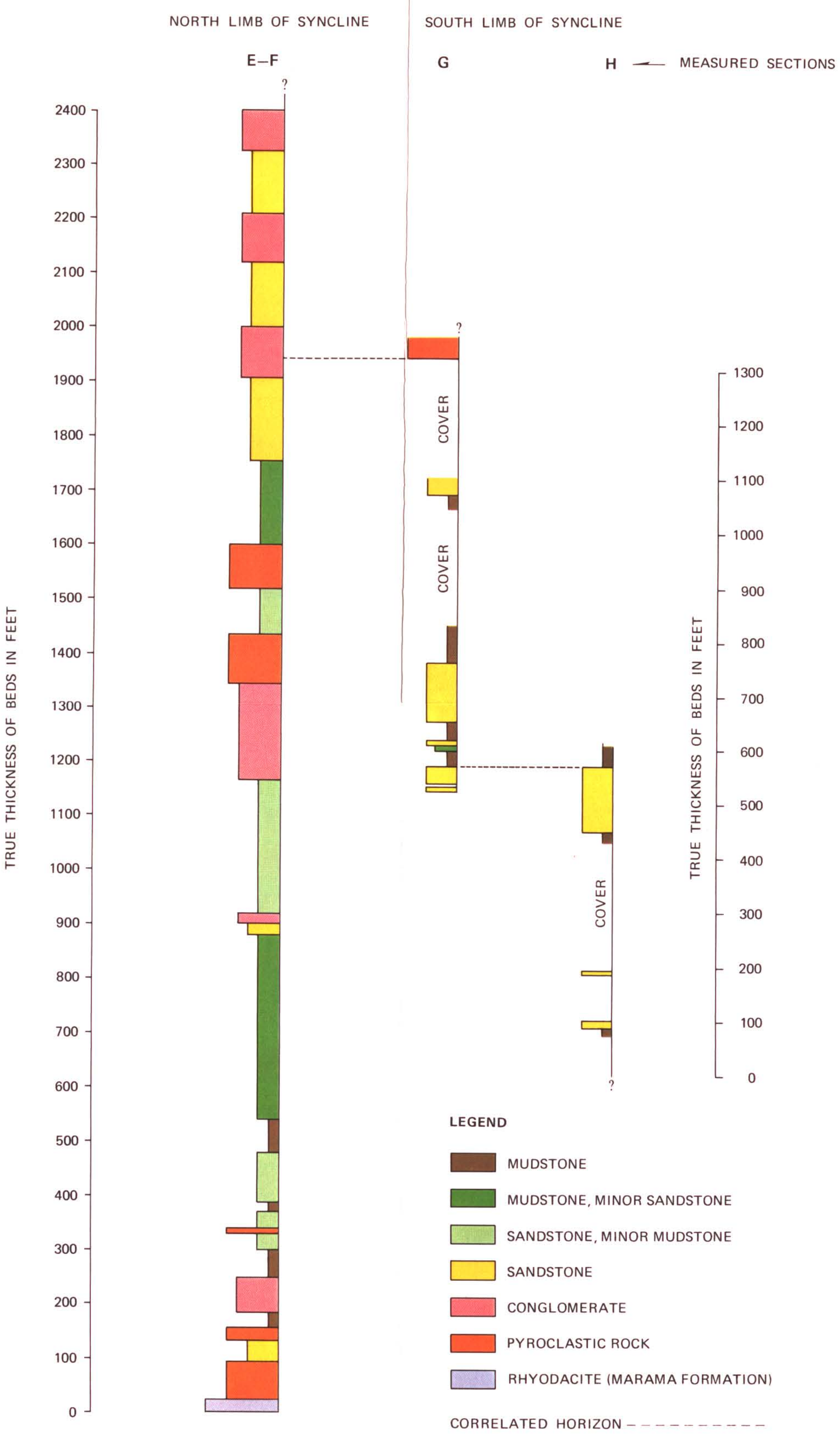

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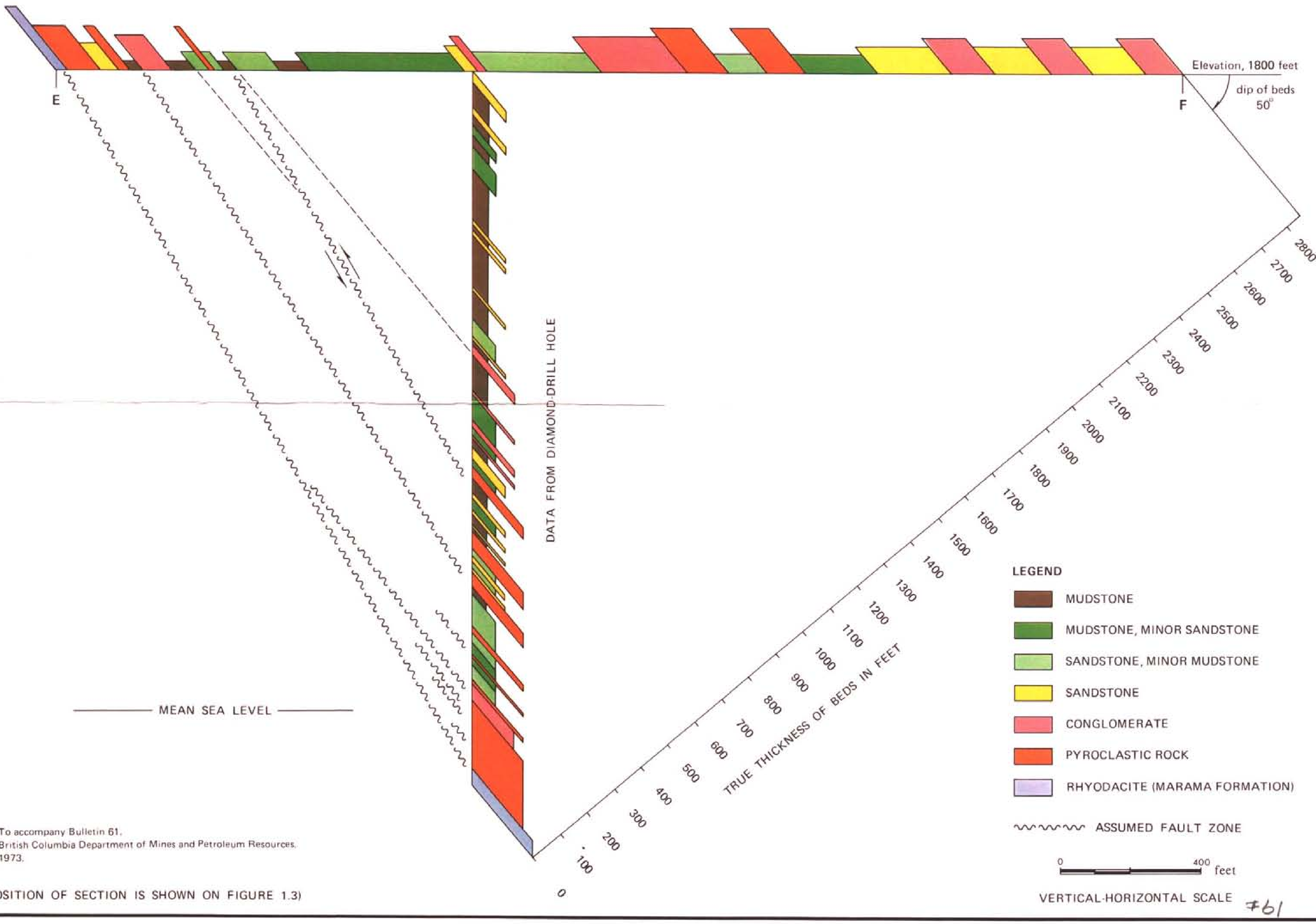
FIGURE 2.7. STRUCTURE SECTION OF WHITE LAKE BEDS ON NORTH LIMB OF THE SYNCLINE



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(POSITION OF SECTION IS SHOWN ON FIGURE 1.3)

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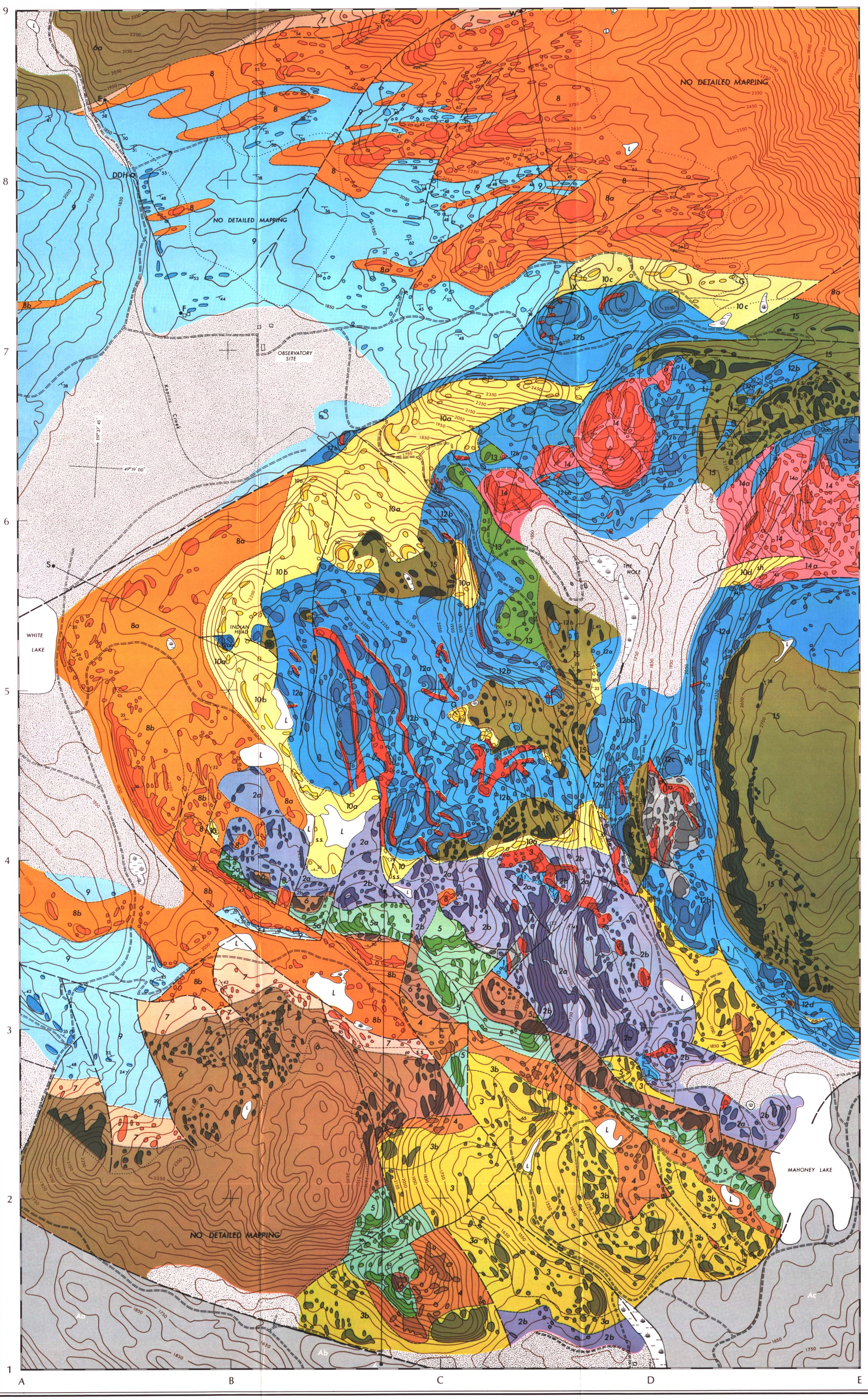
Figure 1.3

DETAILED GEOLOGY NEAR WHITE LAKE

Geology by B. N. Church, 1967



LEGEND

GLACIAL AND RECENT DEPOSITS

UNDIVIDED SEDIMENTARY ROCKS

EARLY TERTIARY ROCKS

SKAHA FORMATION

UPPER MEMBER

15 MIXED BOULDER CONGLOMERATE

LOWER MEMBER

14 'GRANITE BRECCIA,' MAINLY BRECCIATED GRANITE AND APLITE

14a GRANITE BOULDER CONGLOMERATE AND ARKOSE

13 'AUGITE PORPHYRY' (TEPHRITE)

12 'BASAL BRECCIAS,' UNDIVIDED

12a BRECCIATED OLD TOM FORMATION

12b BRECCIATED SHOEMAKER FORMATION

12bb INTENSELY BRECCIATED CHERT

12c BRECCIATED VASEAUX FORMATION

12d MIXED CONGLOMERATE AND BRECCIA

13 AUGITE PORPHYRY INTRUSIVE ROCKS

WHITE LAKE FORMATION

UPPER MEMBER

10a AGGLOMERATE, TUFF, SEDIMENTARY ROCKS

10b INDIAN HEAD VOLCANIC BRECCIA

10c AUGITE PORPHYRY (TEPHRITE)

10d MAINLY SHALE, POSSIBLY EQUIVALENT TO 9 OR 12

MIDDLE AND LOWER MEMBERS

9 WHITE LAKE SEDIMENTARY ROCKS, MUDSTONE, SANDSTONE, CONGLOMERATE, COAL, AND PYROCLASTIC ROCKS

MIDDLE MEMBER

8a PYROCLASTIC ROCKS AND LAHARS WITH ABUNDANT XENOLITHS OF 2

8b PYROCLASTIC ROCKS AND LAHARS WITH ABUNDANT XENOLITHS OF 6

LOWER MEMBER

8 TRACHYTE AND TRACHYANDESITE LAVAS AND PYROCLASTIC ROCKS

11 UNDIVIDED WHITE LAKE INTRUSIVE ROCKS

MARAMA FORMATION

7 UNDIVIDED RHYODACITE AND RHYOLITE, SOME BASAL CONGLOMERATE

MARRON FORMATION

PARK RILL MEMBER

6 MAINLY MEROCRYSTALLINE ANDESITE

6a VITRIC ANDESITE

NIMPIT LAKE MEMBER

5 UNDIVIDED TRACHYTE AND TRACHYANDESITE

5a APHANITIC VOLCANIC BRECCIA

KEARNS CREEK MEMBER

4 MAINLY VESICULAR LAVA

KITLEY LAKE MEMBER

3 UNDIVIDED TRACHYTE AND TRACHYANDESITE

3a SMALL FELDSPAR PORPHYRY

3b CLOT-LATH FELDSPAR PORPHYRY

3 FELDSPAR PORPHYRY INTRUSIVE ROCKS

YELLOW LAKE MEMBER

2 UNDIVIDED RHOMB PORPHYRIES

2a SMALL ANORTHOCLASE-AUGITE PORPHYRY

2b LARGE ANORTHOCLASE-AUGITE PORPHYRY

SPRINGBROOK FORMATION

1 UNDIVIDED CONGLOMERATE AND BASAL BRECCIA

PRE-TERTIARY ROCKS

Aa OLD TOM FORMATION

Ab SHOEMAKER FORMATION

Ac VASEAUX FORMATION

SYMBOLS

BEDROCK EXPOSURE

GEOLOGICAL BOUNDARY

BOUNDARY OF DETAILED MAPPING

BEDDING 20

FAULT (APPROXIMATE POSITION)
MINOR DISPLACEMENT
MAJOR DISPLACEMENT

TOPOGRAPHICAL CONTOUR (INTERVAL, 50 FEET) 2250

STRUCTURE SECTION

DIAMOND-DRILL HOLE .... DDH

COAL MINE

ROAD

LAKE L

MARSH

STREAM

GRANITE .... G

AGGLOMERATE .... agglom.

LIMESTONE Li

SANDSTONE .... s.s.

SHALE .... sh.

feet 1000 0 1000 feet

metres 300 0 300 metres

MN
23°
N

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